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ZAVOD ZA MEHANIZACIJU POLJOPRIVREDE
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UNIVERZA V MARIBORU FAKULTETA ZA KMETIJSTVO IN BIOSISTEMSKE VEDE
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PRIČA O TRAKTORU S NASLOVNICE

KIROVEC K 700

Povijest traktorske tehnike u Rusiji izuzetno je bogata. Razvoj traktora započeo je još u 19. stoljeću. Blinov iz St. Peterburga je već 1888. godine konstruirao parni traktor s gusjenicama koji se stručnoj literaturi često navodi kao prvi upotrebljivi traktor gusjeničar na svijetu na kojem su za vožnju i upravljanje korištene isključivo gusjenice.

1913. godine je u Rusiji bilo samo 165 traktora i iako se ta brojka doima malom, stanje nije bilo bitno drugačije niti u razvijenim europskim državama i SAD-u, gdje je do masovnijeg uvođenja traktora došlo tokom i nakon Prvog svjetskog rata. U tadašnjem Sovjetskom Savezu je 1924. godine na velikim prostranstvima radilo tek oko tisuću traktora. Tadašnja vlast je uočila da ogromne poljoprivredne površine neće biti moguće obrađivati bez suvremene mehanizacije, u prvom redu traktora, te je uspostavljena suradnja s američkom industrijom traktora - tada najrazvijenijom na svijetu. U početku je SSSR krenuo s uvozom fordovih traktora Fordson, 1926. je bilo naručenih 24.600 primjeraka, te je već naredne godine udio fordovih traktora i teretnih vozila bio 85 % ukupno evidentiranog broja vozila u SSSR-u. Do 1934. je broj traktora dosegnuo 200.000 i kontinuirano se povećavao do Drugog svjetskog rata. Traktor je postao moćan simbol poljoprivredne proizvodnje na velikim prostranstvima tadašnjih kolhoza i sovhoza. Do 1934. godine prevladavali su traktori Ford, International Harvester, John Deer, Allis Chalmers i Case pa su stoga i kasnije proizvedeni sovjetski traktori većinom bili plod američkih licenci. Vrhunac uvoza dosegnut je 1931. kada je 99 % traktora uvezeno iz SAD-a, nakon čega se počela intenzivnije razvijati domaća industrija traktora.

Proizvođač traktora Kirovec ima izuzetno dugu tradiciju, tvrtka je osnovana još 1801. godine, a prvi proizvod bila su brodska jedra. Od 1812. započinje proizvodnja različitih strojeva, u šezdesetim godinama 19. stoljeća proizvodnja parnih lokomotiva, a do kraja stoljeća vojne brodove i brodske parne strojeve. Godine 1868. poduzeće dolazi u posjed Nikolaja Ivanoviča Putilova i 1922. je preimenovano u Crveni Putilovec. Prvi traktor po fordovoj licenci (model Fordson) proizveden je 1924. i nazvan Fordzon-Putilovec. Traktor je bio u potpunosti jednak američkom izvorniku, Fordsonu, u povijesti zapisanom kao traktor koji je pokrenuo revoluciju na području traktorske tehnike postavši dostupan malom poljoprivredniku u SAD-u, kasnije i u Europi, čime su traktori ušli u masovnu upotrebu. Do 1931. je s pokretne trake sišao 25-tisućiti primjerak Fordzon-Putilovca, kroz čiju su proizvodnju sovjetski stručnjaci prikupili iskustvo za naredne projekte i započela je proizvodnja traktora Univerzal 1 i Univerzal 2. Kako je 1934. godine tvrtka preimenovana u Kirovski zavod, kasnije proizvedeni traktori nose ime Kirovec. Tokom Drugog svjetskog rata tvornica je masovno proizvodila tenkove, najpoznatiji je bio teški tenk oznake KV1, da bi se nakon rata vratili osnovnoj djelatnosti, proizvodnji traktora.

U drugoj polovici 50-ih godina dvadesetog stoljeća cilj je bio razvoj snažnijih izvedbi suvremenih traktora. Otprilike u isto vrijeme u SAD-u su se pojavile prve izvedbe traktora s izodijemetralnim kotačima (svi kotači jednakog promjera). Proizvodnja traktora Kirovec K 700 utemeljena je u Kirovskom zavodu 1961. godine, prvi primjerci izašli su 13. srpnja 1962., a 1964. započinje serijska proizvodnja. Traktor je bio konstruiran s izodijametralnim kotačima i središnje postavljenom kabinom s dva sjedala, za vozača i suvozača, postavljena jedno do drugog kao u osobnim ili teretnim vozilima. Zanimljivo je spomenuti da se navedeni traktor izvozio, osim u države istočne Europe, također u SAD, Kanadu, Australiju, Francusku, Italiju… I danas se u Njemačkoj može pronaći veći broj očuvanih primjeraka, od kojih su neki još uvijek u pogonu. Kirovec se u proizvodnji zadržao više desetljeća, uz povremene izmjene dizajna.

Primjerak traktora na slici potječe s početka šezdesetih godina prošlog stoljeća. Masa traktora je bila 12.900 kg, mjenjač je imao šesnaest stupnjeva prijenosa za vožnju naprijed i osam nazad. Motor V izvedbe s osam cilindara i opremljen turbo kompresorom je proizvodio za to doba impresivnih 225 KS pri 1700 min^{-1} (po DIN-u, odnosno 250 KS po SAE standardu). Upravljanje je bilo hidrostatsko, a hidraulična pumpa imala je protok 75 l min^{-1} što je omogućavalo silu podizanja trozglobne poteznice od 55 kN. Neke izvedbe traktora imale su udvojene kotače ili vrlo široke (terra) pneumatike. Godine 1975. započinje osuvremenjivanje Kirovca s modelom K 701. Početkom osamdesetih godina ponuđena je izvedba traktora s 500 KS, a 1985. s motorima 205 i 350 KS. Iste godine iz tvornice je izašao 500.000-ti primjerak. Ovaj broj je impozantan tim više jer se radi o traktorima vrlo velikih snaga. Više generacija traktora Kirovec nosi zajedničku oznaku K uz različite brojevne oznake, iako se konstrukcijski bitno razlikuju.

Početkom devedesetih godina prošlog stoljeća nastavlja se modernizacija Kirovca. Danas tvrtka nosi ime Peterburgsky Traktorny Zavod i posljednji model traktora iz 2014. godine nosi oznaku K 744P. U ponudi su vlastiti motori snage od 220 do 308 kW, te mercedesovi i cumminsovi motori snage od 225 do 314 kW. Posljednje generacije traktora Kirovec opremljene su elektroničkim upravljanjem trozglobnom poteznicom i ostalim suvremenim sustavima. Osim traktora tvrtka danas proizvodi građevinske strojeve i drugu mehanizaciju. Zanimljivo je spomenuti da je tvrtka Horsch imala u ponudi traktore Kirovec, modificirane za njemačko i druga tržišta, za pogon svojih strojeva velikih radnih zahvata za dopunsku obradu tla.

Tekst: Viktor Jejčič

Slika u tehnici gvaš: Dušan Jejčič

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Poštovani kolege i čitatelji,

Ovogodišnji zbornik radova 44. međunarodnog simpozija „Aktualni zadaci mehanizacije poljoprivrede" četvrti je u nizu publiciran isključivo na webu u elektroničkom obliku, što ga čini dostupnim velikom broju čitatelja. Pristup web izdanju je besplatan na adresi http://atae.agr.hr/proceedings.htm od 30. ožujka tekuće godine. Aktualno izdanje sadrži 52 rada, među kojima se nalaze po jedan (1) rad iz Belgije, Češke, Crne Gore i Ukrajine, po dva (2) rada iz Austrije i Litve, tri (3) rada iz Srbije, po pet (5) radova iz Hrvatske i Italije, šest (6) radova iz Slovenije i dvadeset i pet (25) radova iz Rumunjske. Zahvaljujemo svim autorima, recenzentima, sponzorima i kolegama mehanizatorima koji su svojim radom omogućili održavanje ovog simpozija. Posebno se na potpori zahvaljujemo Ministarstvu znanosti, obrazovanja i sporta Republike Hrvatske i Zakladi Hrvatske akademije znanosti i umjetnosti. Svim sudionicima želimo ugodan boravak u Opatiji za vrijeme održavanja Simpozija.

Dear colleagues and readers,

This year's Proceedings of the 44th international Symposium "Actual Tasks on Agricultural Engineering" is fourth in a series published exclusively on the web in electronic form, making it available to a great number of readers. Access to the web edition is free at site http://atae.agr.hr/proceedings.htm from March 30th of the current year. The latest edition includes 52 articles, among which there are per one (1) paper from Belgium, Czech Republic, Montenegro and Ukraine, two (2) papers from Austria and Lithuania, three (3) papers from Serbia, five (5) papers from Croatia and Italy, six (6) papers from Slovenia and twenty-five (25) papers from Romania. Organiser is grateful to all the authors, reviewers, sponsors and colleagues that made this meeting possible. We especially thank the Ministry of Science, Education and Sports of the Republic of Croatia and Croatian Academy of Sciences and Arts for continuous sponsorship. We wish all participants a pleasant stay in Opatija during the Symposium.

Chief Editor

Zagreb, siječanj-January 2016

Dr. sc. Igor Kovačev

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44. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

UDC 631.431.7
Pregledni rad
Review paper

MACHINERY INDUCED COMPACTION OF AGRICULTURAL SOIL AND MITIGATION STRATEGIES IN THE DANUBE REGION

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SUMMARY

This overview paper deals the causes, the consequences and mitigation strategies of machinery induced soil compaction. An integrated approach of research in agricultural engineering, cropping systems and extension services are necessary for solving the soil compaction issue.

Key words: *soil compaction, rubber tracks, controlled traffic farming, tire inflation pressure, TASC , Terranimo®*

INTRODUCTION

In the 68th General Assembly of the United Nation Organisation the year 2015 was declared to the International Year of Soil. Soils perform a variety of environmental, social and economic functions (Blum 2005). Soil degradation affects our capacity to produce food, prevent droughts and flooding, control biodiversity loss, and tackle climate change

(Jones et al. 2012). Therefore, if the intensification of agriculture in Europe is to be sustainable, it is essential that it does not continue to degrade our soils.

Sustainable intensification means simultaneously improving the productivity and environmental management of agricultural land (Buckwell, A. et al. 2015). According a study by Blum et al. 2015 in Buckwell et al. (2015) 41 % of the arable land in Europe could be suitable for sustainable intensification. A high potential for intensification is assumed to have in the new member states in the EU.

Agricultural soils can be affected in their ecological functions (biomass production; filter, buffer and transformation processes) through usage of agricultural machinery. Soil fertility can be negatively influenced by soil compaction with farm machinery. Soil compaction reduces the pore distribution, air permeability, hydraulic conductivity in the soil and root and plant growth. Resulted effects are yield depression, rut formation, soil erosion and increased draft force and fuel consumption in soil tillage. A sustainable agriculture requires physical soil protection. In agriculture, soil compaction as well as soil erosion by wind and water are classified as the most harmful processes which do not only end in a reduction of site specific productivity but are also responsible for gas emission and a requirement for greater fuel energy in tillage processes (Horn et al. 2003).

Subsoil compaction is a major concern in agricultural production, mainly due to its persistence. Effects of topsoil compaction are alleviated in a few years, when the soil is tillaged, effects of subsoil compaction persist much longer and may even more or less permanent (Etana and Hakansson, 1994).

REVIEW OF AGRICULTURAL SOIL COMPACTION

With increasing performance of agricultural machinery in plant cropping, the field performance and labour productivity grow and also the risk of potential soil compaction. Agricultural traffic induced soil compactions have effects on the production function of the soil. Yield depressions, reduced hydraulic conductivity, increased N_2O-emission, increased soil erosion and higher energy demand for repair (subsoiling) are some negative effects, where the farmers and the general public are burdened. Soil compaction can reduces yield by 10-20 %, increases tillage energy, time and costs by 200-300 % and reduces infiltration rate to almost zero and hence increases runoff and flooding (Godwin, 2015). High field performance in the field operation can be reached with high working speed ("High speed farming") and/or increased working width. This driving factors are mostly coupled with higher machinery weight. An example for the development of machinery weight is shown for the combine harvester in Figure 1.

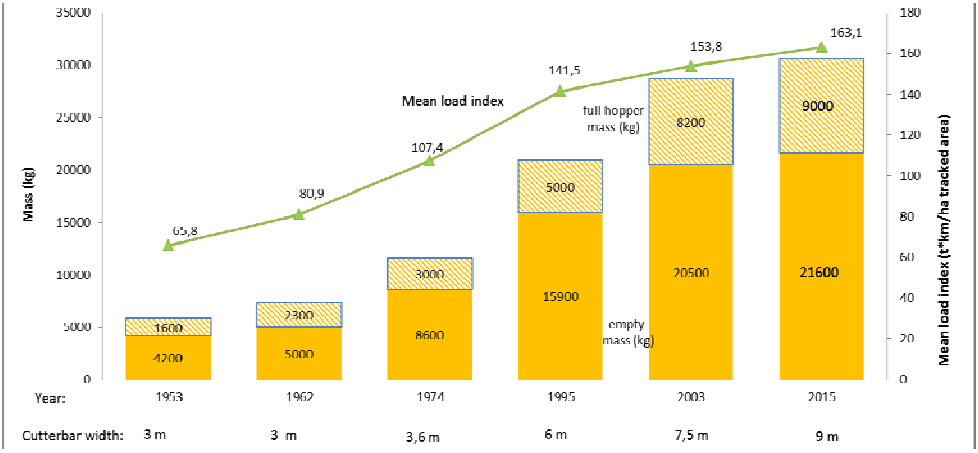

Figure 1 Development of combine harvesters in empty mass, hopper capacity and mean load index. (Load index is the product of the half loaded combine harvester mass multiply with driven distance in the field. This product is divided by the tracked area). Bernhardt et al. 2006 extended by Moitzi 2015.

Mode of Action in the tyre/soil interface

The interaction of tyre and soil is shown in Figure 2. The wheel load and the contact area are the significant factors for calculating the contact area pressure (equation 1).

$$Contact\ area\ pressure\ (bar) = \frac{Wheel\ load\ (N)}{Contact\ area\ (cm^2)\times 10} \quad (1)$$

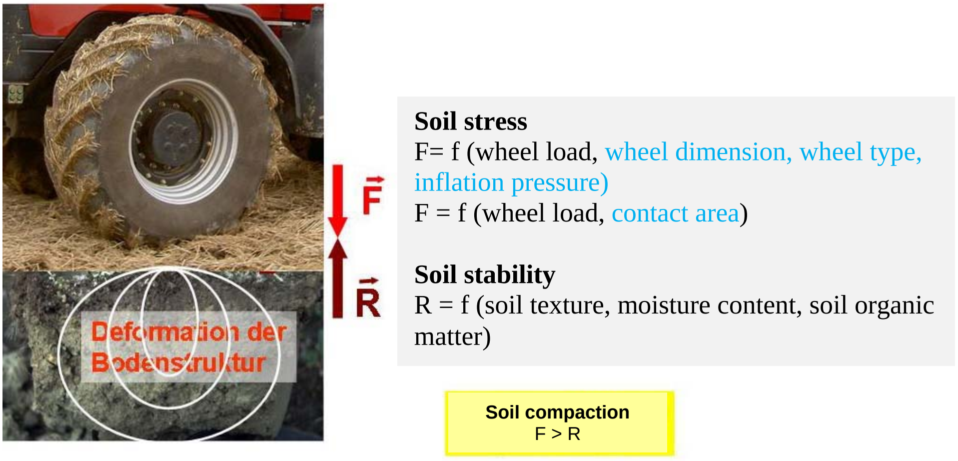

Figure 2 Mode of action in the Tyre/Soil Interface

The soils as a three phase systems undergo an intensive alteration in their physical, chemical and biological properties both during natural soil development as well as during processes like tillage and soil erosion (Horn et al. 2003). The effect of soil stress application results in soil deformation processes with changing the soil porosity and hydraulic conductivity (Figure 3).

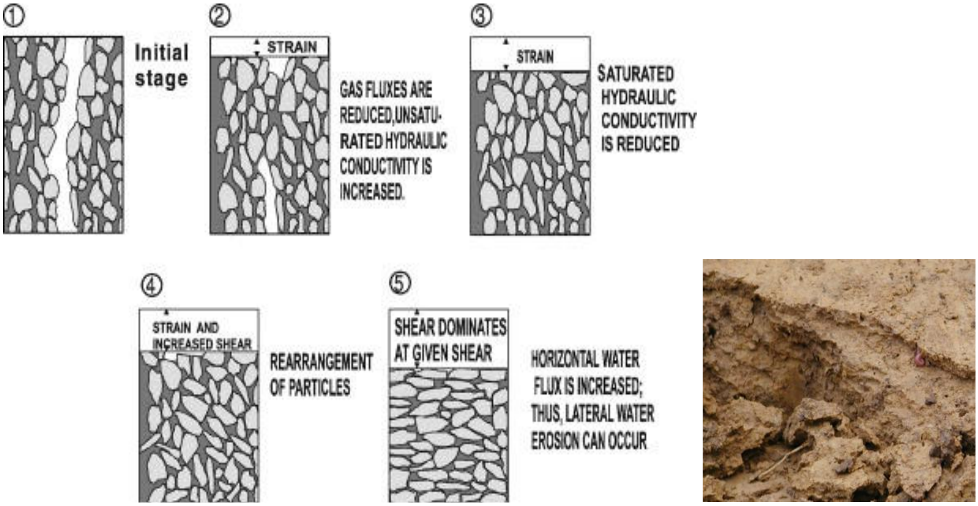

Figure 3 Soil deformation (compaction and shear) effects on changes in physical properties with formation of platy structure (Horn et al. 2003)

The consequences for soils with platy structure are lateral fluxes, anoxic conditions and increased penetration resistance.

Effect of soil stability on soil compaction

A consequence of soil stress is the deformation, which results in the increase of soil bulk density. According Söhne (1952) there are two kinds of soil deformation. The elastic deformation is a reversible process. After stress application the deformed soil "spring" back to the initial position. The plastic deformation is irreversible with the result of decreased porosity and increased bulk density. The stability point (threshold between elastic and plastic deformation) is mainly depending on the soil texture, moisture content and soil organic matter content. For field capacity (pF 1.8 and pF 2.5) in different soil texture the stability point with the risk of severe soil compaction is shown in Table 1.

It is shown that a soil with a higher sand content and dry soils have a better soil stability than soils with high clay content at wet condition (pF-value 1.8).

Some consequences on the soil particle level and visible effects in the field are shown in Figure 4.

Table 1 Stability point for agricultural soils at moist (pF-value 1.8) and dry (pF-value 2.5) soil conditions (TASC 2013)

Soil texture	Stability point (bar)		Risk of severe soil compaction at	
	pF 1.8	pF 2.5	pF 1.8	pF 2.5
Clay Soil 45 % clay	0.80	0.95	<0.70[1)] 0.70-0.80[2)] 0.80-0.90[3)] >0.90[4)]	<0.85 0.85-0.95 0.95-1.05 >1.05
Silty soil 15 % clay, 80 % silt	1.05	1.30	<0.75 0.90-1.05 1.05-1.20 >1.20	<1.15 1.15-1.30 1.30-1.45 >1.45
Clay loam and loam 21 % clay	0.85	1.10	<0.75 0.75-0.85 0.85-0.95 >0.95	<1.00 1.00-1.10 1.10-1.20 >1.20
Sandy loam, loamy sand 11 % clay	1.10	1.45	<0.95 0.95-1.10 1.10-1.25 >1.25	<1.30 1.30-1.45 1.45-1.60 >1.60
Sandy soil 5 % clay	1.30	1.70	<1.10 1.10-1.30 1.30-1.50 >1.50	<1.50 1.50-1.70 1.70-1.90 >1.90

[1)]very low risk, [2)]low risk, [3)]moderate risk [4)]high risk

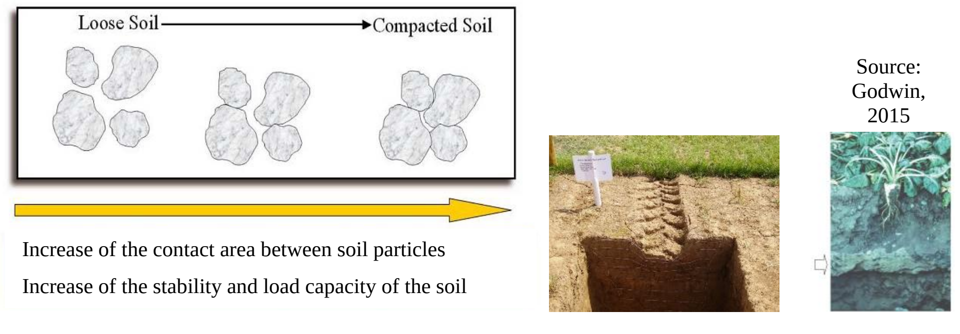

Figure 4 Some consequences of soil compaction: soil particle (left), rut depth (middle), plough pan

Effect of wheel load and contact area on soil compaction

The loads imposed by modern farm machinery have considerable potential to increase subsoil stress. Whereas top soil compaction can be mechanically removed with conventional tillage, subsoil compaction removal (subsoiling) are more energy and cost intensive. Subsoil compaction should therefore be avoided. As far as the subsoil is concerned, ground contact pressure and wheel load are the dominating influences in terms of potential for damage.

In Figure 5 shows, that the wheel load determines the gradient for pressure reduction in the soil and how deep the pressure bulbs reach into the soil.

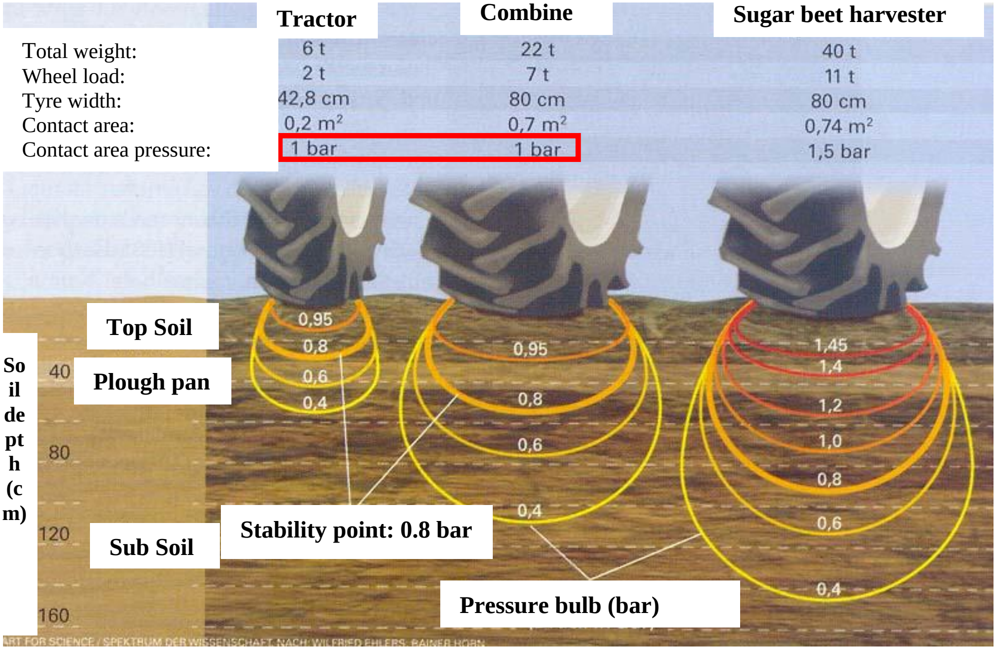

Figure 5 Distribution of pressure bulbs under a wheel of a tractor, combine harvester and sugarbeet harvester (Von Rienk R. van der Ploeg et al. 2006)

Ground pressure determines the initial level of stress at the surface, but wheel load decides the rate at which the pressure-induced stress decreases with depth (Figure 6).

Some basic statements (Sommer 1985) can be derived from Figure 7:

- Soil stress will be depleted with the depth, because more soil particles carry the stress.
- In situation with the same contact area pressure (a and c in Figure 8), the pressure bulbs are larger and reach deeper into the soil.
- A linear increase in the contact area and wheel load lead to a larger depth effect, although the contact area pressure is the same (Söhne 1953).
- In situation of the same wheel load, the contact area pressure determines the soil stress. That means, using broader or dual tires has small effects on reducing the depth effect of wheel load (b and c in Figure 8). Only a disproportional enlargement

of the contact area ("Super wide tyres") with reduced contact area pressure can reduce the depth effect of the wheel load.

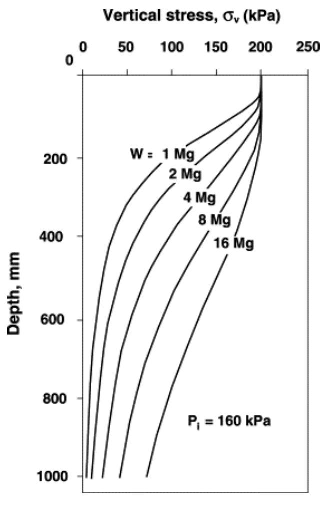

Figure 6 Theoretical relationship between vertical soil stresses and depth at constant inflation pressure (Chamen et al. 2003). W: wheel load in Mg, P_i: inflation pressure in kPa

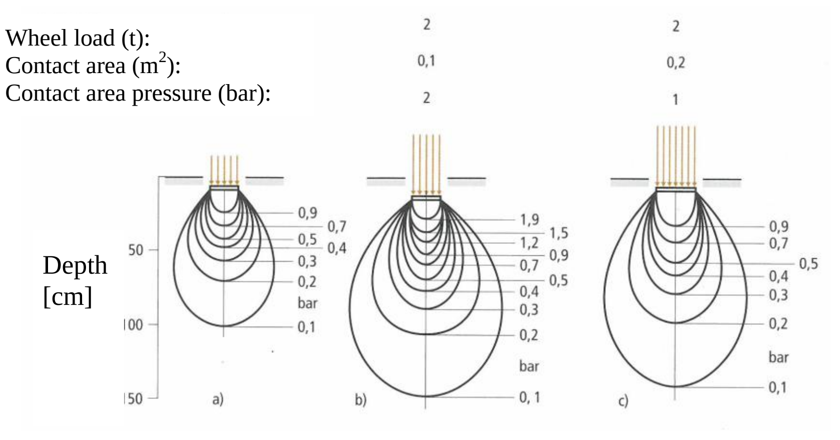

Figure 7 Soil stress – shown as pressure bulbs in three different loading situations (Bolling & Söhne, 1982)

Low Ground Pressure (LGP) Farming is simple, required low investment costs relatively and increases field performance and improves the fuel efficiency (Godwin 2015). Multiple pass with the same wheel load lead to a more solid soil and so the stability increases. Bolling 1987 show, that the first pass has the highest soil stress and decreases with the depth. The number of wheel or track passes following the same track (whether from individual machines or tandem axles) also increase the stress that reaches the subsoil. It is generally better to use dual wheels rather than tandem axles (Chamen et al. 2003).

Effect of tillage-system on soil compaction

The effect of the chosen tillage-system on the soil stress is schematically shown in Figure 8. Especially conventional ploughing in furrows delivers soil stress in the subsoil. On-land-ploughing would decline subsoil compaction.

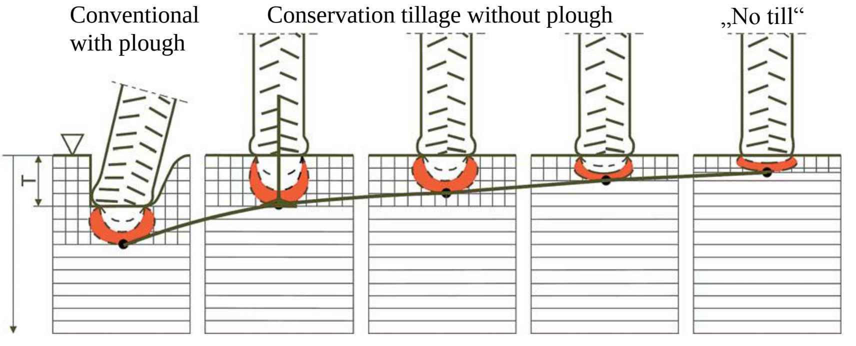

Figure 8 Soil pressure in different tillage systems (Brunotte & Sommer 2013)

Plough pan

A plough pan, which is generated by conventional furrow ploughing, disseminated the applied stress more laterally and less vertically. Plough pans increase the bearing stability in the top soil and can protect the subsoil. Despite the more pronounced compactness of the plough layer under conventional management, it turned out to be less rigid compared to the “relictic” plough layer under conservation management. Peth et al. (2006) assume that wheeling with a heavy sugar beet harvester (rear wheel140 kPa, front wheel 110 kPa, total mass 37 Mg) resulted in a breakup of the plough pan (Figure 9).

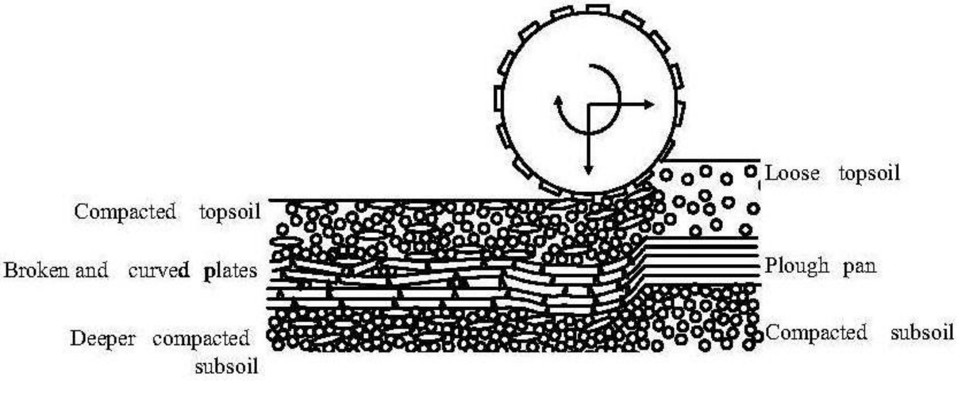

Figure 9 Schematic sketh of stress-dependent changes in the plough pan-layer rigidity as a consequence of the initial wheeling with a heavy sugar beet harvester (Peth et al. 2006)

SIMULATION TOOLS FOR DETERMINATION OF SOIL COMPACTION

For determination of the potential risk of soil compaction, computer based models are developed:

TASC (Tyres/Tracks And Soil Compaction) is an easy-to-use Excel application designed by Agroscope ART (Switzerland) for evaluating the soil stresses caused by machine running gear in arable farming. It can be applied for arable land and forest soils. TASC V3.0 is the latest version (2013) and was extended to computation of traction efficiency and fuel consumption. With technical parameters (tire, track dimension, inflation pressure, wheel load) and soil parameters (soil texture, hardness of topsoil) the potential risk of soil compaction can be determined. TASC can be used additionally

- to calculate the tyre contact area, the contact pressure and the stress propagation in the soil
- to predict compaction damage and the depth action in farming and forestry
- to determine the minimum slip rate beyond which the soil will shear
- to assess the traction force according to the trailed tool (in conformity with the ASABE
- Standard) and the corresponding fuel consumption
- to record track areas
- to select suitable tyres or rims
- to choose appropriate tyre inflation pressures according to the tyre type, wheel load and speed of travel (according to the ETRTO standards, technical data for more than 1270 agricultural and forestry tyres are available).

Terranimo® (**Terra**mecha**nic**al **mo**del) is a computer model of an international team formed around Swiss and Danish scientists, that predicts the risk of soil compaction by farm machinery. The model estimates the risk of compaction for realistic operating conditions. It is designed to include the most recent knowledge on soil strength and stress from machinery. These stress and strength aspects are interacting in a complicated way. The results may thus be valuable for understanding the dynamics when arable soil is loaded with machinery. The knowledge gained may help identify the most beneficial traffic systems for sustainable farming. Terranimo® is continuously updated with the most recent results in soil compaction research. The tool is thus considered of interest for researchers and extension officers interacting with farmers. However, the simple design with default or easily modified machinery and soil conditions makes the tool useful also for farmers interested in reducing compaction of their soils. Terranimo® may help identify the 'weakest points' in some specific management system. The potential benefit of taking into use wider, low pressure tyres or machinery with more axles etc can be quantified. Also, the effect of soil moisture conditions on soil vulnerability to compaction can easily be displayed and may be an eye-opener to a better management of the fields. Terranimo® can be used free of charge. The creators of Terranimo® have no responsibility for potential unforeseen harm that might be caused through the use of Terranimo®. Terranimo® International is the common label for a range of national versions in nine languages. It can be accessed through the web portal www.terranimo.dk.

TASC-Simulation of the soil compaction risk

The technical data of two high-performance combine-harvesters (cutterbar width: 9 m) are shown in table 2. The replacement of the main wheels with rubber-tracks increases the contact area by almost 100 %. The mean contact area pressure is reduced from 1.77 bar to 1.04 bar.

Table 2 Technical parameter of a combine harvester with different undercarriage concepts

	Combine with Rubber-Track (front axle)	**Combine with Wheels**
Empty Mass (t) without cutterbar	18.6	15.0
Mass (t) cutterbar (9 m)	3.0	3.0
Mass (t) full hopper	9.0	9.0
Total mass (t)	**30.6**	**27.0**
Front axle load[1)] (kg force) (kN)	24480 kg 240.07 kN	21600 kg 211.82 kN
Front tire load (kg force) (kN)	12240 kg 120.04 kN	10800 kg 105.91 kN
Rubber/Tire-Dimension	182.5 cm x 63.5 cm	680/85 R 32
Tire inflation pressure (bar)		1.8
Contact area[2)] (cm^2)	11589	5976
Mean contact pressure[2)] (bar)	1.04	1.77

[1)] front axle load:rear axle load=80:20; [2)] calculated with TASC V3.0

The pattern of stress propagation in the soil depends to a great extent on the stability of the topsoil. The softer the topsoil, the more the compressive stresses will spread out vertically down through the soil. The simulation results (TASC V3.0) for the two combine harvesters (Table 2) show, that the highest compaction risk is realized in the wheel combine on clay soil (Table 3 and 4). The lowest risk is shown, when a rubber track combine is operated on a sandy dry soil.

Table 3 Severe soil compaction risk in a humid soil (pF 1.8) with a firm topsoil surface (left) and semi-firm topsoil surface (right) up to a depth of …cm

	Clay soil	Clay loam and loam	Sandy soil
Wheel combine	45 cm/51 cm	42 cm/48 cm	15 cm/29 cm
Rubber track combine	9 cm/36 cm	0 cm/33 cm	0 cm/2 cm

In the TASC application the hardness of the topsoil is defined in terms of three categories, "soft", "semi-firm" and" firm" to a resistance to penetration from 0 – 4.9, ≥ 5 – 7.9, and ≥ 8 kgf (kilogram force) respectively. The hardness of the topsoil can be easily and quickly tested with a screwdriver (TASC 2013).

Table 4 Severe soil compaction risk in a dry soil (pF 2.5) with a firm topsoil surface (left) and semi-firm topsoil surface (right) up to a depth of …cm

	Clay soil	Clay loam and loam	Sandy soil
Wheel combine	36 cm/43 cm	27 cm/37 cm	0 cm/13 cm
Rubber track combine	0 cm/27 cm	0 cm/18 cm	0 cm/0 cm

In the TASC application the hardness of the topsoil is defined in terms of three categories, "soft", "semi-firm" and" firm" to a resistance to penetration from 0 – 4.9, ≥ 5 – 7.9, and ≥ 8 kgf (kilogram force) respectively. The hardness of the topsoil can be easily and quickly tested with a screwdriver (TASC 2013).

MITIGATION STRATEGIES OF SOIL COMPACTION

Technical mitigation strategies for soil protecting traffic according Sommer & Brunotte, 2003 can be categorized as followed:

- Limitation of wheel load
- Increase of the contact area: e.g. rubber tracks, twin tyres, automatic tyre pressure controller.




- Improvement of the soil stability: e.g. conservation tillage, increase of the organic soil matter.
- New Mechanisation processes: e.g. Conservation tillage, Onland-ploughing, Controlled Traffic Farming (CTF)

According Chamen et al. (2003), the preventative strategies suggested for the avoidance of subsoil compaction are summarised as follows:

- No repeated soil loosening as a routine cultivation technique.
- Increased soil stability and reduced soil stress.

- The selection of machines and field practices with a low risk potential.
- The assimilation of new, low risk technologies.

Rubber Tracks

Agricultural tractors can have different types of undercarriage such as two wheel drive, four-wheel drive, and steel tracks. Despite a higher tractive performance and lower soil compaction, steel-tracked tractors are not popular due to their complexity and the difficulties of moving steel-tracked vehicles on roads. Recently, rubber belt tracks have become a notable solution for agricultural tractors, because they unite tractive performance and lower soil compaction with a better trafficability. Triangular rubber belt systems have been developed to replace the conventional wheeled configuration found on combine harvesters, and these can also be used on tractors (Molari et al. 2014). A comparative investigation for two tractor configurations (four-wheel drive, half and fully tracked) show a better tractive efficiency and a reduced soil compaction for the solution with four rubber tracks with respect to the others. In addition, a reduction of the tractive efficiency with the increasing of the slip was highlighted in the half-track solution caused by an unfavourable weight distribution on the axles (Molari et al. 2014).

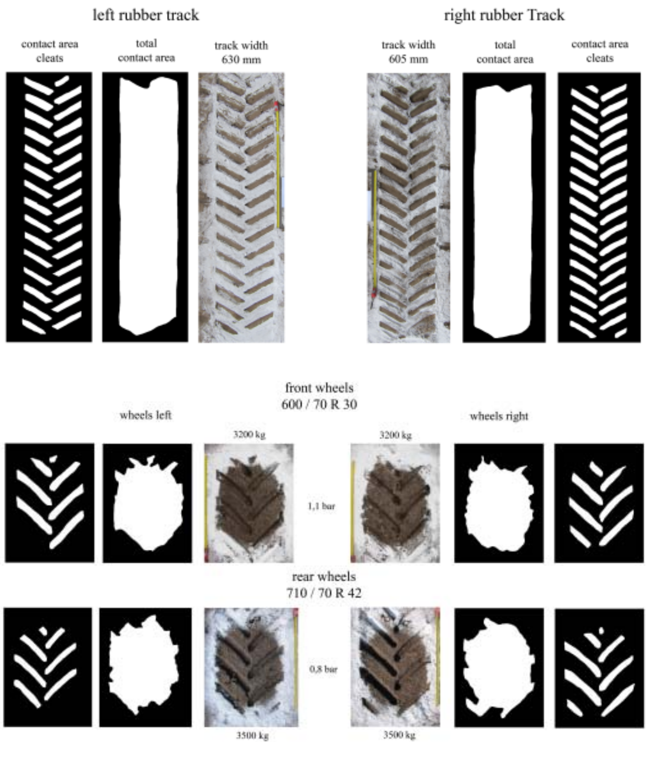

Figure 10 Visualized contact area for a rubber tracked tractor (left) and wheeled tractor (right); Eichinger 2015

In framework of a Master thesis an on-farm-research was done at an arable farm in Lower Austria with the aim to compare a wheeled tractor (JD 8500, 282 Hp – PTO max.) and with a tracked tractor (JD 8400 T, 255 Hp – PTO max.) in two field operations (tilling with deep tiller and cultivating with a cultivator) on a sandy Chernozem and clay soil (Eichinger 2015). Besides the fuel consumption and field performance also the contact area between soil and tyre/rubber track was measured. In Figure 10 the visualized contact area of tyre/rubber and soil, which is differentiated into the total contact area (cleat area and inter-cleat area) and cleat contact area is shown. This differentiation influences also the calculated mean contact pressure (Table 4). On dry, firm soils and with low wheel load, mean contact pressures till 2.48 kg cm^{-2} are realized.

Table 5 Contact area and mean contact pressure of a wheeled tractor and tracked tractor (Eichinger 2015)

	Contact area (m^2)		Mean contact pressure (kg cm^{-2})	
	Cleat and inter-cleat-area/soil	Cleat-area/soil	Cleat and inter-cleat-area/soil	Cleat-area/soil
Wheeled tractors				
1 Front tyre (600/70 R30), 1.1 bar	0.36	0.13	0.86	2.48
1 Rear tyre (710/70 R42), 0.8 bar	0.49	0.16	0.71	2.18
2 Front and 2 rear tires	***1.70***	***0.58***		
Tracked tractor				
Right track (60.5 mm width)	1.34	0.53	0.47	1.21
Left track (63.0 mm width)	1.39	0.50	0.46	1.26
2 Rubber tracks	***2.73***	***1.03***		

Controlled Traffic Farming (CTF)

The main problem is how to combine the production function and tracking function of the agricultural soil. With controlled traffic within the field, there is a systematic differentiation between track-area and plant-growing area. This system is an easy way to reduce input costs while enabling reduction in run-over area by wheels of agricultural machines. In other words, the aim of CTF is to control and mitigate the negative impact of agricultural machinery on the soil, which is mainly in this case the soil compaction. Soil compaction can lead to dramatic reduction in the infiltration properties of soil, increase of soil loss due to water erosion and other serious environmental and yields impacts.

The core of CTF system is implementation of uniform track lines which was significantly improved by introduction of Differential Global Positioning System (DGPS) with an accuracy of centimeters. Ideal track lines concentrate all traffic (tractors, sprayers and harvesting machines) on the field to two parallel lines (means one ride of two-track machine), this system is called ComTrac (Figure 11, left). Main problem of implementation of this system is wheelbase and working width of machines operating on the field. In most cases the wheelbase of harvesting machines is not consistent with other machines that are deployed on the field therefore the special axles of final drive of tractor can be used (Figure 11, right). This extension of wheelbase is costly and can be challenging on roads.

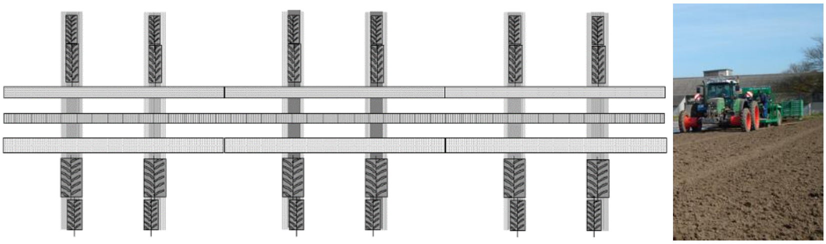

Figure 11 System ComTrac (left) (Chamen, 2006), extension of tractor wheelbase (right) (Foto: Jens Kjeldahl)

In the case that farmers do not have machines with same wheelbase but uses narrow working width and wheelbase of harvester match neighbour parallel traffic lines the TwinTrac system can be used. Another system with additional wheeled line for harvester is called AdTrac. Figure 12 on the left shows system TwinTrac which using nearby parallel tracks while on the same figure on the right the AdTrac has additional line for harvester. There are many other systems of permanent track lines, at least there were shown the basic ones.

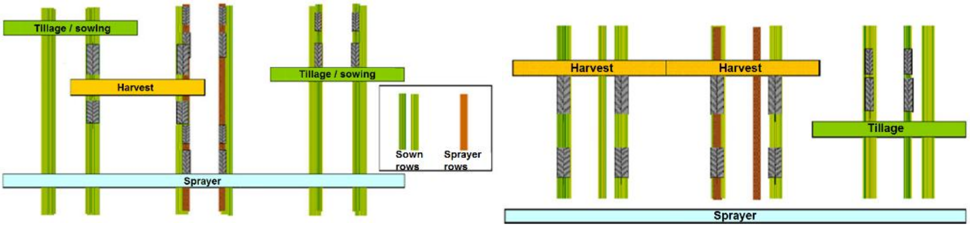

Figure 12 System TwinTrac (left), system AdTrac (right) (Kumhála et al., 2013)

Kroulík et al. (2009a) stated that during use of random traffic with working width of 8 m the run over area is about 63%. On the other hand using the same intensity of tillage (as in the case of random traffic) and the use of AdTrac system the area covered by prints of tires was about 31%. The reduction of run-over area would be lower while using the same wheelbases of agricultural machines (ComTrac system). These differences in run-over areas may have a significant impact on the crop yields. For example Arvidsson & Håkansson (1996) observed yield of spring barley (*Hordeurn vulgare L.*) during five year experiment in Sweden. The results of this experiment showed that the load of 350 $t{\cdot}km{\cdot}ha^{-1}$ of tractor to the ground has impact on the reduction of yields by approximately 12 %. Similar results were confirmed by Ratford et al. (2001) and Lipiec et al. (2003). However, most authors agree that difference in crop yield can be monitored after three or four years after CTF system introduction.

The use of precision navigation systems has another important benefit the reduction of omissions and overlaps which can lead to additional reduction in cost, especially during chemical and fertilizers application and seeding. The results when comparing the same machine unit with the same driver alternately with the navigation using RTK signal and without navigation use revealed that the utilization of guidance system gives significant benefits. When machine was operated manually the pass-to-pass errors were obviously bigger than with autonomous (fully automated) steering systems with RTK navigation. The outcome values show prevailing overlaps of passes in the range between 1 and 6 % of machine's working width. This value can be significantly minimized by utilization of precise guidance systems, based on RTK signal. Therefore these systems can be a possible way for fuel, chemicals, changeable tool parts and other additional material savings (Kvíz et al. 2014).

COUNTRY REPORT

Austria

The potential risk of soil compaction due farm machinery is aware on farms. Large scale combine harvester, sugar beet harvester, potato harvester, forage harvester and trailers including slurry tanks can have a high risk of soil compaction (especially on soft soil conditions). Some farmers use the technical measurements (rubber tracks, automatic tire pressure controller). In Figure 13 an arable farmer in Upper Austria fitted in the year 2015 two conventional AWD-tractors with rubber tracks (half-tracked and fully tracked).

Figure 13 Half-tracked (left) and fully-tracked (right) AWD-tractor with rubber tracks

For increasing the contact area between tyre and soil, tyre pressure control systems are offered by retailers. According the Austria – Rural Development Programme for the period 2014-2020, there is in the category "investment for agricultural farms with improvement of the environmental effect" a financial support for the investment of a tyre pressure control. 40 % of the maximum investment sum (10000 €) can be supported. It will be expected, that automatic tyre pressure controls will be installed in heavy agricultural machinery in the next years.

Croatia

Agriculture professional public has been for a long time aware of soil compaction as a serious issue since during last 20 years a lot of powerful but also heavy machinery, weight of whom sized to 20-25 Mg has become ”standard or normal” machinery that changed previous machinery whose weight rarely exceeded 10 Mg. Unfortunately, serious aftermaths, like yield decrease influenced by soil damage have become evident. Countermeasures were needed but results or soil recovery won't be fast. In spite of mentioned, better ever than never is wisdom that still works. So, some of big agricultural enterprises react very fast to professionals' advice introducing low pressure tyres, terra tyres at tractors, combines and trailers, decreasing thus specific and total soil loading. Besides mentioned some of farms equipped tractors, combines and trailers with controlling tyres pressure on the go. Some farms bought rubber track tractors, combines and trailers that also decrease soil load and compaction (Figure 14).

Further approach of soil compaction mitigation Croatian big farmers find solution in non-conventional tillage systems and Controlled Traffic Farming or Tramline farming systems supported by GPS. Both solutions include integrated soil tillage implements (seed-bed preparation and sowing simultaneously). For small farmers although they are informed about soil compaction issue thematic workshops should be organized to completely full-fill new approaches.

Figure 14 Tractor and sugar beet harvester with rubber tracks

Czech Republic

Agricultural entrepreneurs now farm around 4264 thousand hectares of agricultural land in the Czech Republic, around half (54 %) of the total area of the country. The size structure of businesses differs greatly from the structure of businesses in the 25 member states of the European Union. In terms of the size structure of the farms it shows that the farms with acreage more than 1000 ha manage 54.8 % of agricultural land of Czech Republic. If we summarize farms with acreage over 500 ha, this share is 71.1 % of agricultural land. The evaluation of the field size represented by LPIS (Land Parcel Identification System) shows that the fields with acreage above 20 hectares cover a share of 58.9 %. These conditions allow to use modern, high performance equipment with relatively high level of efficiency. From the other hand, there are the negative effects of intensive farming on the environment and soil fertility. A major problem of the current crop production is mainly soil compaction, which is clearly linked to the passes of machines across the field.

The risk of soil erosion significantly increases with the degree of soil compaction. More than 50 % of the arable land in Czech Republic is endangered by erosion according to expert analysis. Farming in accordance with environmental protection is provided on the basis of standards of Good Agricultural and Environmental Condition - GAEC now. Since 2015, in connection with the new programming period for the Common Agricultural Policy 2014 - 2020 the conditions are ensured by 7 standards. Farming in the accordance with the standards of GAEC is part of cross-compliance checks and it is one of the conditions for granting the full amount of direct aid. Intensity of the farming which will lead to control and decreasing soil erosion summarizes the standard number 5. The standard is focused on the application of soil conservation technologies and their application on crop establishment on erosion-threatened areas. From the other hand the choice of soil conservation technologies for farmer according to GAEC framework is relatively limited.

One of the tasks for research institutions is to find and verify the technology that would be acceptable for the conditions of Czech agriculture in terms of applicability, functionality and sustainability of management. An example is a technology Strip-till, which was newly added to the list of soil conservation technologies. In the context of field trials other technologies and techniques with soil conservation potential are tested. Utilization of GPS guidance, telematics and monitoring systems opens up the possibility of better field work organizing and trajectory optimization with respect the shape and acreage of the field. Resources are already available, but their potential is not fully exploited.

Serbia

The awareness of soil compaction problem is in Serbia on high level, especially among advanced farmers in the agricultural part of the country, Province Vojvodina. Most of them prevent it by common measures e.g. utilization of wide low pressure tyres or twined-tyres. One of the frequently used measures is to skip field traffic and operations on high damp soil.

Figure 15 Typical measure of soil pressure abatement, twin-tyres on Belarus tractor (left); Low depth subsoiler combined with rotary harrow for plough pan elimination (right)

Another measure for soil compaction reduction is application of conservation tillage, highly accepted in semi-arid regions. Crop residues layer contribute attenuation of soil compaction and, in the same time, contribute preservation of soil water.

As the biggest problem, especially for loamy soils, is the creation of plough pan. This can be relatively easy eliminated by using low depth (about 40 cm) subsoilers combined with other tool, like this presented in the Figure 15 right.

This implement can be applied annually or biannually. Application of deep subsoilers is also desirable, every third or fourth year. The best solution is trailed type, with oscillating tools. There are three domestic manufactures of subsoilers, but their utilisation is still not wide spread, and the reasons are purchase and operation costs. The benefits of tyres' pressure changing, lower for on field and higher for public road transport, are well known, but, again due to additional costs, applied only on big farms, over 500 ha. There is well organized extension service, as well as few farmers associations, which can enable dissemination of messages related to this problem, which is already included in educational process.

Slovak Republic

In conditions of the Slovak republic the problems of the compaction of the arable soil are very significant. According to the analysis provided by the Soil Science and Conservation Research Institute (SSCRI) in Bratislava, which is the major pedological institution in Slovakia, more than 22 % of the arable land can be considered as a soil having higher soil bulk density due to soil compaction. At the above research institute there was prepared the system of measures which can reduce the share of the compacted soils (Kobza et al. 2005):

- engineering measures: decreasing of the tire contact pressure by using of correct tire inflation pressure, using of adequate types of tires, using of dual tires, etc.,
- organizational measures: providing of field operations in time of the optimal soil moisture content, reducing of the passes of transport machines on a fields, implementation of the controlled traffic farming systems, reducing of the machines passes by means of using of combination machines, etc.,
- agrotechnical measures: using of cropping systems allowing to eliminate soil compaction due to alternation of the grown crops with increasing of the soil organic matter contents, using of the soil conservation tillage systems.

For conditions of the Slovak agriculture it is very typical the change of size of farms. As farms have become larger and labour more costly farmers have maintained productivity by using larger machines. As tractors become heavier, engineers have tried to keep tire soil contact pressures from increasing by using tires with larger diameters, wider widths and tire construction that can operate at lower inflation pressures. Dual tires and tandem axles have also been added.

As a very important tool allowing to reduce the soil compaction is considered a **control traffic farming (CTF)** system. According to Galambosova et al. 2015, therefore the Department of Machines and Production Systems, Faculty of Engineering of the Slovak University of Agriculture in Nitra, Slovak Republic, has established at the University farm in Kolinany in the year 2009 a long-term experiments focused on CTF system at a 16 ha field. Within the experiments the soil compaction is permanently recorded by measuring a soil penetrometric resistance. Organisation of field traffic and adoption of CTF reduced the cropped area affected by traffic by approximately 50% compared with random traffic. Within permanent beds (non-trafficked soil), the average grain yield was approximately 0.5

t ha^{-1} higher compared with the single pass treatment, and up to 1.8 t ha^{-1} higher when multiple passes were performed. Considering the ratio of non-trafficked-to-trafficked area within the CTF system, the economic benefits due to yield improvements can potentially to increase gross income by approximately EUR 32 per ha for the 6 m basic module. According to the results obtained further improvement resulting from reducing a soil compaction, elimination of overlaps and optimisation of field traffic is very realistic.

Strip tillage eliminates soil compaction, encourages more favourable soil temperature, moisture and aeration conditions for germinating seeds and seedling plants. This can translate to improved crop establishment and early season performance. Strip-till also offers the opportunity to place fertilizers directly into the root zone, away from crop residues that could otherwise intercept or immobilize nutrients. Based on experience obtained in Slovakia it can be stated that strip-till can provide conservation and efficiency benefits over conventional tillage practices. By leaving the inter-row untilled, crop residues are retained on the soil surface providing increased erosion resistance and organic inputs. Strip-till can also reduce field passes and input costs compared to conventional tillage.

In conditions of the Slovak agriculture it is very important to reduce the share of the lands belonging to the category of compacted soils. There can be used different tools allowing to mitigate the effects of the factors causing compaction of the soils. Everything depends upon the ability and solutions of the farm managers.

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44. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

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AGRICULTURAL DROUGHT, PAST, PRESENT AND FUTURE CHALLENGES

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ABSTRACT

Despite the hard work developed in understanding, predicting and monitoring drought, this phenomenon remains a major problem around the world. Agriculture is often the first sector to be impacted by drought because access to water resources and soil moisture reserves determine crop productivity. Agricultural drought depends on the crop evapotranspiration demand and the soil moisture availability to meet this demand.

Several challenges are generated by agricultural drought and all of them must be efficiently and effective approached. Some of the existing drought indices fail to detect agricultural droughts and their severity, a better agriculture tailored approach is missing, new methodologies adapted to existing technologies are needed etc.

The paper will debate the concept of agricultural drought and will perform an analysis of past, present and future challenges.

Key words*: agriculture, land drainage, water, technology*

INTRODUCTION

Due to the complexity of drought phenomenon, the definitions which are currently used were enounced according to the fields their address. There is a relative wide acceptation which states that drought have their origin in a precipitation deficit and which result in a water shortage for a specific activity or a target group.

In 1987 Wilhite proposed, based on a study realized on more than 150 definitions of drought, the following classification of this phenomenon: Meteorological drought, Agricultural drought, Hydrological drought and Socio-economic drought (Wilhite, Glantz; 1987).

Tate and Gustard, in 2000, classified drought as follows (Tate, Gustard; 2000):

- Climatological drought (deficit of precipitations)
- Agro-meteorological drought (deficit of water in soil)
- Hydrological drought (deficit of river flows)
- Hydrogeological drought (groundwater deficit)
- Operational drought (conflicts between requests and available resources).

In 2012, R. Maliva and T. Missimer, in their work „Arid Lands Water Evaluation and Management”, propose a drought classification on 7 directions (Maliva, Missimer; 2012):

- Meteorological drought;
- Climatological drought;
- Atmospheric drought;
- Agricultural drought;
- Hydrological drought;
- Socio-economic drought;
- Water management drought.

When we discuss about agricultural drought we are refering to soil status from humidity shortage point of view. Authors like Novak V. propose to use the notion of soil drought considering that this way will describe better the situation from field (Novak, 2007). Kulik (1962) defines agricultural drought as being the period in which exists only 19 mm of available water in the first 20 cm of soil.

G. Monacelli in a report about drought from 2005 proposed the following definition for agricultural drought: “Agricultural drought links various characteristics of meteorological (or hydrological) drought to agricultural impacts, focusing on precipitation shortages, differences between actual and potential evapotranspiration, soil water deficits, reduced groundwater or reservoir levels, and so forth.”

According to Dunkel Z., agricultural drought definition should include 2 approaches, one including the inadequacy of available soil moisture while the other one is about the link between yield and water shortage (Dunkel, 2009). In 2014, Labedzki and Bak, in a paper about meteorological and agricultural drought indices used in drought monitoring in Poland, motioned that “Agricultural drought is an effect of various characteristics of meteorological and hydrological drought in agriculture comprising the reduction of evapotranspiration, soil water deficits, and reduced crop yield.”

Authors like Sobisek propose the term of physiological drought to describe the link between water shortage and plants growth and production (Sobisek, 1993).

However, a good agricultural definition should include all the factors involved in this field. Human factor is one of the most important. We can start the debate from the idea that *agriculture* is a late Middle English adaptation of Latin *agricultūra*, from *ager*, "field", and *cultūra*, "cultivation" or "growing" and knowing that agriculture usually refers to human activities. In this way, sustainable land management, efficient agricultural practices and a good understanding of land-energy-climate-water nexus are indispensable elements in understanding agricultural drought. Two other key factors include the growing seasons and the average yield.

The role of meteorological drought in influencing agricultural drought can't be neglected but we shouldn't reduce the causes of water shortage in the soil profile to only one.

METHODS

This paper is based on an ample analysis of existing scientific literature linked with agricultural drought and on a proposal regarding a new approach in studying this type of event (see figure 1).

There will be also discussed the indicators used to analyze agricultural drought. A significant number of different indices have been developed to quantify a drought (among them being Agrohydropotential (AHP), Dry day Sequences, Generalized Hydrologic Model, Crop Moisture Index, Moisture Availability Index, each with its own strengths and weaknesses.

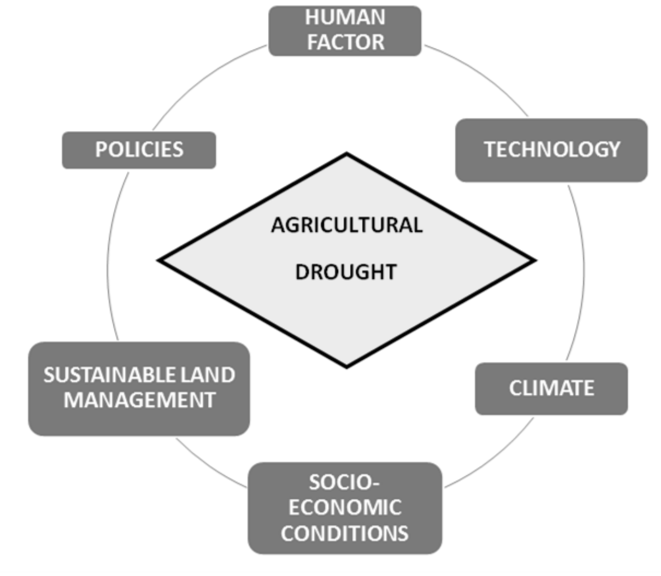

Figure 1 Theoretical approach for agricultural drought study

DISCUSSION

The most important challenges generated by agricultural drought are linked to the quality of drought indices, the need for a better agriculture tailored approach as well as the necessity to adopt new methodologies for mitigating the effects of agricultural drought adapted to existing technologies etc.

According to Wilhite (2005), agricultural drought is defined more commonly by the availability of soil water to support crop and forage growth. Other scientists link agricultural drought to meteorological drought due to the dependence of agricultural sector to water resources and thereby to precipitations. UNCCD (1994) make here a difference by mentioning that “agricultural drought focuses on factors such as differences between actual and potential evapo-transpiration and soil-water deficits, are crop-specific and depend heavily on the timing of rain and dry periods relative to crop-cycles” resulting that „agricultural drought can therefore occur in the absence of meteorological drought”. However, the problem is not so simple. Agricultural drought is an issue which includes aspects related to human resources, technology, climate, policies, sustainable land management and socio-economic conditions. Thus, we cannot reduce the problem of agricultural drought to lack of precipitations (or values between averages) and/or the crops demands for water. Human factor can intervene in both of these situations and the problems can be easily resolved. The interventions can be in terms of the quality of human resources, technologies and policies.

Technologies dedicated to mitigate the effects of agricultural drought include rainwater harvesting, GIS, sensor technology, irrigation technology, water conservation technologies etc. The role of climate in studying agricultural climate is more than obvious. In the last decades, a lot of studies were focused on manipulating climate in order to simulate extreme weather events (e.g. drought). However, many of these researches focused only on excluding rainfall (e.g. using roofs in some study areas) without considering the complex aspects of drought. The climate plays and important part in generating drought conditions but it’s not at a base of a drought event.

There is a wide scientific literature focused on the links between agricultural productivity (and we can say also here agricultural drought) and socio-economic factors. According to these studies, agricultural productivity not only depends on climate and biophysical variables but relies also on the availability of capital and labor (Simelton et al., 2009).

Sustainable land management is defined as the use of land and water resources, including soils, water, animals and plants, for the production of goods to meet changing human needs, while simultaneously ensuring the long-term productive potential of these resources and the maintenance of their environmental functions. The SLM principles are including the necessary directives to prevent and, if required, to mitigate the effects of agricultural drought. Thus, the study of agricultural drought using SLM approach is a must for an efficient management of this type of crisis.

Many indices and indicators are available to assist in the quantitative assessment of agricultural drought severity, and these should be evaluated carefully for their application to each region or location and sector. To best characterize agricultural drought it is critically important to use a combination of indices and indicators since no single one can capture the full severity of a particular drought event. Agricultural drought indices generally evolved around monitoring soil water balance and the subsequent deficit. Some of the mostly used agricultural drought indices are:

- Relative soil moisture index (Thornthwaite and Mather, 1995);
- Crop moisture index (Palmer, 1968);

- Crop-specific drought index (Meyer et al., 1993);
- Agricultural drought index (Matera et al., 2007);
- Soil moisture drought index (Narasimhan and Srinivasan, 2005);
- Evapotranspiration deficit index (Narasimhan and Srinivasan, 2005);
- Normalized Vegetation Drought Index (Tucker, 1979);
- Enhanced Vegetation Index (Liu and Huete, 1995);
- Vegetation Drought Response Index (Brown et al., 2008);
- Temperature Condition Index (Kogan, 1995);
- Normalized Difference Water Index (Gao, 1996).

Considering the complexity of agricultural drought phenomenon as well as the multitude of factors which can be key generators of this type of drought, none of the previously mentioned indexes is able to present an acceptable view of the studied event. Nevertheless, using a combination of several factors, with different approaches and uses, can be obtained a view of the studied phenomenon and can be set up a list of measures for mitigating the negative effects.

Agricultural drought also requires a management based on an ecosystem services approach, strongly linked to nutrients management issue and with methodologies which can be included in the relations generated by food-energy-water nexus. The following figure identifies as potential measures the use of irrigation and controlled drainage systems for mitigation agricultural drought effects but in certain relations with previously mentioned factors.

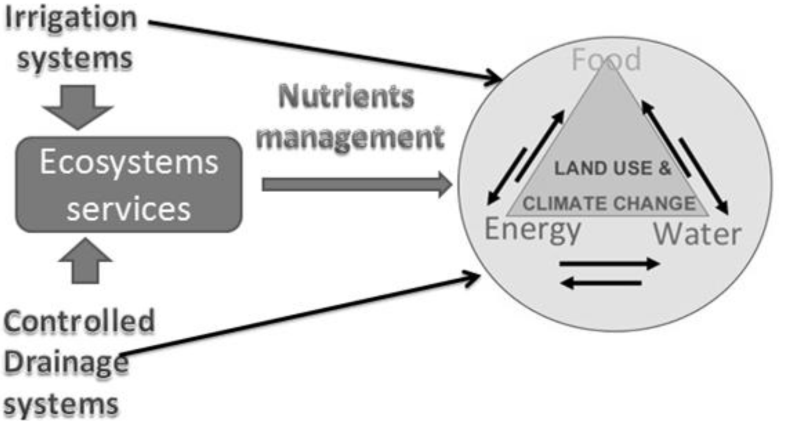

Figure 2 Technical measures for mitigating agricultural drought (conceptual approach)

Returning to the list of agricultural drought indices, we can observe that none of them is able to express the complexity of the relations presented in figure 2 being obvious the necessity to identify and propose new indicators for this type of drought.

CONCLUSIONS

Reviving agricultural growth at the global level is a must in the near future considering the increasing global demand for cereals to feed the growing populations. There is a strong need for undertaking a comprehensive review of all agricultural drought indicators in order to identify a reliable early warning system and to propose a sustainable management for mitigating agricultural drought effects. Given the context of climate change, water scarcity, and food security, a better agriculture tailored approach is missing and new methodologies adapted to existing technologies are needed for understanding and reducing drought risk and impacts on agriculture

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44. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

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Original scientific paper

CLIMATE ADAPTIVE LAND RECLAMATION AND IMPROVEMENT SYSTEMS – AN INTEGRATED APPROACH OF CURRENT CHALLENGES IN AGRICULTURE

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ABSTRACT

Land degradation affects large areas of Eastern Europe where social, economic and political changes generated high pressures on land resources, all of these under the global climate change. Agricultural lands and agricultural production are threatened by climate changes especially due to the severe changes in rainfall and temperatures variability requiring counteracting measures like land reclamation and improvement arrangements. LRI arrangements are managing land, water and plants, are both energy users and providers, have a strong impact on land management and are answering to climate changes by mitigating their effects and by creating microclimates.

Policy makers need a set of measures from a wide range of fields in selecting and implementing innovative climate adaptive land reclamation systems using an innovative trans-disciplinary approach, integrating both stakeholders and scientists knowledge as well as results from case studies and covering a range of pressures and threats on agricultural water management in different bio-physical and socio-economic environments across Europe.

This paper will debate an integrated approach of food security, low-carbon energy, sustainable water management and climate change mitigation using innovative climate adaptive LRI systems.

***Key words**: land reclamation and improvement, integrated approach, innovative, climate adaptive*

INTRODUCTION

Global population is expected to increase from 7 to 9 billion until 2050, situation which will lead to an even significant increase of food demand and, consequently, of water needs (Birendra et al., 2011; de Fraiture et al., 2010; Siebert and Doll, 2010). Agricultural lands and agricultural production are threatened by climate changes especially due to the severe changes in rainfall and temperatures variability. The increasing pressure on lands and agricultural water management stemming from complex water-food-energy linkages requires an improved integrated land and water resources management (Ragab and Prudhomme, 2002). Water scarcity and water excess (water logging) have a negative impact on agricultural productions and can be managed with the help of land reclamation and improvement arrangements (irrigation, surface drainage, deep drainage, soil erosion control etc.).

METHODS

The paper is based on an analysis of the conceptual framework presented in the next figure and which tries to explain the methodology which used be used in designing climate adaptive land reclamation works. The actual methodology in designing land reclamation works has an economic approach: reducing the effects/ removing the stress factors for maintaining/ increasing agricultural production at low costs.

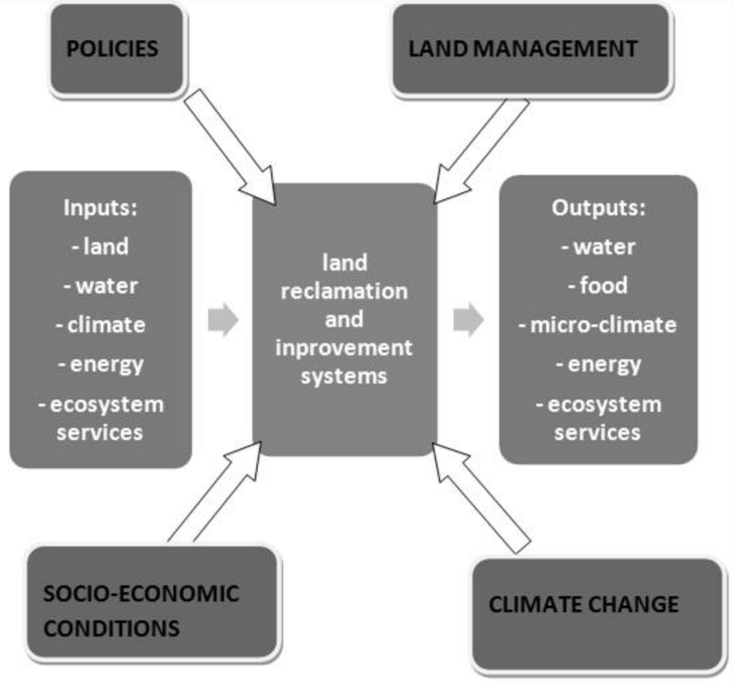

Figure 1 Conceptual framework for land reclamation and improvement systems design

Unfortunately are not considered the potential impact on environment, adaptation to climatic variability, the possibilities of soil and water conservation, climate changes manipulation techniques using these types of works. The integration of land reclamation works in sustainable land management represents a new scientific approach especially regarding the problem from the point of view of ecosystem services provided by these works. This type of approach will overrun the interdisciplinary borders and will assume o stronger cooperation from planning to implementation.

DISCUSSION

Land reclamations means "making land capable of more intensive use by changing its general character, as by drainage of excessively wet land; irrigation of arid or semiarid land; or recovery of submerged land from seas, lakes and rivers" *(*www.ecologydictionary.org). Land reclamation counteracts a specific form of land degradation while land improvement refers to increasing the land value and its productive capacity. Land reclamation and improvement works (LRI works) includes mainly irrigation and drainage systems but also soil erosion control works. LRI arrangements are managing land, water and plants, are both energy users and providers, have a strong impact on land management and are answering to climate changes by mitigating their effects and by creating microclimates.

Land reclamation and improvement works are a significant part of agricultural water management and have influences spread in all components of land-water-climate-energy nexus. They provide important ecosystems services including groundwater recharge, flood retention, carbon sequestration, erosion control, accumulation of SOM, recycling of soil nutrients, supporting diversity by providing habitats for flora and fauna. Integrating these different benefits in the framework of agricultural water management requires breaking down disciplinary boundaries between engineers, ecologists, agronomists, economists, hydrologists and climate scientist and the appliance of some reliable climate-energy-economic models as well as land-use models.

An improved understanding of ecosystem services provided by these works and of relations developed in the frame of land-water-climate-energy nexus and the implementation of climate adaptive land reclamation and improvement systems will decrease the pressures on basic resources.

Water scarcity and water stagnation are both causes of land degradation. There are several technical options which addressed water stagnation and water scarcity impacts in agriculture and which have often been considered as adaptation strategies (Fleskens et al., 2005). Land reclamation and improvement works are representing a main category of these technical options. However, the limits to such approaches need to be better understood (Vincent et al., 2013) and their interactions with the provision of ecosystem services becomes more important (Dale and Polasky, 2007). Moreover, a special attention must be granted to ecosystem services provided by land reclamation and improvement arrangement, approach which so far was much neglected. Agricultural land management has important interactions with the ecosystem services such as carbon sequestration (Follett, 2001; Lal, 2008) and GHG emissions from peat soils (Wessolek et al., 2002; Kluge et al., 2008).

These kind of dynamic interactions between land management and preferences of relevant stakeholders need to be better understood (Fleskens and Hubacek, 2013).

Moreover, understanding the interactions between agriculture and water, and in a broad context the land-water-energy-climate nexus, is crucial. Agriculture is inextricably linked to the natural systems, climate, energy and to water in particular (Strzepek and Boehlert, 2010; Konikow and Kendy, 2005; Milly et al., 2005; Rosegrant et al., 2009). There is a strongly need for relevant climate-economy-energy models using an ecosystem services approach for a better analysis of land use.

Competition for land between the energy sector and agriculture (especially related to biofuel production and water supply) is a more recent concern (e.g., Reilly and Paltsev 2009, Wise et al. 2009). Few studies, however, have accounted for other relevant factors such as changes in agricultural demand, competition over land and water resources for other uses (such as bioenergy production), and the availability and cost of new agricultural technologies in terms of new water and energy sources. Even there exists a significant knowledge on new water harvesting techniques as well as on different types of energy sources, these advancements were not significantly integrated so far in land reclamation and improvement policies leaving this sector under environmental, economic and social pressures generated by lack of fresh water sources, high cost of energy etc.

At European level is a large quantity of knowledge on land reclamation systems and the degradations they address but this knowledge is dispersed, fragmented and sometimes incomplete especially regarding the complexity, functioning and services of land reclamation works and their interaction with food-climate-energy-ecosystem nexus. Land reclamation and improvement works should also be part of sustainable land management which is defined as the use of land and water resources, including soils, water, animals and plants, for the production of goods to meet changing human needs, while simultaneously ensuring the long-term productive potential of these resources and the maintenance of their environmental functions (UN Earth Summit, 1992). Understanding regional certainties is a key element for practitioners and policy makers involved in planning, designing and operating climate adaptive land reclamation and improvement systems but also in setting new relevant policies for this sector.

IPCC studies (Parry et al., 2007; Metz et al., 2007; IPCC, 2012) estimates indicate that climate change is likely to reduce agricultural productivity, production stability and incomes in some areas that already have high levels of food insecurity. Developing climate-smart agriculture is thus crucial to achieving future food security and climate change goals.

Climate-smart agriculture contributes to the goals of making sustainable development concrete. It integrates the three dimensions of sustainable development in addressing food security and climate concerns in a forward-looking perspective. It is guided by the need for more resource efficiency and resilience. These principles are also central in the Rio + 20 outcome document, which recognizes resource efficiency as key to a green economy and affirms the need to enhance agriculture’s resilience (FAO, 2013).

Preserving and enhancing food security requires agricultural production systems to change in the direction of higher productivity and also, essentially, lower output variability in the face of climate risk and risks of an agro-ecological and socio-economic nature. In order to stabilize output and income, production systems must become more resilient, i.e.

more capable of performing well in the face of disruptive events. More productive and resilient agriculture requires transformations in the management of natural resources (e.g. land, water, soil nutrients, and genetic resources) and higher efficiency in the use of these resources and inputs for production. Transitioning to such systems could also generate significant mitigation benefits by increasing carbon sinks, as well as reducing emissions per unit of agricultural product (FAO, 2010).

Improved water harvesting and retention (such as pools, dams, pits, retaining ridges, etc.) and water-use efficiency (irrigation systems) are fundamental for increasing production and addressing increasing irregularity of rainfall patterns. Today, irrigation is practiced on 20 percent of the agricultural land in developing countries but can generate 130 percent more yields than rain-fed systems. The expansion of efficient management technologies and methods, especially those relevant to smallholders is fundamental. Improving ecosystem management and biodiversity can provide a number of ecosystem services, which can lead to more resilient, productive and sustainable systems that may also contribute to reducing or removing greenhouse gases. Services include, control of pests and disease, regulation of microclimate, decomposition of wastes, regulating nutrient cycles and crop pollination. Enabling and enhancing the provision of such services can be achieved through the adoption of different natural resource management and production practices (FAO, 2010).

CONCLUSIONS

Most of the impacts of climate change agriculture and rural livelihoods are expected to result from changes in the water cycle. Rainfall variability and the subsequent increase in frequency of extreme weather events, including droughts and floods, combined with an increasing acceleration of the water cycle through increased evapotranspiration, will have an impact on every element in agricultural ecosystems: crops, livestock, trees, fish, rural communities and physical infrastructure. For this reason, climate change adaptation strategies for agriculture will need to be viewed though a ‘water lens’.

Reviewing the operation and designing criterions of irrigation and drainage works, in the frame of sustainable land management and under the pressure generated by climatic changes, should be made in correlation with identifying manipulation techniques of climatic changes using the infrastructure of land reclamation works. According to IPCC report from 2007, precipitations are presenting spatial and temporal variability with hardly predictable scenarios. Experiments on precipitation manipulation were developed in many zones, with different characteristics and different scenarios. In order to understand better the impact of an altered regime of precipitations (with effects both on humidity excess and deficit) must be designed and implemented a new generation of experiments. Sprinkler irrigation technique can be those analyzed through a new approach using the results of the experiments already done and using these irrigations in new experiments, especially on cultivated arable lands.

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44. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

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Original scientific paper

HYDROCARBONS SOIL POLLUTION IN ROMANIA: ISSUES AND SOLUTIONS

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SUMMARY

In Romania, according to the National Strategy and National Action Plan for Contaminated Sites Management in Romania, there are more than 215 potentially contaminated sites. According to the same report on the management of contaminated sites in 2013, starting more than 150 years ago, the oil industry in Romania is considered extremely important for economic development. Contaminated sites related to petroleum industry are ranging from small (extraction fields) to large and complex (refinery or storage facilities large - distribution of petroleum products). This paper will present the most used remediation methods at nationally level for petroleum contaminated sites. Moreover they will be presented and feasible alternatives that could be applied in Romania. The three methods presented here can be classified as a biological method (bioremediation), a thermal method (thermal desorbtion) and a physico-chemical method (electrochemical method). If the first two methods are already used at real scale at national level, the third method was studied during the development of an european project.

Key words: *soil pollution, hydrocarbons, remediation, bioremediation, thermal desorption, electrochemical treatment*

INTRODUCTION

According to the "Progress in the management of Contaminated Sites in Europe" from 2014, the estimates for the extent of local soil contamination are available for about one third of the countries surveyed from European Union; an average of about 4.2 Potentially Contaminated Sites are reported per 1,000 inhabitants and about 5.7 Contaminated Sites per 10,000 inhabitants. A tentative extrapolation to the whole of Europe produces an estimate for the total number of Potentially Contaminated Sites of 2.5 million, of which about 14% (340,000 sites) are expected to be contaminated and likely to require remediation.

In the same report an international evaluation is done according to which, after 27 countries have reported the data, about 1,170,000 potentially Contaminated Sites have been identified to date and this is estimated to approximate 45% of the number of possible sites for the EEA-39. About one third of the estimated total of 342,000 Contaminated Sites for the EEA-39 have already been identified and about 15% of the estimated total have been remediated. However, there are substantial differences in the underlying site definitions and interpretations that are used in different countries (EEA, 2014).

At European level, many countries have finished the contaminated sites inventory until 2011. In figure 1 the main contaminants that affect the solid matrix, are presented.

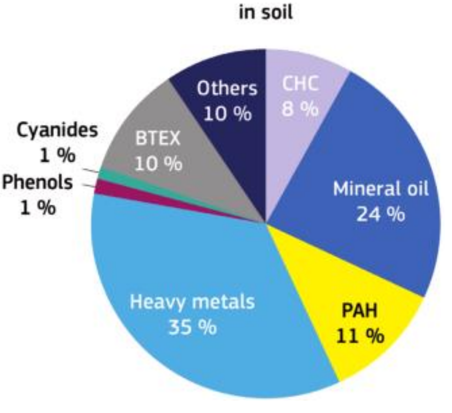

Figure 1 The main contaminants that affect the solid matrix (soil) (EEA, 2014)

At European level exist policy targets for local soil contamination, and Romania, until 2020 has the following target: environmental remediation of the majority polluted areas. Taking into account that Romania did not supply the necessary data for this study, this paper will use the data published in the Romanian document "National strategy for the management of contaminated sites", in 2013.

METHODS

In the present paper three methods used for soil treatment will be presented. The first two methods are widely used at national level (thermal desorption and bioremediation), while the third one was studied during a PhD thesis and a European project, RECOLAND. The objective will be to present the main steps in the application of the first two methods after which to focus on the presentation of the third one as a possible solution to an actual problem.

Thermal desorption

Thermal treatment is one of the effective methods to rapidly treat the oil-contaminated soil. However this method costs much due to the high energy consumption comparing with other conventional treatments, like biological ones (Taehoon et al, 2015). The general description of thermal desorption is described in the report issued by the United States of America. Department of the Navy, Contract Report CR 98.008–ENV, Overview of Thermal Desorption Technology. Port Hueneme, CA: 1998. Thus, thermal desorption is a term applied to many different types of soil remediation technologies. All of these technologies consist fundamentally of a two-step process, as illustrated in Figure 2. In Step 1, heat is applied to a contaminated material, such as soil, sediment, sludge, or filter cake, to vaporize the contaminants into a gas stream that, in Step 2, is treated to meet regulatory requirements prior to discharge. A variety of gas treatment technologies are used to collect, condense, or destroy these volatized gases.

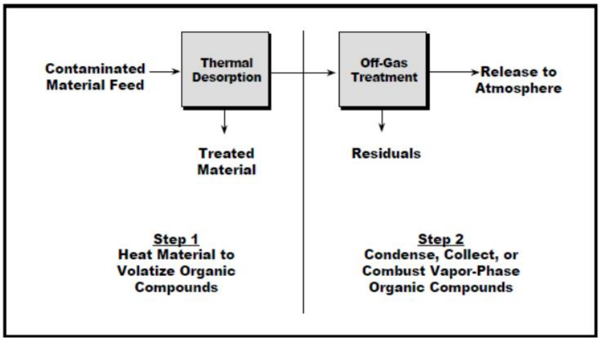

Figure 2 Generic thermal desorption process (United States of America. Department of the Navy. Contract Report CR 98.008–ENV Overview of Thermal Desorption Technology. Port Hueneme, CA: 1998)

Bioremediation

According to the Environment Protection Authority (EPA) guidelines from 2005, bioremediation, when properly managed, is an environmentally sound and cost-effective method of treating soils containing organic chemicals. Bioremediation may then enable appropriate reuse of the treated soil and minimise disposal of waste soil to landfill, whilst providing for adequate protection of human health and the environment. Bioremediation is not a new concept and is being increasingly used as a relatively economical environmental remediation technology. The ex situ bioremediation treatment of soil is generally undertaken in contained and managed biopiles or, subject to limitations, by landfarming. Bioremediation can occur naturally or can be encourage with addition of microbes and fertilizers. The microbes present in the soil first recognize the oil and its constituent by biosurfactants and bio emulsifiers, and then they attach themselves and use the hydrocarbon present in the petroleum as a source of energy and carbon (Bijay et al, 2012). The low solubility and adsorption of high molecular weight hydrocarbons limit their availability to microorganisms. The addition of biosurfactants enhances the solubility and removal of these contaminants, improving oil biodegradations rates (Bijay et al, 2012). Biological remediation using microorganisms and plants is generally considered a safe and less expensive method for the removal of hazardous contaminants. The microorganisms have the primary catalytic role in degrading or mineralizing various contaminants and converting non-toxic by-products during soil bioremediation processes (Sing et al, 2009).

Electrochemical remediation

The third technology presented in this paper is one based on the application of an electrical current in the polluted area. Electrokinetic remediation, variably named as electrochemical soil processing, electromigration, electrokinetic decontamination or electroreclamation uses electric currents to extract radionuclides, heavy metals, certain organic compounds, or mixed inorganic species and some organic wastes from soils and slurries (Istrate, 2009, Acar et al, 1994). At first, these types of technologies were used mainly for the remediation of metals, radionuclides and polar inorganic pollutants from soil and groundwater, and the process was called Electrokinetic Remediation. In recent years, several researches have been developed about DCT (direct current technologies) and their effectiveness in the removal of organic pollutants from soils and sediments. These studies seem to suggest that DCT can be effectively used for the mineralization of many organics, with lower energy expenditure, if compared to traditional electrokinetic remediation methods (Acar et al., 1995).

The electrochemical remediation depends on several important factors, as it will be presented in the following (De Battisti, 2008):

- soil chemistry, or soil-contaminant interaction: the kinetics of the removal of contaminants is bound to adsorption phenomena, ion-exchange, buffering capacity;
- water content: inhomogeneous distribution of humidity and consolidation may take place during an elecrokinetic treatment;
- soil structure: clogging of the soil porous texture and blocking of the electro-osmotic flow may take place due to hydroxide formation (presence of heavy metals);
- positioning of the electrodes and electrode structure: solidity of the structure, easy workability, chemical stability, costs, are major actors. Silicon pig-iron, graphite, activated titanium are electrode materials of practical interest.

The electrode distribution when electrochemical remediation is applied can vary from the bench scale to commercial installations as it is presented in figure 3.

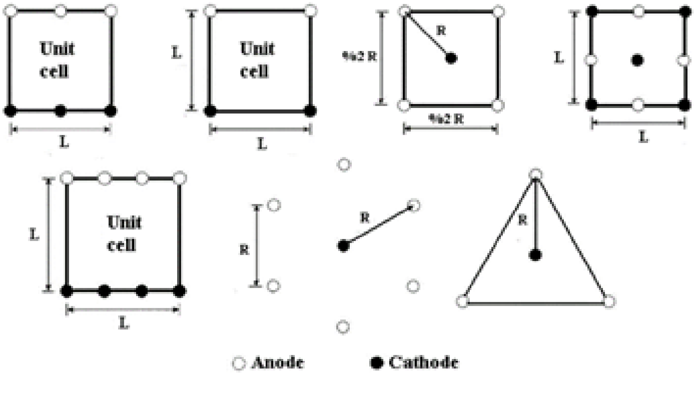

Figure 3 Possible electrode distribution for the application of electrochemical remediation (De Battisti, 2008)

RESULTS AND DISCUSSION

Thermal desorbtion and bioremediation

Regarding the first two methods (thermal desorption and bioremediation), in this paper a case study will be presented, where both of them are applied sequentially. This case study will refer to an area contaminated with petroleum residue. The first step is to implement a good management plan. This management plan of contaminated sites involves five main stages (Ivancu, 2013):

1. Identification of the potentially contaminated site and the registration of it in a database. The sites located in the database will have priority.
2. Preliminary investigation in order to identify the potential contamination sources, lodging transmission and receiver based on the history of the area, location and activities throughout time.
3. Detailed investigation needed to do the hydrogeological and geochemical characterization of the site, contamination sources, transmission routes, and receptors confirmation and the assessment of the contamination extent.
4. The risk assessment to which the receptors are exposed to the confirmed contamination at the site.
5. Options / remedial measures: limiting the contamination, eliminating / reducing contamination or only natural attenuation and monitoring accompanied by receptor behavior modification.

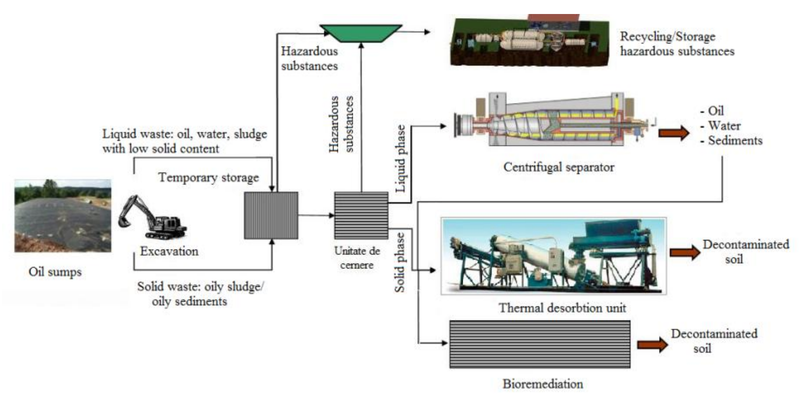

Figure 4 The remediation process overview (Ivancu, 2013)

Electrochemical remediation

For the third method, electrochemical method, the results obtained during a PhD research and a European project, will be presented. The experimental research used a setup (Figure 5) done with the funds from a project co-financed under the Sectorial Operational Programme “Increase of Economic Competitiveness” POSCCE-A2-O2.1.2.-2009-2, REC-OLAND ID519, SMIS-CSNR: 11982, Nb. 182/18.06.2010 (2010-2013). The working principle of the setup is the same with the one of the setup used for a PhD research performed during an international PhD.

In figure 5, the experimental setup used for the experiments done in laboratory is presented.

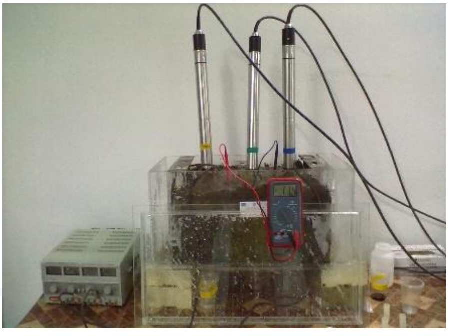

Figure 5 The experimental setup – electrochemical cell, power supply and the sensors used for pH and redox measurements

The test has been performed with the main purpose to observe the behavior of the integrated system and the effectiveness in terms of contaminant removal that can be obtained after a periodical change of polarity. This trial been conducted on a simple sample of sand with a total weight of 2.4 kg, previously artificially contaminated by diesel fuel. The test ISECOPC (In Situ ElectroChemical Oxidation with Polarity Changing) has been performed on diesel contaminated sand, in the experimental setup 2 for a treatment period of 28 days with a specific voltage of 1 V/cm (table 1).

Table 1 The main characteristics of ISECOPC

Test	ISECOPC	
Matrix	Fine sand	
Contaminant	Diesel	
Sample weight	2.4	[kg]
Sample density	1.5	[kg/L]
Exposure time	28	[d]
Voltage (constant)	18	[V]
Specific voltage	1	[V/cm]
Oxidant	H_2O_2	[ml]

The oxidant used for this test was hydrogen peroxide with a concentration of 10%. The quantity of oxidant that must be inserted into the contaminated sample was calculated at about 810 ml. The quantity was divided in 6 dosages of 140 ml that have been administrated in the first two days of the week.

The parameters that have been monitored during this trial are: the pH, the current, the redox potential and at the end of the experiments the values for TOC and TPH were also identified. From the beginning until the end the pH ranged around the value of 7.

The values for the current did not exceed the value of 100 mA. The high value of the current is normal because of the insertion of the oxidant that increases the concentration of ions. The trend of the current is decreasing and is characterized by small intensity peaks that are localized after a short period from the oxidant injection. The monitoring of the current has been done with a digital multimeter. The data will be presented only for the first two weeks. As for the previous test, the hydrogen peroxide that was used for this test had a concentration of 10%.

Regarding the evolution of soil pH it is noted that the changes made during this test are very similar to those in the previous tests, where at anode the pH tends to decrease and at the cathode to increase. The difference consists in the fact that the variation is very small, almost undetectable. This is due to the fact that the first tendency for the pH is to decrease as in the other tests, and so to form the acid and basic front at the two electrodes. The acid front that moves from the anode to the cathode and the basic front that moves from the cathode to the anode (in the beginning of the tests), change their direction after the polarity of the experiment (node becomes cathode and vice versa) is changed.

Another parameter that has been monitored during the test ISECOPC is the redox potential. Redox potential (also known as oxidation/reduction potential or ORP) is the tendency of a chemical species to acquire electrons and thereby be reduced. Each species has its own intrinsic reduction potential; the more positive the potential, the greater the species affinity for electrons and tendency to be reduced. The redox potential is a measure (in volts) of the affinity of a substance for electrons — its electronegativity — compared with hydrogen (which is set at 0). Substances more strongly electronegative than (i.e., capable of oxidizing) hydrogen have positive redox potentials. Substances less electronegative than (i.e., capable of reducing) hydrogen have negative redox potentials.

The trend of redox potential for the first week of the trial is presented in figure 6. In this figure is presented the evolution for only the first week because it was wanted to underline the tendency of the redox potential.

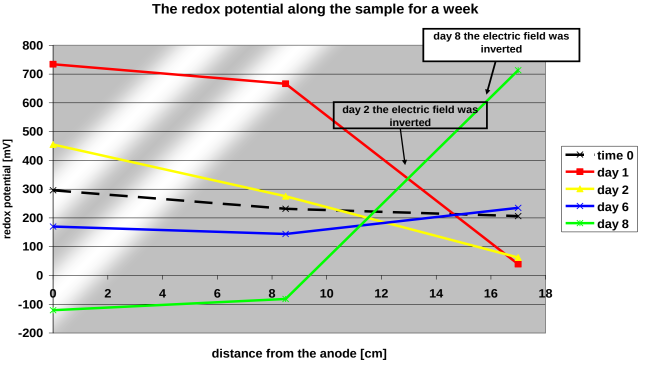

Figure 6 Redox evolution during the first week of treatment for test ISECOPC

High redox potential near the anode indicates highly oxidizing conditions, while low redox potential near the cathode indicates reducing conditions. It was noticed that after the first day of treatment the redox potential decreased linearly from the anode to the cathode to a value closed to zero. This is due to the electric potential of DC and its redox reactions at electrodes. In these conditions it was decided to change the polarity of the experiment. Before the polarity changing the profile is very marked after which the values for the redox potential at different distances from the anode tends to be closer as values.

At the end of the test ISECOP, two parameters were analyzed, the TOC and TPH. After 28 days of treatment, the sand sample has been divided in three parts that corresponds to the cathode, middle and anode area. The removal percentages obtained at the end of the test were very good. For TOC it was registered almost 50% removal and for TPH around 70%. The analysis for these two parameters have been done according to standard methods: DM 13/09/1999 for TOC, EPA 5021A 2003 + EPA 8015 D 2003 (Hydrocarbons <=C12) and ISO 16703:2004 (hydrocarbons >C12).

The TPH distribution was evaluated at the end of the experiment (Figure 7) to assess any influence of the electrode distance or of the transport phenomena on the pollutant removal. The TPH concentration in the soil sample ranged from 2.26 g/kg_{DW} at the anode of the specimen to 2.77 g/kg_{DW} in the section closest to the cathode and in the middle. Despite this small variability, that can be considered due to analytical errors and to a quite heterogeneous distribution of the hydrophobic pollutants of concern, as expected, no significant influence of the electrode distance or of the transport phenomena was detected for sand. For TOC it can be noticed also the uniformity in removal percentages along the soil sample.

The final soil water content ranged from 21.7% for the soil near the anode, to 21.3% at the cathode site, with an almost linear distribution in space.

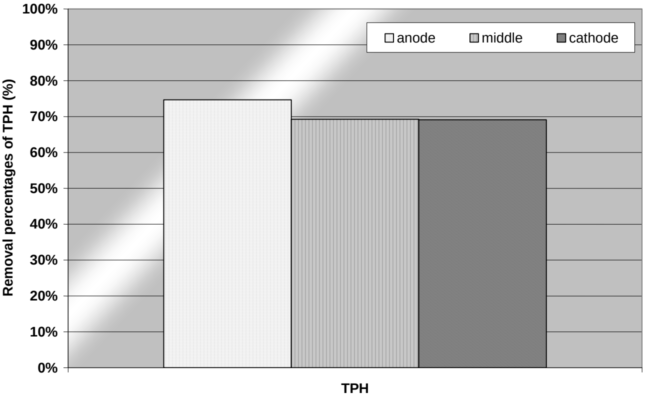

Figure 7 Removal percentages distribution for TPH along the soil specimen at the end of test ISECOPs

Taking into account the values measured for the current and voltage, it was possible to approximate the energy consumption necessary for the remediation. Energy consumption per unit volume of soil is calculated using the following equation (Reddy and Chinthamreddy, 2003):

$$E_{\mu} = \frac{1}{V_s} \int VI\ dt$$

where, Vs is volume of soil processed; V is voltage difference between the electrodes (applied voltage); and I is electric current. Eμ is calculated as kWh m^{-3}.

For the test presented here the specific energy expenditure is 125,47 [kWh/m^3].

CONCLUSIONS

The effects of pollutants specific to petroleum refining released in the atmosphere affect human health or vegetation. Pollution generated by petroleum industry and environmental protection (chlorosis, necrosis, photosynthesis and transpiration reduction), water and soil (increase water acidity, it opacity, water flora and fauna, spontaneous and cultivated flora etc.), constructions, corrosion, installation (cause by corrosion of contacts and cables etc.) There are also risks for human health, for bio environment and vegetation, aromatic compound with mutagen and cancer generating character and last but not least, affect environment safety, with explosion and fire risk, when petroleum products floating on the water layer get in the basement of buildings.

Regarding the thermal method, even though is one of the most effective methods to rapidly treat the oil-contaminated soil this method costs much due to the high energy consumption comparing with other conventional treatments. But, recent research have shown that, new technologies can be developed in order to maintain the system efficiency and to reduce the costs. There are some new systems based on microwave thermal desorption that reached to a reduction of the cleaning costs by 77 % based on the microwave thermal desorption technology, which is resulted from the high performance of microwave and microwave absorber to effectively heat the soil container in the system.

Researches using bioremediation has shown great promise to date. Further researches in this field can result in the development of most efficient and less time consuming technologies. Also, further research is critical to investigate its application beyond the laboratory-scale and to develop the kinetics of degradation. Bioremediation is usually simple and less labor intensive. Also bioremediation is considered the most economical at the required efficiency when the soil to be treated is more. Although public attitudes toward bioremediation are generally favorable, the lack of knowledge about microorganisms and their natural role in the environment could affect the acceptability of their use. Before bioremediation techniques to be used widely, their efficacy and safety will have to be convincingly demonstrated and communicated to the public.

Regarding the third treatment presented in this paper, the electrochemical treatment, the results were quite good for such a limited period of treatment. Of course the results have to be confirmed at a real scale application. The matrix that has been chosen and that presented a lot of problems during some previous tests is the sand. The new technology consists in the combination of electrochemical and chemical oxidation with polarity changing (anode and cathode becomes vice versa). The test entitled ISECOPC has shown very good results in terms of TOC and TPH (48 % for TOC and 70% for TPH). The final average concentration for TPH was about 2.5 g/kg_{DW}. Taking into account the fact that the limits for the intervention point, according to the Romanian legislation, is of 2 g/kg_{DW} it can be said that the results are not so far from the limits. Anyway, as it was noticed from the previous conclusions, the treatment depends on the period for which is applied. So, if the same treatment will be applied for more than 28 days the final concentration for TPH should decrease until reaches a value below 2 g/kg_{DW}. One important aspect that must be underlined is the fact that respect to the previous tests, in ISECOPC the distribution of the final concentration was uniformly distributed.

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44. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

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Expert paper

IMPLEMENTATION OF RECOLAND PROJECT FOR THE REMEDIATION OF CONTAMINATED SITES

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SUMMARY

In the present paper the main stages of RECOLAND project, as well as the main results obtained after the project implementation will be presented. One of the main results of RECOLAND project is the development of a system that allows human health risk assessment due to soil contamination with toxic and persistent pollutants (PTP). The novelty of the result is given firstly by the fact that the multicriteria decision system is developed based on soil suitability planning considering the economic component in addition to the human health risk assessment and remediation method efficiency. This kind of tool is allowing to improve the management of the contaminated soils ensuring the life quality.

Key words: *European project, contaminated soils, organic contaminant, inorganic contaminant*

INTRODUCTION

The problematic of polluted soils with organic and inorganic pollutants has become quite serious in the last decades. In Romania the fundamental law about environment is Law no. 137 of the 29.12.1995, published in the Official Monitor no. 70 of the 17.02.2000. Today, this law has been replaced by Law no. 294 of the 27 June 2003, concerning the approval of Government Ordinance nr. 91/2002 for the modification and the completion of the environment law protection no. 137/1995, which was publish in the Official Monitor nr. 505 of the 14 July 2003 (with all the ulterior modifications). Another act which specifies limits for environmental pollutants in soil is Order 756 of the 11 March 1997, from Official Monitor no. 303 of the 11 the June 1997. In this document, chapter III is entitled "Regulations concerning the pollution of soils". This order establishes the thresholds of alert and the thresholds of intervention for pollutant concentrations in soils.

The project "Multi-criteria decision system for the remediation of contaminated sites with toxic and persistent pollutants from major industrial areas"/RECOLAND is a project developed under the Operational Programme "Increase of Economic Competitiveness" (POSCCE) Priority Axis 2 – Competitivity through Research, Technological Development and Innovation; Operation 2.1.2 – Projects of R&D of high-level scientific that will involve specialists from abroad. The main objectives of the programme estimates that actions completed will generate until 2015 an annually average productivity increase of approx. 5.5% and it will allow at national level to reach a level of about 55% of the EU average.

One of the main results of RECOLAND project is the development of a system that allows human health risk assessment due to soil contamination with toxic and persistent pollutants (PTP). The novelty of the result is given firstly by the fact that the multicriteria decision system is developed based on soil suitability planning considering the economic component but also the environmental one and the quality of life. These issues are particularly important for the management and spatial planning of large areas that are historically contaminated.

The general objective of the project was to develop a multicriteria decision system (an informatics system) in order to allow: health risk assessment and its use as a decision criteria in determining the suitability of lands from historically or accidentally contaminated areas; identification of the optimal remediation solution for contaminated soils with persistent and toxic pollutants; cost analysis of the proposed soils remediation solutions (soils contaminated with toxic and persistent pollutants) and contaminated sites assessment for the reduction of environmental pollution by risk-based approach.

Using the developed informatics environmental analysis system, it is possible to verify the land suitability from the contaminated areas (for instance construction or agriculture) taking into account risks from soil contamination with carcinogenic pollutants. The developed model interconnect different research domains (environment, health and information and communication technology - ICT) in order to reduce negative impact on human health and on the environment from soils contamination with organic and inorganic pollutants.

METHODS AND RESULTS

During the RECOLAND implementation, eight main stages could be underlined:

a) Identification and rental of contaminated area with heavy metals in order to assess the proposed remediation technologies for polluted soils; concerning the main topic of the project, also a technical report on the situation of contaminated soils at local and national level was developed.

b) Completion of research infrastructure.

c) Study of the physico-chemical characteristics of the contaminated soil chosen for the experimental research.

d) Experimental research concerning the bioremediation process on contaminated soil, laboratory experiments and costs estimation.

e) Design, implementation and testing of the pilot plant that was used for the application of electrochemical treatment; laboratory analysis and costs estimation.

f) Experimental development regarding the thermal treatment (incineration and pyrolysis) of the contaminated soil; laboratory analyzes and costs estimates.

g) Laboratory tests performed in order to identify pollutants concentrations from the treated soil by each of the applied methodologies.

h) The development of the multicriteria system (soft) and its testing for identifying the optimal solution for the management and planning of the use of a contaminated area.

The first stage in the project development was to identify the area of interest which was considered the starting point for the proposed activities regarding industrial research and experimental development. Thus, a site of 4,000.00 m^2 from Central Romania was chosen. This site is part of a well-known area in terms of significant historical contamination with heavy metals. For the implementation of activities foreseen in RECOLAND project, it was necessary to purchase some equipment that were used on one hand for experimental activities related to the testing of proposed remediation methods for the polluted soils and on the other hand for the chemical analyzes. In order to achieve the physico-chemical characterization of the soil from the identified studied area, 24 samples were taken from different sampling points, at different layers. The 24 samples of soil were taken using an agrochemical bore at two sampling depths: 0-20 cm and 20-40 cm. The sampling grid was established on site: an area of 4,000.00 m^2 from a total area of 1.89 ha.

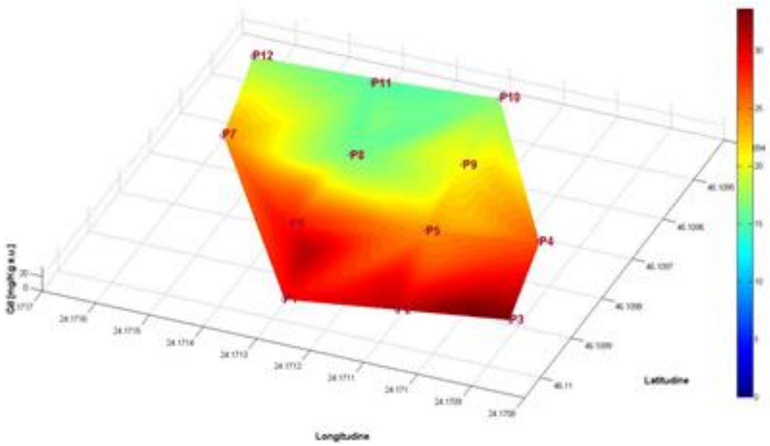

Figure 1 Distribution levels of Cd concentrations [mg/kg_{dw}] in the investigated area [sampling depth 0-20 cm]

In order to determine the soil pedological characteristics, samples from different layers were collected up to a depth of 1.20 m. The studied soil profile is classified as Protisoils limestone-type aluviosol molic-gleic, drained class. There are young soils that are formed on fluvial carbonate parent materials (carried by the river). For illustrating the distribution of the pollutant concentration in the investigated area, for each pollutant, maps illustrating the distribution of the contaminants concentration level were completed for each of the two sampling depths (Fig.1 and Fig.2). As it can be seen, in the case of cadmium, as well as for most of the heavy metals identified through chemical analysis, their concentration exceeds the limits imposed by Romanian regulation (Order 756/1997) mainly for samples taken from depth 0-20 cm. Due to this observation, it was established that the excavation depth for testing remediation methods at laboratory level and at real scale must be 0-20 cm.

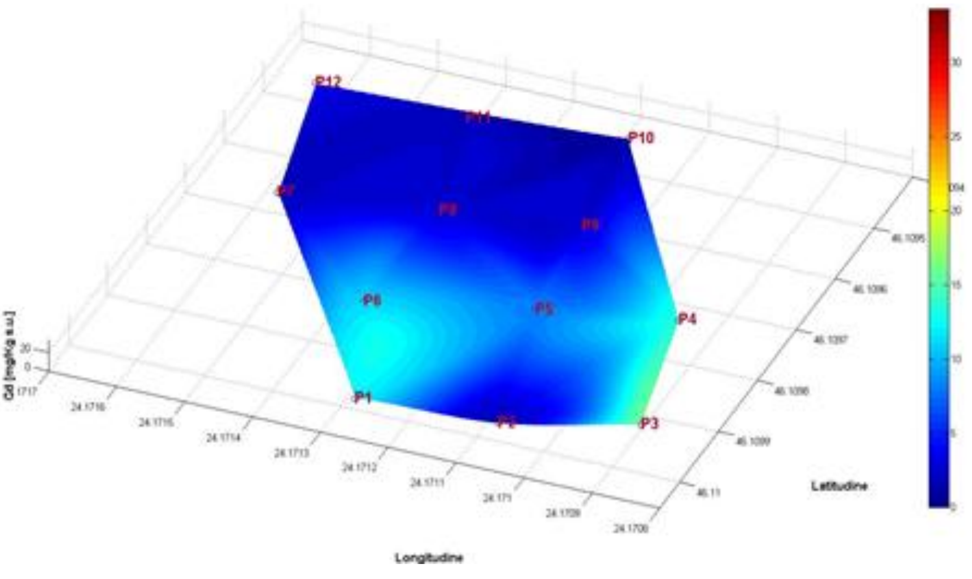

Figure 2 Distribution levels of Cd concentrations [mg/kg$_{dw}$] in the investigated area [sampling depth 20-40 cm]

Next, in the framework of the project, an environmental assessment of the site subject to the decontamination process was also carried out. On the other hand, regarding the multicriteria decisional system, the main parameters for the informatic system were updated taking into account the results of the physico-chemical analysis performed on the polluted soil. These analyses were completed according to the standards, protocols and analysis plans that exist at national or international level.

The interpretation of the physico-chemical analyses allowed to restrict the area of interest to about 1,200.00 m^2, where, for the 0-20 cm layer was identified a concentration level above the limit of intervention - sensible use according to Order 756/1997 (according to the real scenario of the investigated area, the agricultural one). Known that the experimental area was mainly polluted with heavy metals and since the RECOLAND project had as main objective to provide a software product that takes into account the case of accidental/historical pollution both with heavy metals and organic pollutants, it was decided to perform an artificial contamination of soil with different types of pollutants: oil for PAHs soil contamination and transformer oil for PCBs contamination). Consequently, the soil was excavated and stored on an impermeable platform in order to achieve in a first phase the controlled pollution and after the bioremediation at real scale. On the platform, the soil was placed in four experimental lots with different types of contamination.

In RECOLAND project three main methods of contaminated soils treatment were tested: bioremediation, electro-remediation and thermal treatment (incineration and pyrolysis). In order to test an in situ remediation method that can be applied for the existing historical contamination (inorganic pollution with heavy metals) in the investigated area phytoremediation was applied.

Bioremediation treatment

Ex situ bioremediation experiment was carried out on each of the four experimental lots on a surface of 1,000.00 m^2; the thickness of the soil layer was 20 cm. After one month from the controlled pollution of the soil, a screening of heterotrophic micro-organisms for each of the four experimental lots was conducted and the dominant microorganisms were isolated, identified and purified by successive passages on nutrient media. These microorganisms were tested for the ability to use petroleum hydrocarbons and polychlorinated biphenyls from transformer oil by cultivation in mineral medium whose sole carbon source was represented by each of the two pollutants. After selecting the competent bacterial strains in biodegradation, the politulpinal inoculum has been made. It was applied on the artificially contaminated soil with organic pollutants in each of the experimental lots. Additionally, the polluted soil was fertilized with a mix formed from fermented organic manure and vegetable scraps (corn stalks), at a dose of 150 t/ha. These activities were performed in order to create a favorable environment for the replication and nutritious native bacterial activity and of those introduced by inoculation. The monitoring of soil quality parameters (pH, organic carbon contained, total nitrogen, C/N, phosphorus and potassium) and pollutants concentration level in soil (heavy metals: Zn, Cu, Fe, Mn, Pb, Ni, Cr, Cu, Cd) and (organic compounds: Total Petroleum Hydrocarbon - TPH, Polycyclic Aromatic Hydrocarbons - PAHs and Polychlorinated Biphenyls - PCBs) was performed at 1 month, 3, 5 and 10 months from the application of controlled pollution.

Electrochemical treatment

Regarding the experimentation of electroremediation method applied to contaminated soils, tests on three experimental installations were conducted in laboratory using both historically polluted soil with heavy metals and artificially contaminated soil with organic compounds. Analyzed pollutants are known as being characterized by a high degree of toxicity (Reddy et al, 2009; Istrate et al, 2013). The experimental setups used for the tests were at three different scales: IPER 1 (figure 3) was the smallest scale and had the capacity to treat 3 kg of contaminated soil, IPER 2 (figure 4) was a medium scale and had the capacity to treat up to 60 kg of contaminated soil and IPER 3 (figure 5) was the largest scale and had the capacity to treat up to 750 kg of contaminated soil. Table 1 shows the soils contamination types, the analyzed pollutants and the experimental setups used for applying electroremediation. Apart the experiments done on the mentioned setups, a final test at a larger scale, on the field was performed, and the test was identified as SRP.

Laboratory tests were developed by varying the amount of soil being treated, by applying a constant voltage of 1 V/cm (Rohrs et al, 2002) and by using an average treatment time of 21 days (the longest period associated to the electrochemical method was 42 days). The monitored parameters throughout the experiments were: current value, pH, ORP, temperature, humidity, the conductivity and the pollutant concentrations.

Table 1 Types of soil contamination used during the experimental campaigns

Initial soil	Contaminated soil	The experimental instalation
Historical contaminated soil with heavy metals: Pb, Cd, Be, Cr, Ni, As, Hg	Artificial contaminated soil with PAHs (crude oil)	IPER 2
Historical contaminated soil with heavy metals: Pb, Cd, Be, Cr, Ni, As, Hg	Artificial contaminated soil with PCBs (transformer oil / condensate oil)	IPER 2
Historical contaminated soil with heavy metals: Pb, Cd, Be, Cr, Ni, As, Hg	Artificial contaminated soil: PCBs and PAHs (mixture of transformer oil / condensate and crude oil)	IPER 1, IPER 2, IPER 3
Historical contaminated soil with heavy metals: Pb, Cd, Be, Cr, Ni, As, Hg	Additional uncontaminated	IPER 1, IPER 2
Historical contaminated soil with heavy metals: Pb, Cd, Be, Cr, Ni, As, Hg	Artificial contaminated soil: PCBs and PAHs (mixture of transformer oil / condensate and crude oil)	SRP

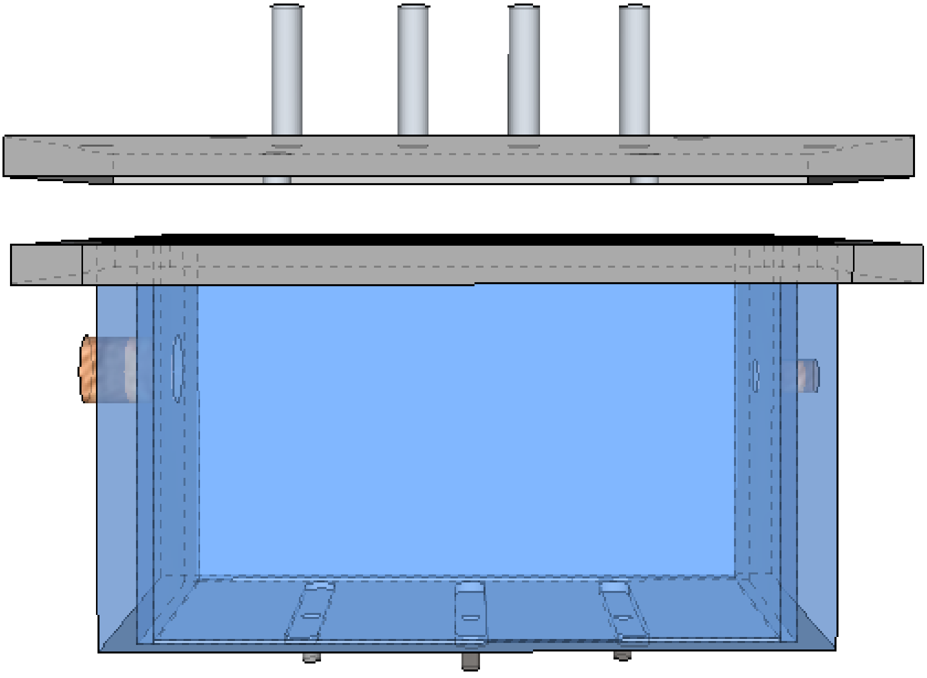

Figure 3 Front view of the electrochemical cell of the experimental setup IPER 1

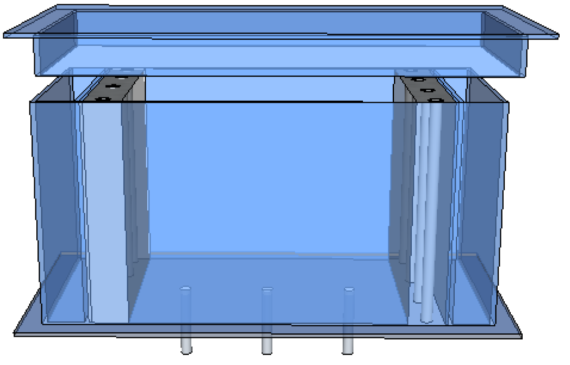

Figure 4 Front view of the electrochemical cell of the experimental setup IPER 2

Figure 5 Experimental setup IPER 3, the larger one, used at laboratory scale

Throughout the electrochemical tests, the specific objectives were: to test the integrity of the three installations, to establish the parameters that influence the application and effectiveness of electrochemical technology, to identify the key parameters that have an important influence on the efficiency of electrochemical treatment, to monitor the changes of the main parameters that characterize the electrochemical process in order to observe the differences that may arise from one contamination type to another; to observe a possible scale effect that might occur between the three facilities for the complex polluted soil (heavy metals, crude oil and transformer oil). Subsequently to the experimental activity at laboratory level, the electrochemical method was tested on an area of 10 m^2 situated on a concreted platform. On the platform, the treatment effectiveness in the removal of PCBs and PAHs in soil was also evaluated.

Thermal treatment: pyrolysis and incineration

The testing of thermal treatment on contaminated soil included tests performed in laboratory for the incineration of contaminated soils as well as for the pyrolysis of the contaminated soils (Fig. 6). Therefore, based on the completed previous work, and in accordance with project objectives, during the implementation period of the project, 21 experimental campaigns were developed. The main objective the study of thermal treatment processes through incineration and pyrolysis processes was to assess the methods efficiencies for removing different kind of contaminants from polluted soils. With this aim, historically contaminated soils with heavy metals and artificially polluted with organic substances (PAHs, PCBs and pesticides) were considered. Two experimental systems were used: i) a system with rotary reactor and secondary combustion chamber and ii) a compact combustion plant with horizontal tubular reactor and batch loading.

Soil incineration experiments observed the thermal treatment of the soil with 3 process temperatures: 600°C, 800°C, 1000°C and the two retention time of the material in the reactor was 30 min. and 60 min. Concerning the soil pyrolysis process temperatures were 400°C, 600°C and 800°C for the same retention time: 30 min. and 60 min. and 22 experimental campaigns were carried out.

In order to get a more complete picture of the decontamination process, of method efficiency and of the potential impacts of the method, it was decided that, additionally to the analysis on soil resulted from the incineration/pyrolysis (solid residue), to be sampled and analyzed also compounds from the emissions of the exhaust gases (solid and gaseous phase).

Figure. 6 The tubular reactor used for the application of thermal technologies

Human health risk assessment

Even if risk has become a central concept in terms of the environmental practice and policy, it has to be underlined that, it is not something that can be easily done or defined precisely (Ferguson et al, 1998). During the RECOLAND project, a particular attention was focused on developing a tool which is allowing assessing the contaminated sites for the reduction of environmental pollution by risk-based approach. The following exposure pathways were considered for the estimation of the risk coefficient: ● exposure through ingestion of contaminated soil; ● exposure through consumption of phytogenous products; ● exposure through dermal contact due to the skin contact with contaminated soil. For the exposure pathways listed above, the following derived intercompartimental links were considered: links between the concentrations of pollutant in the soil and those from the phytogenous products. So, the developed instrument across the RECOLAND project is pointing out the best solution concerning the contaminated soils remediation based on decontamination method efficiency, costs and risk assessment. If the proposed remediation solution had not any significant influence on the consider carcinogenic pollutants analyzed not as a comparison with legal values or in terms of risk, the developed informatics system allows the evaluation of the influence that has it the change of the type of land use (for instance from the agricultural use to the industrial one).

CONCLUSIONS

Starting from the obtained results in RECOLAND project, it can be noticed that the multicriteria decision system can be used to estimate the health risk associated with the exposure to contaminated soil with heavy metals and organic compounds and to establish which remediation method is the best solution for the treatment of contaminated soils. The obtained results underline also the role of risk assessment in selecting the optimum solution for the remediation of contaminated soil, as well as for the planning of the sites as residential, industrial/commercial or agricultural areas.

ACKNOWLEDGEMENTS

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Pregledni rad
Review paper

GREEN INFRASTRUCTURES: TREE TRENCHES FOR STORMWATER MANAGEMENT IN URBAN ENVIRONMENTS

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SUMMARY

Stormwater management in urban areas is a pivotal issue to cope with, in order to avoid the disastrous effects that heavy precipitation events caused in recent years.

Considering only the Italian situation, the important city of Genoa has witnessed two catastrophic floods in a three years span (2011-2014). Many other examples could be reported regarding several other urban areas worldwide.

Resilience to clime change or, in general, to extraordinary rainfall events, of urban areas has therefore become an import research topic in the scientific community.

As with any climate related issue, there is not a single approach or solution that could be indiscriminately applied in any context or circumstance.

However, the elements known as stormwater tree trenches look very promising if extensively applied, at least, at a neighbourhood scale and in synergy with other green and/or grey infrastructures such as: permeable pavements, rain gardens, stormwater bump-outs (curb extensions).

Tree trenches perform in a very similar way to other infiltration devices, like basins and dry wells, (infiltration, storage, evapotranspiration etc.) but in addition, they provide an increased tree canopy, with all the benefits associated with this possibility.

The aim of this paper is to supply an overview of these structures, underlining their benefits and flaws, their application fields and their relevance in the future of sustainable urban planning, through the analysis and comparison of some interesting literature and official project manuals.

Key words: *urban stormwater management, infiltration practices, perviousness, sealed soil*

INTRODUCTION

Runoff is one of the many problems urban planning has to face regarding the resilience of cities towards climate change related issues.

It must be noted though, that this problem is not a novelty. Burian et al. (1999) have effectively reviewed the history of wet-weather flow management through the centuries, going back to the 3000 B.C..

That said it is impossible to deny the role played by impervious surfaces in worsening this phenomenon. According to USEPA (2003) impervious surface increase five time the runoff compared to a natural vegetated ground. Hence, urban contexts, with their wide impermeable covered surfaces, demand an immediate response in term of planning choices.

It is important to point out that urban runoff does not affect cities' livability only in regard to floods and draughts but it also affect microclimate, heat wave, and other phenomena related to the level of humidity (Demuzere et al. 2014; Gill et al., 2007, Sussams et al., 2015).

Green infrastructures (GI) can provide a suitable solution to address what is commonly called combined sewer overflow (CSO) (Kolss & Calarusse, 2005). In many urban contexts wastewater and stormwater are managed in a combined sewer system (CSS), in these cases wet weather events often cause CSO, mainly due to the surface run off on impervious surfaces (fig.1) and CSO is a well-known responsible for pollution of surface water bodies (EPA 841-F-03-003**)**.

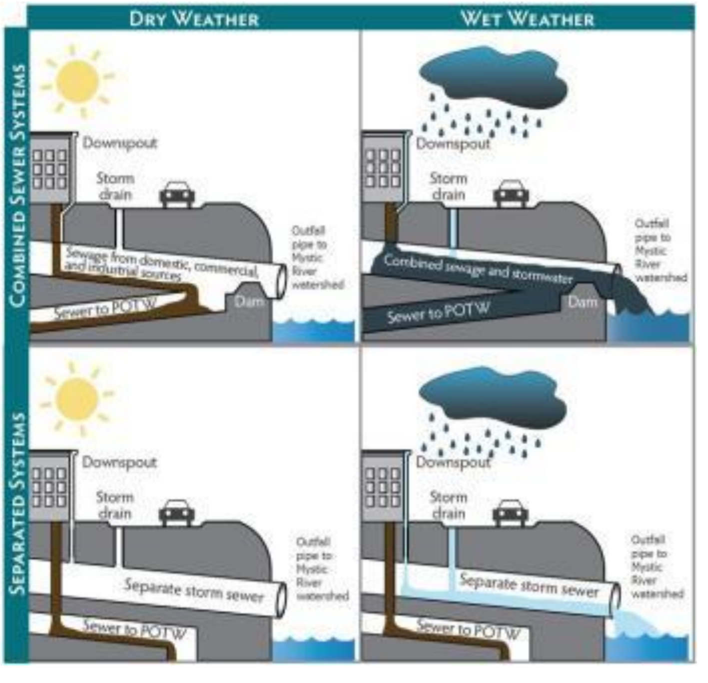

Fig.1 Combined sewer overflow (source: EPA)

According to the European Environmental Agency (EEA, 2011) “Green infrastructure as a term does not have a single widely recognized definition.” However, we can try to describe them as “[…] a network of green features that are interconnected and therefore bring added benefits and are more resilient” than stand-alone facilities.

Benedict and McMahon’s (2006) have stated a definition that has been amply used, defining a GI as “an interconnected network of natural areas and other open spaces that conserves natural ecosystem values and functions, sustains clean air and water, and provides a wide array of benefits to people and wildlife” (Benedict & McMahon, 2006).

In general, to the term GI are associated two different approaches at urban and landscape scales. While at landscape scale GI are intended mostly as features related to habitats and ecosystems connectivity, in this paper we will refer to GI, with a more urban scale approach, as wet weather management assets “that uses soils and vegetation to utilize, enhance and/or mimic the natural hydrologic cycle processes of infiltration, evapotranspiration and reuse”. (US Environmental Protection Agency, 2008, Managing Wet Weather with Green Infrastructure. Action Strategy).

There is a vast array of features that can be included in the aforementioned definition of GI:

- Green roofs
- Rain gardens
- Stormwater curb extension (stormwater Bump-outs)
- Stormwater planters
- Stormwater tree trenches
- Street swales and infiltration basins
- Permeable pavements

For scientific research purpose, it must be noted that there is a lack of standardization regarding the names of these structures, and GI as a whole (Younga, et al. 2014). This dishomogeneity is also reflected at a structural design level, which points out the first issue that has prevented these design choices to spread out, so far.

Grey infrastructures, the complex systems of pipes and tunnels traditionally used to manage storm and wastewater, are much more standardized and predictable than their green counterparts (Mansell, 2003).

METHOD

A literature research has been conducted on the Science Direct database using “Green Infrastructure” and “Stormwater Tree Trenches” as keywords, alongside with a wider one on the popular research browser Google. Sixty-four papers have been selected and analyzed through this research selecting those ones dealing with urban contexts, for what concerns the ScienceDirect database, and municipal/administrative papers and manuals from the google search.

BENEFITS AND CONSTRAINS OF GI

The main benefits of GI can be summarized as followed (fig. 2).

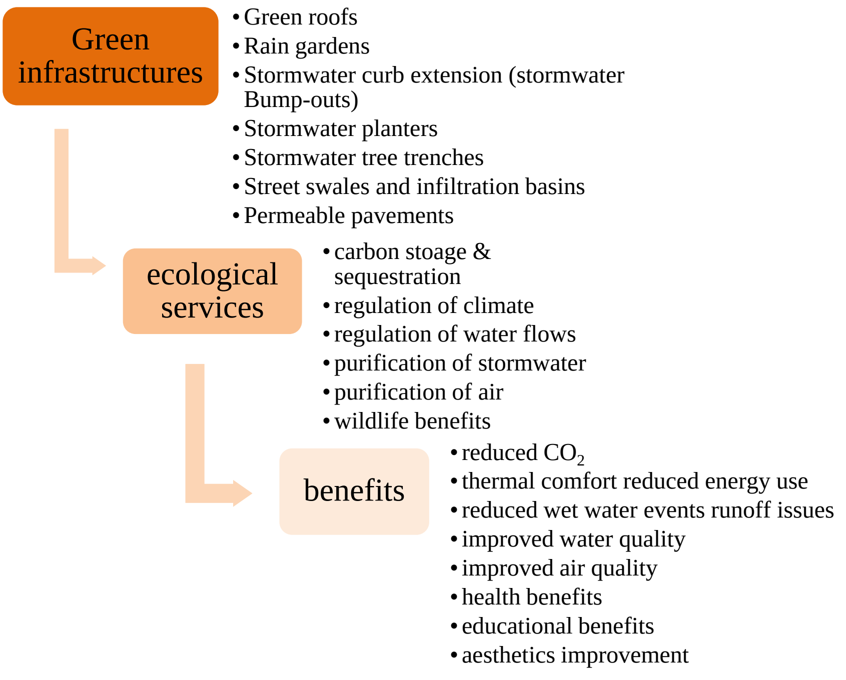

Fig. 2 Green urban infrastructure services and benefits (elaboration from Demuzere et al. 2014)

On the other hand, their main constraints seem to be related to their nature of being distribute infrastructures:

- Interdepartmental jurisdiction
- Ambiguity for GI maintenance
- Site suitability

and to a general lack of knowledge of the designer/maintenance workers, the administrative management and public perception/involvement

- Engineers and maintenance workers lack of knowledge about plants, ecology and gardening
- More unpredictable than grey infrastructures
- Lack of public awareness (Laforteza et al., 2009; Seymoure et al., 2010)

STORMWATER TREE TRENCHES

Stormwater tree trenches (STT), (figs. 3, 4, 5) are defined as a system of trees that are connected by an underground infiltration structure (Philadelphia Water Department).

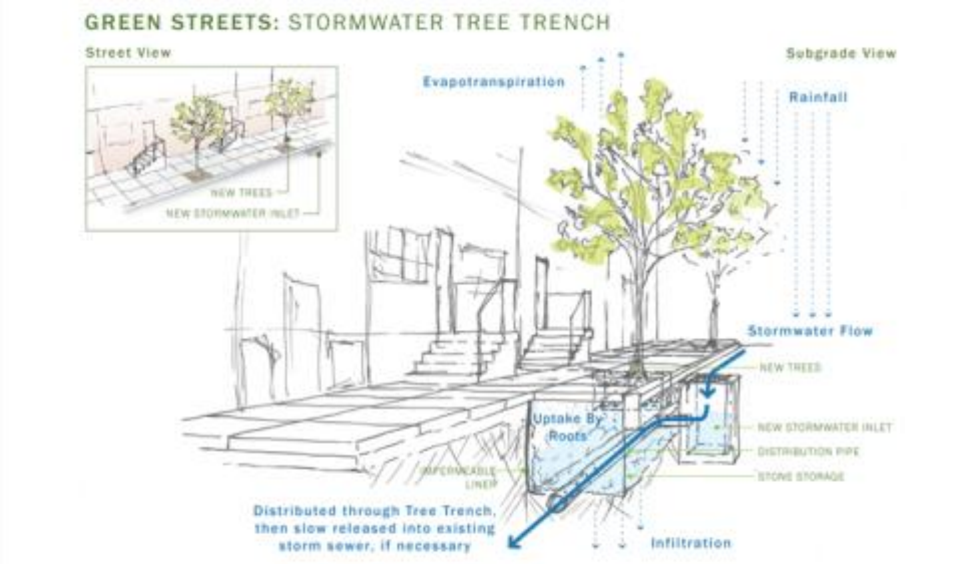

Fig. 3 Stormwater tree trench structure (source: Charles River Watershed Association)

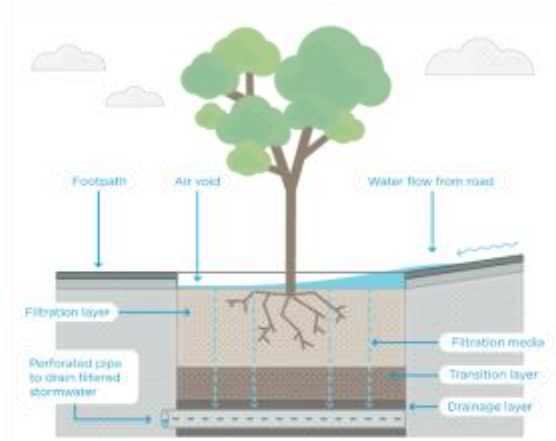

Fig. 4 and **5** Ben Franklin Parkway STT (Philadelphia Green Street manual, 2014) and STT section (City of Melbourne Urban water)

Stormwater tree trenches are systems of trees linked by an infiltration structure positioned below the ground. The main benefits such structures can provide are: reduced runoff increasing the amount of stormwater managed, improved growing environment for trees, due to a bigger grow space, compared to most traditional tree pits and bioremediation, helping removing trace amounts of harmful chemicals including metals, organic compounds, fuels, and solvents.

On the ground surface, they can appear as a series of disconnected inground tree pits or as a linear bed with very flexible design that makes these facilities a versatile asset in managing peak flows, flow volume and water quality. What characterize them is the underground infiltration structure, that can be realized using various structural elements like suspended pavement, structural cells, structural soil, and an underlying drain pipe structure, connecting various pits and trenches and, if necessary, to the existing storm sewer.

The essential element is the porosity of the infiltration bed for a more efficient management of run off as well as to provide an adequate growing substrate for the trees. In this regard, the use of structural soil (Day & Dickinson, 2008), and support structures (e.g. silva cell http://www.deeproot.com/products/silva-cell/overview) could help solving the soil compaction issue, especially for parking lots and roadside installations.

THE BENEFITS OF URBAN TREES

Together with the aforementioned GI's benefits, STT can provide also those related with the use of trees in an urban context.

There are many well known benefits related to the use of trees in urban contexts concerning their ability to help clean the air, reduce energy needs, raise property values, and mitigate heat island effects, as well as noise and glare reduction, wind control, and shade. Nevertheless, their important role in helping managing stormwater has been vastly overlooked. Their main contributes in this regard are (Coder, 1996; Fazio, 2012):

- Transpiration
- Interception
- Reduced Throughfall
- Increased Infiltration
- Phytoremediation

URBAN TREES DESIGN ISSUES

The ability of trees to grow and remain healthy is mainly a consequence of the available soil volume (Figure 6). Trees with insufficient soil volume tend to be short-lived and are less effective as components of a green infrastructure (Lindsey & Bassuk, 1991; Casey Trees, 2008). Poorly designed/chosen sites usually require continual and costly plant maintenance and often plant replacement as well.

Other common design failures are caused by compacted soil, improper (too small) tree pit size, a lack of soil for root growth, and impervious surfaces directly above the tree roots

(USEPA, 2013). Compaction can limit water infiltration and tree root growth. Trees placed in spaces that lack adequate volume and soil and regular access to rainfall or stormwater are destined for failure (Day & Dickinson, 2008). Impervious surfaces allow run off water to leave rapidly the GI site, preventing infiltration phenomena and pushing the roots to grow towards the ground surface. This problem is often the most perceived one, even by non-experts, as the roots interacts with surface pavements and covers causing a variety of issues.

Fig. 6 effect of soil volume on tree growth (Day & Dickinson, 2008)

If not adequately designed streetscapes and even individual tree planting spaces often fail to address these needs. This problem is mainly related to a lack of specific competences of designers and maintenance workers, which should be specifically addressed by universities and public authorities, for what concern their personnel formation.

On the other hand, properly designed street tree systems can be realized in most of the urban environments, even some challenging ones. Stormwater, alongside tree roots’ space, can be managed and arranged through careful and creative design (Portland BES, 2005; City of Philadelphia, 2014). Tools as pillars, structural cells and structural soil can allow large volume of uncompacted soil for STT Structural soils are engineered to support some vehicle traffic but can provide enough porosity for infiltration and root growth (Day & Dickinson, 2008). Moreover, permeable surface covers and curbside inlets increase infiltration into the soil profile enhancing tree survival and managing runoff. Overflow pipes direct excess flows from large storms to high-flow management systems (USEPA, 2013).

CONCLUSIONS

A growing number of research and municipalities' projects state that GI are proving to be a viable solution in helping solving the issues related to wet weather events in urban contexts (tab.1) (Portland BES, 2005; The Civic Federation , 2007; Tsoulasa et al., 2007; M'Ikiugu et al., 2012; Schäfflera & Swilling, 2013; Newell et al., 2013; Wen et al, 2014 (b);).

Stormwater Tree Trenches, within the various typologies of GI, can offer increased value and benefit to the urban environment if the specific needs of the trees, especially in terms of soil qualities, are effectively addressed since the design stage.

Tab. 1 Stormwater tree trenches summary table (elaboration from USEPA, 2013)

Practices	new construction/redevelopment/ retrofit
Applications	tree lawns, medians, plazas, streetscapes, parking areas, green roofs, and green streets
Benefits	*Reduces Runoff/ Manages Stormwater*: The connection between tree pits and the integration of other grey and green stormwater management systems reduces runoff and increases the amount of stormwater managed
	Helps Trees Grow: Stormwater tree pits have additional soil volume and grow space, regular irrigation, and improved drainage. Compared to most traditional tree pits, they provide an improved growing environment for trees
	Bioremediation: Soil, roots, and soil biota filter stormwater, removing trace amounts of harmful chemicals including metals, organic compounds, fuels, and solvents

It must be remembered that such structures can have a real impact on run off control only if inserted in a wider system that goes from green roofs to permeable pavements (Wen et al. 2014 (a)), and must be carefully designed and managed in order to maximize their effectiveness. Moreover, at an administrative level still lacks an adequate support for the diffusion of these practices, starting from legislative adjustments and financial incentives.

In the end, for achieving the goal of developing smart cities, green infrastructures will have to play a pivotal role in landscape and urban planning.

Some Municipalities, in particular Philadelphia, Portland, Seattle, Minneapolis, New York City, Melbourne, and Chicago are investing in large-scale GI systems and those like Minneapolis and Portland, which are already in practice by almost a decade show great promise in effectively addressing wet weather event issue. Even Europe, with projects such as Copenhagen climate resilient neighborhood (Klimakvarter.dk) is manifesting interest in the matter. It seems, though, that it still lack a legislative push comparable to the US Clean Water Act (1972) able to drive the necessary shift from an old paradigm based only on grey infrastructures to a much-needed new one.

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Original scientific paper

FLUID DYNAMICS OF SPRINKLER SPRAY FLOW: CLASSIC AND QUANTUM TRAJECTORIES

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ABSTRACT

One of the most challenging modelling problem in modern engineering is that of a particle crossing a continuous phase (air). In sprinkler irrigation practice this may refer to a water droplet travelling in air from the nozzle to the ground. The challenge mainly refers to the difficulty in designing and solving the system of governing equations for that very complicate process, where many non-linearities occur when describing the relations and dependences among the parameters that rule the phenomenon. The problem becomes even more complicated when not just a single droplet alone is assessed but a multi-droplet system is accounted for. In addition to the inter-parameter dependencies, it is also observed an inter-droplet reciprocal connection, mainly due to electrical interactions between the hydrogen and the oxygen atoms of the different water molecules. An alternative to traditional classic approaches to analyse water droplet dynamics in sprinkler irrigation have been recently proposed in the form of a quantum approach, but the whole classic-quantum and single-droplet versus multi-droplet alternatives need to be discussed and pinpointed and these are among the main aims of the present paper which focuses on the theoretical part of the issue, thus highlighting the new perspectives of a deeper comprehension in the spray flow related phenomena.

***Key words**: spray particles kinematics, single- and multi-droplet systems, classic and quantum mechanics, sprinkler water droplets, mathematical modelling.*

INTRODUCTION

Albeit the process of a liquid particle moving within a gaseous phase may describe many different technical applications, broadly investigated in many scientific sectors and from many different points of view, a complete, clear and generally applicable mathematical modelling is still far from having been achieved. Very recently Molle et al. (2012) gave an extremely useful experimental contribution in the field of irrigation, which will be of substantial usefulness for future investigations and modelling attempts. The results of the present paper were mainly reached by featuring the sprinkler irrigation context. The outcomes, if suitably adapted, may also apply to other fields and aims, such as pesticides distribution, heat removal or fire suppression, to name but a few. The fundamental problem is not just that of solving the equations ruling the development of the system and of the phenomenon but, upstream of that, it lies in the characterization of such equations. According to the Authors of this paper such hurdle can be attributed to a not complete understanding of the system-process evolution. This of course should not be taken as a form of underestimation of the analytical difficulties due to the mutual interrelationships between the parameters that govern the process, on the one hand, and the characteristics of the particles involved, on the other. In fact the main thematic scientific literature (Kinzer and Gunn, 1951; Edling, 1985; Kincaid and Longley, 1989; Keller and Bliesner, 1990; Thompson et al., 1993) tries to overcome such computational complication binding the solutions achieved to the specific case studies faced. In general, however, the kinematic analysis of sprinkler water droplets during their aerial path is devised adopting a Newtonian approach and considering a single-droplet system. A ballistic form of the same viewpoint, based on a Newtonian approach for a single-droplet system, was also proposed by the Authors (Lorenzini, 2004; De Wrachien and Lorenzini, 2006; Lorenzini, 2006). This approach will be described in the paper as a classic/single-droplet model. Coming again to the "not complete understanding of the system-process evolutions" quoted above, the issue has very recently led the Authors of the present work to the belief that to fully comprehend and describe the phenomenon another viewpoint could be considered: the quantum one (Dirac, 1931). The results which were arrived at (De Wrachien et al., 2012) were in the form of the time-dependent Schroedinger's equation and of the Scale Relativity Theory (Nottale, 1992) written as a Riccati equation. The former, in particular, was written for single-droplet systems, seen as waves and material particles (Goldstein et al., 2011) and considering a Lagrangian or Eulerian description for both steady and transient states. The present paper, therefore, will treat further possibilities to study the kinematic behaviour of both single- and multi-droplet systems during their aerial path in according to both the classic (i.e. Newtonian) and quantum approach.

THE CLASSIC MECHANICAL PICTURE

We do not wish to review the whole classic approach, as reported in the literature, but to explore the modelling possibilities in relation to the topic of the present paper. Anyway to further deepen the state-of-the-art one could refer to other publications by De Wrachien and Lorenzini (Lorenzini, 2004; De Wrachien and Lorenzini, 2006; Lorenzini, 2006). Some more information on spray kinematics modelling (mainly Lagrangian) both in sprinkler irrigation and in chemical sprays contexts are also available (Keller and Bliesner, 1990; Teske et al., 1998a; Teske et al., 1998b; Teske and Ice, 2002), while spray drift Lagrangian modelling is treated in Hewitt et al. (2002) and in Bird et al. (2002). Recently the Authors (Lorenzini, 2002; Lorenzini, 2004; De Wrachien and Lorenzini, 2006; Lorenzini, 2006; Lorenzini et al., 2012) defined and validated (see also Edling, 1985; Thompson et al., 1993) the following simplified analytical model feasible to solve water droplets kinematics, based on the Second Principle of Dynamics:

$$\begin{cases} m\ddot{x} = -k\dot{x}^2 \\ m\ddot{y} = -k\dot{y}^2 - ng \end{cases} \tag{1}$$

developed in terms of parametric equations:

$$x(t) = \frac{m}{k}\ln\left(\frac{v_{0x}k}{m}t + 1\right)$$

$$\dot{x}(t) = \frac{mv_{0x}}{m + kv_{0x}t}$$

$$y(t) = h - \frac{m}{k}\ln\frac{\cos\left(\arctan\dfrac{\sqrt{\frac{k}{m}}v_{0y}}{\sqrt{\frac{n}{m}g}}\right)}{\cos\left(\arctan\dfrac{\sqrt{\frac{k}{m}}v_{0y}}{\sqrt{\frac{n}{m}g}} - t\dfrac{\sqrt{kng}}{m}\right)} \tag{2}$$

$$\dot{y}(t) = -\sqrt{\frac{ng}{k}}\tan\left[-\frac{\sqrt{ngk}}{m}t + \arctan\left(\sqrt{\frac{k}{ng}}v_{0y}\right)\right]$$

being: f the friction factor according to Fanning (Bird et al., 1960); g gravity; h [m] the initial y co-ordinate; $k = f\rho A/2$ the friction coefficient; m the particle mass; n the droplet actual mass (buoyancy); t time; v_{0x} and v_{0y} initial horizontal and vertical velocity components; x, y, $\dot{x}$, $\dot{y}$, $\ddot{x}$, $\ddot{y}$ co-ordinates, velocities and accelerations along the horizontal and vertical axes. Being the model analytical, albeit simplified, it is applicable to a variety of problems but the more reliable results were obtained for high Reynolds numbers. Obviously, as mentioned above, the model presented is one of the possible ones which can describe a single-droplet system from a classic viewpoint: the choice was mainly due to the fact that such model is tightly related to the second law of dynamics, as previously mentioned. To complete the topic, anyway, one may in general face the kinematic analysis of a multi-droplet system (i.e. composed of N droplets) from a classic viewpoint by means of the following analytical expression (Lopreore and Wyatt, 1999):

$$m_k \frac{d^2 Q_k(t)}{dt^2} = -\nabla_k V \cdot Q(t) \tag{3}$$

where m_k ($1 \leq k \leq$ N) is the k-th particle mass, Q is the classic trajectory, V is a potential function accounting for time dependence (Lopreore and Wyatt, 1999) and ∇_k is the 3-D gradient operator referred to the k-th particle.

Validation of the dynamic model

The validation of the procedure needs a quantitative approach to check this can be done introducing Authors' data in the model. The works chosen for these comparison purposes are by Edling (1985) and Thompson et al. (1993). Among the case studies by these Authors, only those involving a no-wind condition were considered. Results are shown in Figures 1 to 3 in terms of travel distance with respect to the jet inclination (regarding the horizontal direction) and in Table 1 in terms of time of flight with respect to the droplet diameter. Both jet inclination and droplet diameter are studied parameters.

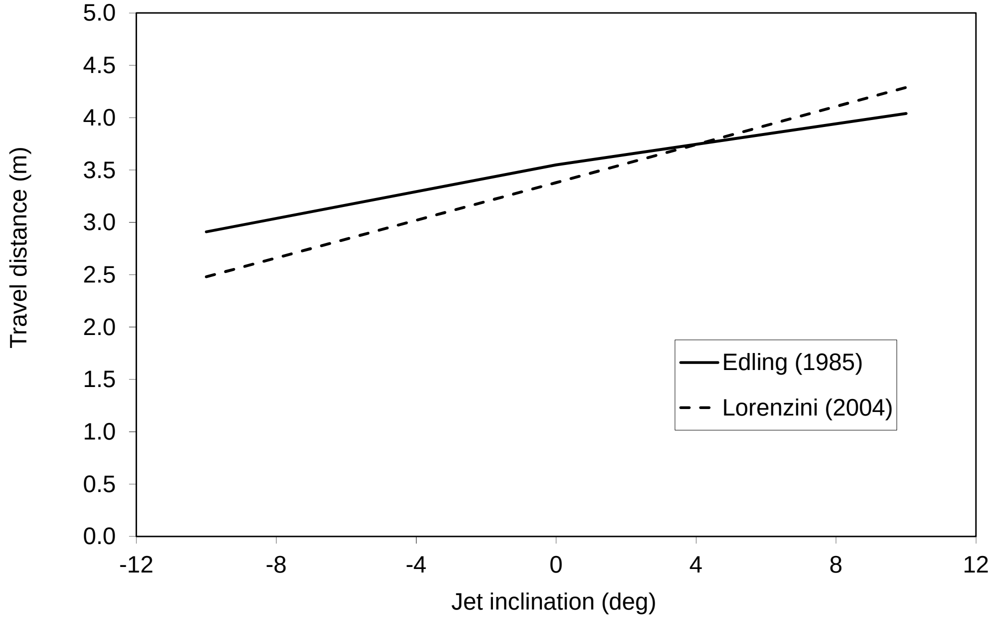

Figure 1 Travel distance of sprinkler droplets: Edling's (1985) data compared to Lorenzini's (2004): flow rate = 1.4x10^{-4} m^{3}s^{-1}; nozzle diameter 3.96x10^{-3} m; air temperature 29.4 °C; nozzle height = 1.22 m; droplet diameter = 1.5x10^{-3} m (R^2 = 0.997)

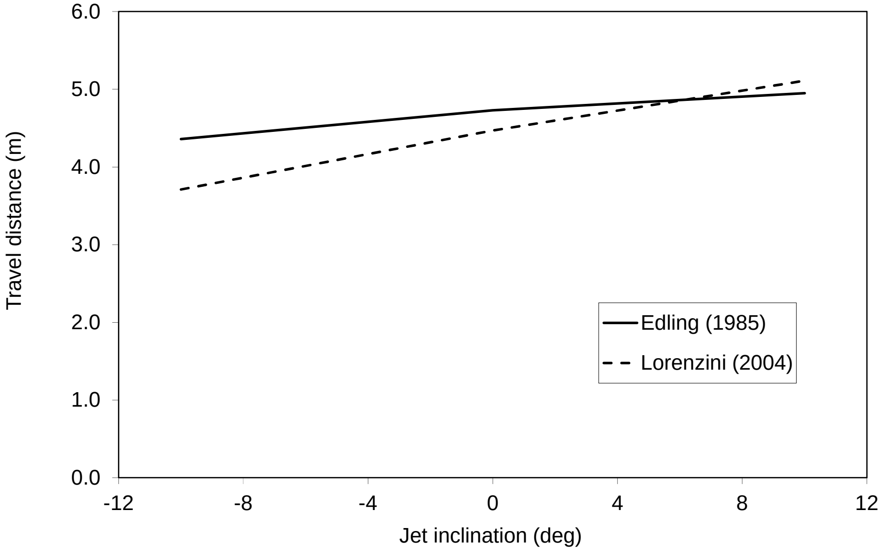

Figure 2 Travel distance of sprinkler droplets: Edling's (1985) data compared to Lorenzini's (2004): flow rate = 1.4x10^{-4} m^{3}s^{-1}; nozzle diameter 3.96x10^{-3} m; air temperature 29.4 °C; nozzle height = 3.66 m; droplet diameter = 1.5x10^{-3} m (R^2 = 0.995)

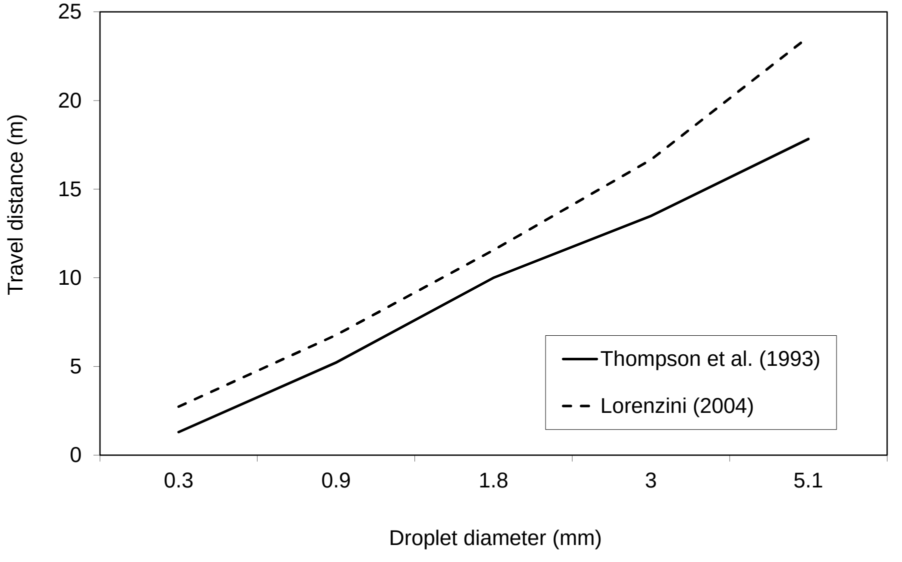

Figure 3 Travel distance of sprinkler droplets: Thompson et al. (1993) data compared to Lorenzini's (2004): flow rate= 5.5x10^{-4} m^{3}s^{-1}; nozzle diameter 4.76x10^{-3} m; air temperature 38 °C; jet inclination=25°; nozzle height = 4.5 m. (R^2 = 0.994)

Table 1 Time of flight of sprinkler droplets: Thompson et al. (1993) data compared to Lorenzini's (2004): flow rate = 5.5 x 10-4 m^3s^{-1}; nozzle of diameter = 4.76 x 10^{-3} m; air temperature 38 °C; jet inclination = 25°; nozzle height = 4.5 m

		Droplet diameter (m)			
		0.9 x 10^{-3}	1.8 x 10^{-3}	3.0 x 10^{-3}	5.1 x 10^{-3}
Time of flight (s)	Thompson *et al.* (1993)	1.54	1.63	1.75	1.84
	Lorenzini (2004)	1.35	1.73	2.00	2.26

Facing a comparative approach, it can be stated that the model here defined proves to be kinematically reliable in its predictions from a qualitative and quantitative points of view, particularly when droplets having a "not too small" diameter are considered. This, being the model defined by neglecting most of the parameters typically introduced in the others, can be considered as a first relevant result. The comparisons performed with the Thompson et al. (1993) data show that when the droplet gets close to a condition of the laminar flow law the model provides less accurate results. This is the limit to the model and it somehow defines the field of acceptability of the method. The model becomes weaker when moves away from the turbulent flow law because of the approximation used to define the value of k in the other two flow patterns. The dependence of the results on the flow state criterion can easily explain the different results obtained for the smallest droplets in the present work and in Thompson et al. (1993).

THE QUANTUM MECHANICAL PICTURE

Quantum mechanics for a single particle

The discrepancies between a classic *Vs.* quantum description, on the one hand, and between a single-droplet *Vs.* multi-droplet one, on the other, may be highlighted examining the following expressions for single- and multi-droplet systems (respectively) as compared to those in the previous section of this paper (Lopreore and Wyatt, 1999; De Wrachien et al., 2012):

$$m\frac{d^2Q(t)}{dt^2} = F(t) \tag{4}$$

$$m_k\frac{d^2Q_k(t)}{dt^2} = \nabla_k\left(V \mid V_{qu}^{\psi_t}\right)Q(t) \tag{5}$$

where: F is force, m particle mass, $V_{qu}^{\psi_t} = -\sum_{j=1}^{N}\frac{\hbar^2}{2m_j}\frac{\nabla_j^2|\psi|}{|\psi|}$ $(1 \le j < k \le N)$ the quantum potential, $\hbar$ the Dirac constant.

Comparing equation (5) with equation (3), the first useful consideration is that, if the quantum potential assumes a value which is in the vicinity of zero, then the quantum and classic kinematic pictures tend to coincide. But as a quantum viewpoint presumes that the “object” evaluated is not just a material particle but also a wave, then for each element of a multi-droplet system one may write the time-dependent Schroedinger’s equation as:

$$D^2\nabla^2\psi(\vec{x},t) - \frac{1}{2}\cdot m\cdot V(\vec{x},t)\cdot\psi(\vec{x},t) = -i\cdot D\cdot\left(\frac{\partial}{\partial t}\right)\cdot\psi(\vec{x},t) \tag{6}$$

where D is the diffusion coefficient, $\psi(\vec{x},t) = R(\vec{x},t)\cdot exp[S(\vec{x},t)]$, R is the wave amplitude, S is the wave phase. Equation (6) can be re-written in the form of continuity and Euler-type “quantum fluid-dynamic equations”, respectively (Wyatt, 2005; Ghosh, 2011; De Wrachien et al., 2012):

$$\frac{\partial}{\partial t}\rho(\vec{x},t) + \nabla[\rho(\vec{x},t)\cdot\vec{v}(\vec{x},t)] = 0 \tag{7}$$

$$\frac{d}{dt}\vec{v}(\vec{x},t) \equiv \left[\frac{\partial}{\partial t} + \vec{v}(\vec{x},t)\cdot\nabla\right]\vec{v}(\vec{x},t) = -\frac{1}{m}\cdot\nabla[V(\vec{x},t) + Q(\vec{x},t)] \tag{8}$$

(ρ is density, $\vec{v}$ is velocity, V is the classic potential, Q is the quantum potential). Equation (6) can be re-worked by means of Nottale’s Scale Relativity theory (Nottale, 1992) using a probability density function for a semi-infinite domain (Hermann, 1997) for writing the second law of dynamics in the complex field (u is a scalar potential, W is a complex velocity):

$$-\nabla u = m\cdot\frac{ð}{dt}\boldsymbol{W} \tag{9}$$

Dividing the real and imaginary parts in equation (9) (U is the imaginary part of W) one gets:

$$\begin{cases} -D\cdot\Delta U - (\mathrm{U}\cdot\nabla)U = -\nabla u \\ \frac{\partial}{dt}U = 0 \end{cases} \tag{10}$$

which (first equation) may be re-written for a 1-D path as a Riccati equation (Al-Rashid et al., 2011), being c a constant and $y(x)$ an arbitrary function of x:

$$\frac{d}{dx}U(x) = -\frac{m}{\hbar}\cdot U^2(x) + \frac{2}{\hbar}\cdot(u(x) - c\cdot m) \tag{11}$$

$$\frac{d^2}{dx^2}y(x) - \frac{2\cdot m}{\hbar^2}\cdot(u(x) - c\cdot m)\cdot y(x) = 0 \tag{12}$$

Both are very powerful tools as they allow for quantum particles computations avoiding the time-dependent Schroedinger’s equation, even if just for 1-D domains, which is useful in particular cases as for instance a droplet vertical downfall.

Quantum mechanics for many-particle systems

Considering multi-droplet systems the time-dependent Schroedinger's equation needs to be suitably re-written, provided that water has a V-shaped molecule resulting in a magnetic field due to the electric potential between oxygen and hydrogen. This results in (Ghosh, 2011):

$$\left[\frac{1}{2}\sum_j \left(-2iD\nabla_j - \vec{K}\left(\overrightarrow{x_j}, t\right)\right)^2 + \frac{1}{m}V\left(\overrightarrow{x^N}, t\right)\right]\psi\left(\overrightarrow{x^N}, t\right) = 2iD\,\frac{\partial\psi\left(\overrightarrow{x^N},t\right)}{\partial t} \tag{13}$$

being $V\left(\overrightarrow{x^N}, t\right)$ the electric potential, $\phi\left(\overrightarrow{x_j}, t\right)$ the external time-dependent scalar potential, $\overrightarrow{x^N}$ the *N*-particle coordinates. This may be transformed similarly to single-droplet systems as:

$$\psi\left(\overrightarrow{x^N}, t\right) = R\left(\overrightarrow{x^N}, t\right) exp\left[S\left(\overrightarrow{x^N}, t\right)\right] \tag{14}$$

then giving the continuity equation:

$$\frac{\partial\rho^N\left(\overrightarrow{x^N},t\right)}{\partial t} + \sum_{k=1}^{N}\nabla_k \overrightarrow{J_k}\left(\overrightarrow{x^N}, t\right) = 0 \tag{15}$$

and the Euler-type equation:

$$\begin{aligned}&\frac{\partial\overrightarrow{v_k}\left(\overrightarrow{x^N},t\right)}{\partial t} + \sum_j \left(\overrightarrow{v_j}\left(\overrightarrow{x^N}, t\right)\nabla_k\right)\overrightarrow{v_j}\left(\overrightarrow{x^N}, t\right) + \\ &\sum_j\left(1-\delta_{jk}\right)\overrightarrow{v_j}\left(\overrightarrow{x^N}, t\right)\times\left(\nabla_k \times\right)\overrightarrow{v_j}\left(\overrightarrow{x^N}, t\right) = -\left(e\vec{E}\left(\overrightarrow{x_k}, t\right) + \frac{e}{c}\overrightarrow{v_k}\left(\overrightarrow{x^N}, t\right)\times\right. \\ &Bxk,t-1m\nabla V0xN,t+UxN,t+QxN,t\end{aligned} \tag{16}$$

∇_k is the gradient operator related to the coordinate $\overrightarrow{x_k}$ of the *k*-th particle;

$\rho^N\left(\overrightarrow{x^N}, t\right) = R^2\left(\overrightarrow{x^N}, t\right)$ the *N*-particle density;

$\overrightarrow{J_k}\left(\overrightarrow{x^N}, t\right) = \rho^N\left(\overrightarrow{x^N}, t\right)\cdot\overrightarrow{v_k}\left(\overrightarrow{x^N}, t\right)$ the fluid current density;

$\overrightarrow{v_k}\left(\overrightarrow{x^N}, t\right) = \frac{\hbar}{m}\cdot\nabla_k S\left(\overrightarrow{x^N}, t\right) - \frac{e}{mc}\cdot\vec{A}\left(\overrightarrow{x^N}, t\right)$ the velocity field of the *h*-th particle;

$\vec{E}\left(\overrightarrow{x_k}, t\right) = -\nabla\phi\left(\overrightarrow{x_j}, t\right) - \frac{1}{c}\cdot\frac{\partial\vec{A}\left(\overrightarrow{x^N},t\right)}{\partial t}$ the external electric field;

$\vec{B}\left(\overrightarrow{x_k}, t\right) = curl\,\vec{A}\left(\overrightarrow{x^N}, t\right)$ the external magnetic field.

The first integrations of equations (15) and (16) were carried out by Madelung (1926), and the work was successively extended by Bohm (1952a; 1952b).

Quantum mechanics within a Density Functional Framework (DFF)

The quantum mechanics approach for many-particle systems leads to the continuity (15) and Eulero (16) equations in configuration space, thus involving the N-particle density $\rho^N(\vec{x}^N, t)$ with the 3N-D velocity field (corresponding to the *k*-th particle) given by:

$$\overrightarrow{v_k}(\vec{x}^N, t) = \left(\frac{h}{m}\right) \nabla_k s(\vec{x}^N, t) - \left(\frac{e}{mc}\right) \vec{A}(\overrightarrow{x_k}, t) \tag{17}$$

The quantum mechanical equations are, however, appealing only if they are in 3-D space in terms of the basic variables $\rho(\vec{x}, t)$ and $\vec{J}(\vec{x}, t)$. For N-particle systems, as a sprinkler spray flow, to obtain the continuity and Euler equations of quantum mechanics in 3-D space one can resort to the DFF which employs a partitioning of the particle-density and the current-density variables (Ghosh, 2011). The DFF provides a single-particle based approach for the description of the motion of many-particle systems in 3-D space.

In the context of the DFF, the single particle density and the current density (for the *k*-th particle trajectory) are, respectively, given by:

$$\rho_k(\vec{x}, t) = R_k^2(\vec{x}, t) \tag{18}$$

and:

$$\overrightarrow{J_k}(\vec{x}, t) = \rho_k(\vec{x}, t) \cdot \overrightarrow{V_k}(\vec{x}, t) \tag{19}$$

with the corresponding velocity field expressed as:

$$\overrightarrow{v_k}(\vec{x}, t) = \left(\frac{h}{m}\right) \nabla s_k(\vec{x}, t) + \left(\frac{e}{mc}\right) \overrightarrow{A_{eff}}(\vec{x}, t) \tag{20}$$

Within this ground the continuity equation can be written as:

$$\frac{\partial}{\partial t} \rho_k(\vec{x}, t) + \nabla \overrightarrow{J_k}(\vec{x}, t) = 0 \tag{21}$$

and the Euler equation as:

$$\frac{d}{dt} \overrightarrow{v_k}(\vec{x}, t) = -\frac{e}{m} \left[\overrightarrow{E_{eff}}(\vec{x}, t) + \frac{1}{c} \overrightarrow{v_k}(\vec{x}, t) \times \overrightarrow{B_{eff}}(\vec{x}, t)\right] - \frac{1}{m} \nabla \left[V_{eff}(\vec{x}, t) + Q_k(\vec{x}, t)\right] \tag{22}$$

Where the effective electric and magnetic fields are given respectively by:

$$\overrightarrow{E_{eff}}(\vec{x}, t) = -\nabla \Phi(\vec{x}, t) - \frac{1}{c} \frac{\partial}{\partial t} \overrightarrow{A_{eff}}(\vec{x}, t) \tag{23}$$

and:

$$\overrightarrow{B_{eff}}(\vec{x}, t) = curl\left(\overrightarrow{A_{eff}}(\vec{x}, t)\right) \tag{24}$$

The quantum potential can be expressed as:

$$Q_k(\vec{x},t) = \frac{h^2}{8m}\nabla\rho_k(\vec{x},t)\frac{\nabla\rho_k(\vec{x},t)}{\rho_k^2(\vec{x},t)} - \frac{h^2}{4m}\frac{\nabla^2\rho_k(\vec{x},t)}{\rho_k(\vec{x},t)} \tag{25}$$

which is trajectory dependent. The Euler equation (22) can be recast into the Navier-Stokes equation given by (Holland, 2011):

$$\frac{\partial}{\partial t}\overrightarrow{J_k}(\vec{x},t) = -\frac{e}{m}\left[\rho_k(\vec{x},t)\overrightarrow{E_{eff}}(\vec{x},t) + \frac{1}{c}\overrightarrow{J_k}(\vec{x},t) \times \overrightarrow{B_{eff}}(\vec{x},t)\right] - \frac{1}{m}\rho_k(\vec{x},t)\nabla V_{eff}(\vec{x},t) + \nabla\overrightarrow{T_k}(\vec{x},t) \tag{26}$$

where $\overrightarrow{T_k}(\vec{x},t)$ represents the stress tensor expressed as:

$$\overrightarrow{T_k}(\vec{x},t) = \left(\frac{h}{2m}\right)^2 \nabla\nabla\rho_k(\vec{x},t) + \frac{1}{\rho_k(\vec{x},t)}\left[\overrightarrow{J_k}(\vec{x},t)\overrightarrow{J_k}(\vec{x},t) - \left(\frac{h}{2m}\right)^2 \nabla\rho_k(\vec{x},t)\nabla\rho_k(\vec{x},t)\right] \tag{27}$$

The stress tensor is due to the contributions of both the quantum potential $Q_k(\vec{x},t)$ and the current density of the k-th particle trajectory. The jet flow is featured as a mixture of N components (particles) and each component, described by Euler equation, is characterized by common effective electric and magnetic fields, and by a trajectory-dependent quantum force of stress tensor (Ghosh, 2011).

For many-particle systems, as a sprinkler spray flow, the DFF represents a versatile tool for description of equilibrium as well as dynamical characteristics of the system. The basic picture is that of a multi-component fluid mixture moving in common effective electric and magnetic fields and component-specific quantum potentials.

This approach leads to the concept of quantum trajectory, in analogy to the well-established concept of classical trajectory and can represent an exciting area of research in sprinkler irrigation systems and, more generally, in the agricultural environment.

THE DYNAMICAL AND NUMERICAL APPROXIMATIONS

In any case an analytical “closed form” solution of the equations describing the quantum kinematics of particles is obviously extremely difficult and even the most advanced techniques often fail to achieve such purpose, albeit in the years to come this attempt will not be abandoned. This is why, recently, different forms of approximation have been introduced to treat the “quantum fluid-dynamic equations”: among those, literature reports numerical and dynamical approximations (Kendrick, 2011), which are both currently being developed. The formers may rely on Eulerian, Lagrangian or Arbitrary Lagrangian-Eulerian descriptions, all characterised by advantages and disadvantages. Lagrangian descriptions are easier in the form through which they write down the equations, as the grid moves with the particle and follows its evolution; but they become difficult to handle as, step after step, the grid becomes non-uniform with problems in the accuracy of the flow solution. Eulerian descriptions are complicate at the beginning of the simulation, due to an increased analytical complication, but prove to be more practical afterwards as the grid does not change with time. A uniform grid following the flow evolution is instead met in the Arbitrary Lagrangian-Eulerian descriptions, also adopted in some computational fluid dynamics codes.

Within each of the three procedures, a given numerical approach can be further subdivided into different algorithms for evaluating derivatives and propagating in time such as the meshless Moving Least Squares (MLS) (Kendrick, 2011). The MLS tends to average out any numerical error which may be accumulating in the solution, helping by this means to stabilize the computational process. The advantages of Mesh based approaches include, also, computational efficiency, higher resolution, accuracy and stability.

The dynamical approximations do not rely in a mathematically-simplified description of the problem but in a physically-simplified one by superimposing some particular conditions (e.g. incompressible flow) or neglecting some other characteristics considered not so relevant to the whole picture. Several approximate methods have been developed in recent years, such as the Linearized Quantum Force (LQF), the Derivative Propagation Method (DPM) and the Vibrational Decoupling Scheme (VDS) (Wyatt, 2005).

Another class of approximate methods are hybrid quantum/classical schemes ,among which is worth mentioning the mean-field approximation and the surface hopping procedure (Meier et al., 2011). In the mean-field approximation approach the force for the classical motion is assessed by averaging over the quantum wave function. This method properly conserves the total (quantum plus classical) energy and is accurate when quantum energy is negligible compared to the classical kinetic energy. In the surface hopping scheme the classical trajectories move according to a force derived from a single quantum state with the possibility of transition to other states. This characteristic allows a given trajectory to bifurcate into different branches , each governed by a particular quantum state and weighted by the amplitude of the state. In this procedure the quantum wave function is expanded in an appropriate basis ,the so-called finite basis representation (FBR). The coefficients in this basis are examined at specific intervals of time in order to determine if a state-to-state transition should occur. An alternative to this scheme is the mixed quantum classical steps (MQCS) in which the quantum wave function is expanded in a discrete variable representation (DVR) rather than in the usual FBR.

Another way to mix quantum with classical mechanics is based on Bohmian quantum trajectories for the quantum/classical connection. Within this context, the quantum system is described by the TDSE that depends, parametrically, on classical variables. In this approach, called mixed quantum/classical Bohmian (MQCB) trajectories, the wave function is used to define the de Broglie-Bohm quantum trajectories which, in turn, are used to calculate the force acting on the classical variables. The main difference between MQCB and MQCS lies in the way the force on the classical variables is calculated. In the MQCS method the force is assessed using different discrete points of the quantum degree of freedom, while in the MQCB scheme the force is evaluated at the continuous points which follow the quantum trajectory.

Much progress has been made in recent years in developing computational methods feasible to solve the quantum hydrodynamic equations. The challenge associated with the quantum mechanical approach will, no doubt, continue to inspire significant progress in the years to come. In relation to this challenge one should highlight that quantum trajectories can be treated quite similarly to the classic ones when considering, for the particles treated, the suitable relations among the dynamic and the potential part of the problem.

CONCLUSIONS

Remarkable progress has recently been made in the development and application of quantum trajectories as a computational tool for solving the TDSE, which involves the time evolution of the wave function. In the Quantum Theory of Motion (QTM) the complete description of a physical system needs the simultaneous presence of the "wave" and the "particle".

The wave motion is governed by the TDSE, and the motion of a particle guided by that wave, for a given initial position, is characterized by a velocity defined as the gradient of the phase of the wave function. An assembly of initial positions will constitute an ensemble of particle motions (the so-called quantum trajectories or Bohmian trajectories), guided by the same wave, and the probability of having the particle in a given region of space at a given time is provided by the quantum mechanical TD probability density (Chattaraj, 2011).

A crucial link between QTM and Quantum Fluid Dynamics (QFD) is the quantum potential. In QTM, the particles are under the stress of forces originated from both classical and quantum potentials, while in QFD the fluid motion takes place under the influence of the external classical potential augmented by the quantum potential.

In addition to featuring water droplet ballistics in a sprinkler spray flow, novel quantum trajectory methods are being developed for a broad range of dynamical problems such as mixed classical-quantum dynamics density matrix evaluation in dissipative systems, and electronic non-adiabatic dynamics.

In this context, the present investigation starts from recent hypothesis made by the same Authors of this paper: a water droplet could be treated as a quantum object, characterised both by material particle and by wave properties. Thus the TDSE may be employed to study the process and a parallel classic-quantum description may be achieved, both for single-droplet and for multi-droplet systems. The latter systems are not only affected by the usual fluid-dynamic parameters but the mutual repulsions and attractions between particles are to be accounted for, in the form of electric-magnetic potentials bound to the molecular structure of water: this allows one to re-write the TDSE and the so-called "quantum fluid-dynamic equations" in a novel and more complete form. Future studies will deepen the novel modelling approach suggested to make it more and more suitable for practical applications.

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44. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

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Prethodno priopćenje
Preliminary communication

INFLUENCE OF WHEEL LOAD AND TIRE INFLATION PRESSURE ON FOOTPRINT AREA IN STATIC REGIME

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SUMMARY

Soil compaction is a phenomenon with negative effects on the environment and on crop productivity. Compaction occurs especially due to the development of mechanized agriculture, which requires the use of heavy agricultural machinery, often on soils with high moisture content. It is known that a series of factors, such as wheel load and tire inflation pressure, are determinant for the size of footprint area, the depth at which stresses are transmitted into the soil, and thus, for the intensity of soil compaction. This paper presents the results of some experimental research carried out in order to determine the influence of wheel load and tire inflation pressure on the footprint area between the tire of an agricultural trailer and a rigid surface. Experiments were conducted in laboratory conditions, using a mesh-type sensor to measure pressure distribution in the footprint area and also the size of footprint areas corresponding to five static wheel loads and for each load were used four values of tire inflation pressure. Tests results showed that for tire inflation pressures between 180 kPa and 300 kPa, at 4.56 kN wheel load, footprint area decreased from 310 cm^2 to 230 cm^2, and by increasing the wheel load to 21.18 kN, footprint area decreased from 1000 cm^2 to 820 cm^2. Also, there were obtained the 3D maps of pressure distribution in the footprints.

Key words: *soil compaction, wheel load, tire inflation pressure, contact pressure, footprint area*

INTRODUCTION

In the actual context of continuously increasing global population, it became necessary the development of mechanized agriculture, hence the use of heavy agricultural machinery, often on soils with high moisture content, increasing the risk of artificial compaction of soil, a phenomenon with negative effects, both on the environment and also on crop productivity.

Soil compaction consists in the increase of bulk density respectively the decrease of porosity [8, 10] due to natural causes, such as: particle size variability, the impact of raindrops, soil wetting, internal soil water tensions, seasonal cycles [4, 12], or artificial causes, such as: agricultural machinery traffic, tillage and animal trampling [13, 19]. Literature mentions a series of factors influencing soil compaction, such as: soil properties (precompaction, bulk density, structure, texture) [1, 7], soil type, soil moisture, speed of agricultural machinery, number of passes, contact pressure, size of wheel load, size and shape of footprint area [1, 2, 5, 7, 20], working load, land slope, wheel track width, tractor and wheel design [11]. In intensive agriculture, soil compaction is mostly caused by high wheel load applied on the soil by tractors and agricultural machinery with increased weight (which is due to the desire to increase the working capacity) [8, 14, 21] or by grazing animal trampling [9]. One technique to minimize or prevent soil compaction consists in reducing the contact pressure, which can be achieved by decreasing wheel load and / or by increasing the footprint area between the soil and the tire of agricultural machinery [9].

Footprint area (or contact area) is defined as the portion of wheel or tire that comes in contact with a supporting surface, which is an important factor for the load capacity of the tire [16, 23, 25]. The term “static contact area” represents the contact area between tire and a rigid or deformable surface, when the tire is loaded statically, and has no forwarding movement [23, 25].

Agricultural vehicles and the rolling surface (farmland or road) are connected through the footprint area, in which are applied the forces acting on the wheel (traction force, bracking force, rolling resistance) [6]. Forces acting on the layers of soil are transmitted into soil depth by means of tires of agricultural machinery. Thus, the footprint will vary both due to the variation of the compressive forces, as well as by the variation of tire inflation pressure.

Tire inflation pressure will affect not only the shape of footprint area, but also the distribution of stress in the soil and thus the compaction [3]. For agricultural soils, due to high tire inflation pressures, smaller footprint areas are formed, soil deformation is larger and stress is distributed deeper into the soil. At low tire inflation pressures, tire deforms more, footprint area increases, mean pressures in the footprint are lower, soil deformation is lower and stresses are distributed to shallower depths [2]. Hence, the use of high tire inflation pressure increases soil compaction [18], while low inflation pressure can significanlty reduce soil compaction and increase crop yield [15].

After [6] footprint area has a major role in relation to crop production and the environment. Shape and size of the footprint are influenced by some factors: soil type, soil physical characteristics, tire type, tire inflation pressure, wheel load.

In contact with a dry hard soil (e.g. road), tire deforms, and the shape and size of footprint are given by tire inflation pressure and wheel load. Under these circumstances, at constant wheel load, for low inflation pressure the footprint mainly tends to have a rectangular shape with more or less curved edges, and by increasing tire inflation pressure the footprint area becomes elliptical [23]. This theory is supported by the studies conducted in [24] in which, at tire inflation pressure of 128 kPa and wheel load of 12 kN the footprint area was elliptical and the increase of wheel load to 17 kN, 22 kN and 27 kN resulted in increased size of the footprint area which however remained elliptical. At constant wheel load of 27 kN and tire inflation of 124 kPa, the shape of footprint area was elliptical, but as tire inflation pressure decreased to 83 kPa, the footprint area became rectangular with curved edges.

In paper [8] was studied the variation of footprint area and pressure distribution in the footprint between tire 13/7.5-16 SL and soil. Tests were conducted both in the presence and in the absence of a sand layer (0.3 m thickness) over the soil, for a wheel load of 1.5 tons and tire inflation pressure of 180 kPa. In the absence of sand layer, the footprint was 0.29 m length and 0.3 m width, and maximum contact pressure of 561 kPa occured on footprint outline. In the presence of the sand layer, footprint lenght increased by 35 % (0.406 m) and footprint width increased by 23% (0.365 m width) and the maximum contact pressure of 186 kPa was recorded along the centerline of the tire.

The influence of tire inflation pressure and wheel load on the footprint area was studied in paper [19]. Experiments were conducted on a sandy loam soil, with tire inflation pressures of 60, 80, 100 and 200 kPa, and for each of these, wheel load was varied (11.8; 17.9; 25 and 32 kN). By increasing wheel load and reducing tire inflation pressure, the footprint area increased from 1400-2000 cm^2 for a wheel load of 1200 kg to 2400-3200 cm^2 for a wheel load of 3200 kg. By doubling the wheel load, footprint area increased by 30-40 % and by doubling tire inflation pressure the footprint area decreased by 70-80 % from its initial value. Contact pressure was distributed uniformly, almost linear with tire inflation pressure, the slope of the curves increasing with the increase of wheel load.

Determining the shape and size (area) of the footprint is particularly important, for auto vehicles and also for agricultural machinery. In case of auto vehicles, the importance falls primarily on the adhesion to the road, while for agricultural machinery the importance is given to both adhesion and the contact pressure, so that shallow and deep compaction to be reduced. Soil compaction affects crop growth of and energy consumption during agricultural works. Hence, tests are necessary to determine to determine the footprint of each type of tire and the influence of tire characteristics, in order to identify the most adequate pressures and stresses to ensure good development of crops and to reduce energy consumption [23]. The measure of footprint area on a rigid surface has been used as reference for properties on road and soil, although is not faithfully representative of its true behavior [17].

METHODS

Experimental research to determine the footprint area between a hard surface (concrete) and the tire, under the influence of various wheel loads and tire inflation pressures, were conducted in laboratory conditions, in the Testing Department for Tractors and Equipment for Agriculture and Food Industry, at the National Research - Development Institute for Machines and Installations Designed to Agriculture and Food Industry – INMA Bucharest.

The agricultural machinery used in the experiment was a biaxial transport trailer type RM5 (Fig. 1), equipped with agricultural tires, romanian model Danubiana 11.5 / 80-13.5, profile D179 (tire width 29 cm, tire diameter 84.5 cm).

Fig. 1 Biaxial transport trailer used in the experiment

Pressure distribution in the footprint was tested under the right side rear wheel of the trailer, by interposing between the tire and the concrete a mesh-type sensor, Tekscan Industrial Sensing with minimum size of the sensitive surface 85 cm x 55 cm (Fig. 2), which was previously calibrated. The sensor is formed of: connexion to the data acquisition system (1), sensels or sensitive elements (2) and connection wires between the sensels (3).

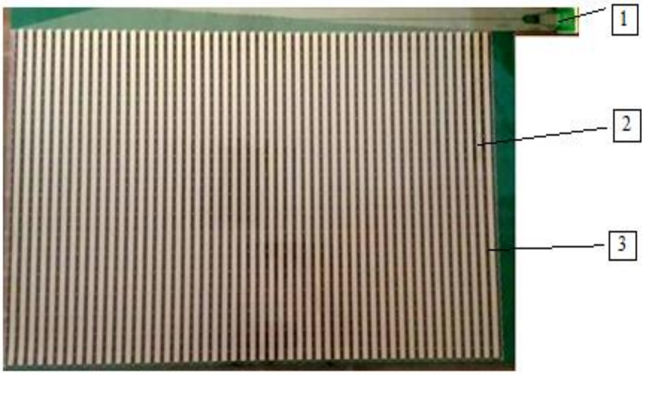

Fig. 2 Mesh-type sensor for measuring the contact pressure

The pressure sensor was covered with a protective polyester film (size 650 mm x 550 mm) against tensioning. Next, the sensor was connected to a VersaTek Handle electronic data acquisition system and to a laptop (Fig. 3).

Fig. 3 Connection of sensor to the data acquisition system and laptop

Wheel load was varied by loading the trailer with metal weights (plates). First, for the empty trailer, the load on the tested wheel, measured with an RW-10PRF weighing machine type platform with electronic indicator, was of 4.56 kN. Then, using a crane, the trailer was loaded with 1, 2, 3, respectively 4 weights, and in each of these cases it was determined the distribution of weight on each rear wheel of the trailer. Thus, were obtained wheel loads of 9.22 kN, 12.8 kN, 17.11 kN and 21.18 kN. During the experiments, for each of the five wheel loads, using a compressor and a pressure gauge, was varied and measured the value of tire inflation pressure (180 kPa, 220 kPa, 260 kPa, 300 kPa).

By varying wheel load and tire inflation pressure, tire diameter has decreased noticeably. For example, at tire inflation pressure of 300 kPa, static tire diameter of empty trailer corresponding to a wheel load of 4.56 kN was of 83.2 cm and for wheel load of 21.18 kN tire diameter decreased to 79.2 cm. Figure 4 shows how the tire has deformed at constant wheel load (21.18 kN), as tire inflation pressure has been reduced from 300 kPa (the maximum value recommended in transport) to 180 kPa.

Fig. 4 Testing with maximum wheel load (21.18 kN), tire inflation pressure of 300 kPa (left) and 180 kPa (right)

RESULTS AND DISCUSSION

Experimental data, for the input and output parameters considered and analyzed in this paper, are presented in Table 1. Data obtained from the experiments were used to graphically plot the variation curves of footprint area, depending on tire inflation pressure, wheel load and contact pressure on the soil.

Table 1 Values of experimental parameters

Wheel load Q [kN]	Tire inflation pressure p_i [kPa]	Footprint area A [cm^2]	Contact pressure p_c [kPa]
4.56	180	312.13	146.093
	220	297.68	153.184
	260	257.22	177.280
	300	234.10	194.788
9.22	180	497.18	185.446
	220	445.68	206.875
	260	403.50	228.501
	300	369.12	249.983
12.8	180	641.60	199.501
	220	575.12	222.562
	260	537.55	238.117
	300	502.87	254.539
17.11	180	819	208.912
	220	759.02	225.422
	260	702.61	243.518
	300	664.85	257.351
21.18	180	999.97	211.806
	220	936.38	226.190
	260	849.68	249.270
	300	817.89	258.959

Tests results were recorded in the I-Scan software, which allowed the real-time display of: 2D and 3D footprint, pressure distribution in the footprint, values of footprint area, contact pressure, maximum pressure and their variation in time.

Figures 5 and 6 present the 3D maps of pressure distribution in the footprints for the minimum wheel load (4.56 kN) and the maximum wheel load (21.18 kN) for minimum and maximum tire inflation pressures. It can be seen that at constant wheel load, for minimum tire inflation pressure, the footprint has rather rectangular shape, but by increasing tire inflation pressure is obtained not only a smaller footprint area, but also its shape changes to an elliptical one. Given that the wheel load is applied in a smaller footprint area, is obtained an increase of contact pressure. It should be mentioned that the value of contact pressure indicated by the software represents an average of the pressures recorded on each sensel of the mesh-type pressure sensor, that came in contact with the tire of the agricultural trailer during experimental testings. From these maps it can be observed that the peaks indicating the maximum contact pressure are recorded on the outline of the footprint area.

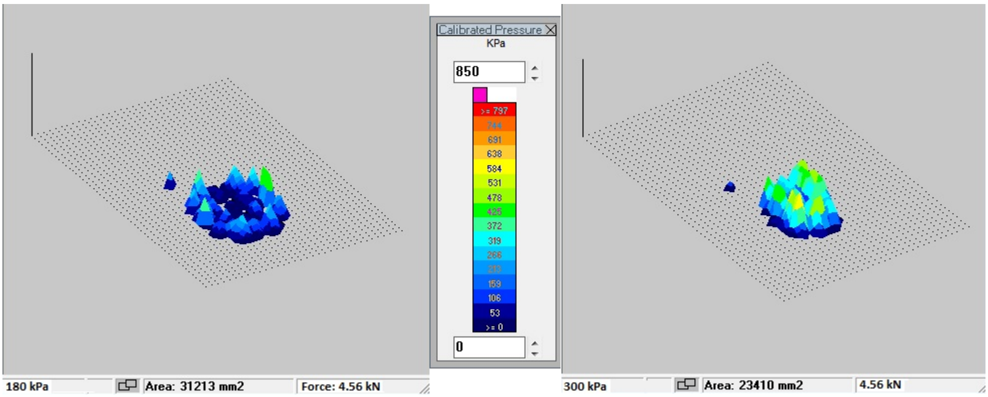

Fig. 5 3D pressure distribution in footprints for a wheel load of 4.56 kN, for tire inflation pressure of 180 kPa (left) and 300 kPa (right)

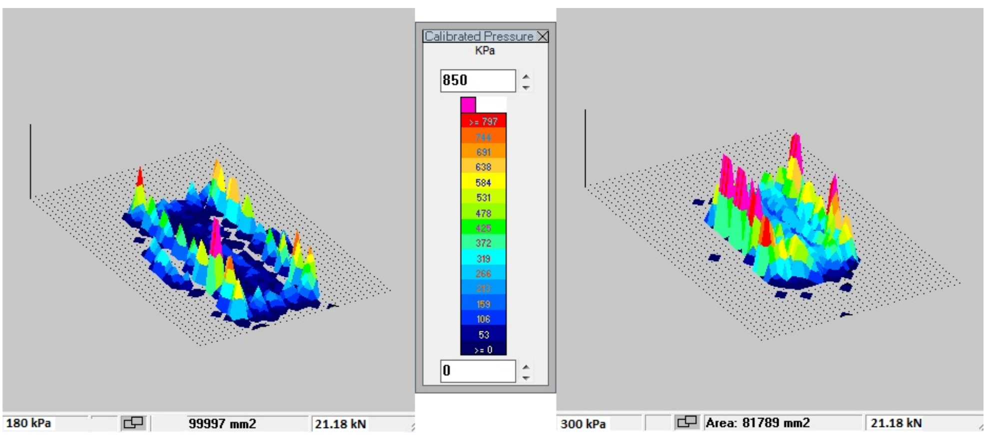

Fig. 6 3D pressure distribution in footprints for a wheel load of 21.18 kN, for tire inflation pressure of 180 kPa (left) and 300 kPa (right)

Figure 7 shows that the footprint area follows an approximately linear distribution, proportional to the wheel load, regardless the value of tire inflation pressure. Regression analysis in MSOffice Excel program shows a high degree of correlation of the experimental data with the law of linear variation, with a correlation coefficient of over 0.995, in all five cases, proving that footprint area is directly proportional to the increase of wheel load. For tire inflation pressures between 180-300 kPa and wheel load of 4.56 kN, footprint area decreased from 310 cm^2 to 230 cm^2, respectively from approximately 1000 cm^2 to 810 cm^2 for a wheel load of 21.18 kN. At the variation of footprint area with the wheel load, regression lines are not parallel, as they open in fan shape for the five tire inflation pressures, from wheel loads ranging between 4.56 kN and 21.18 kN.

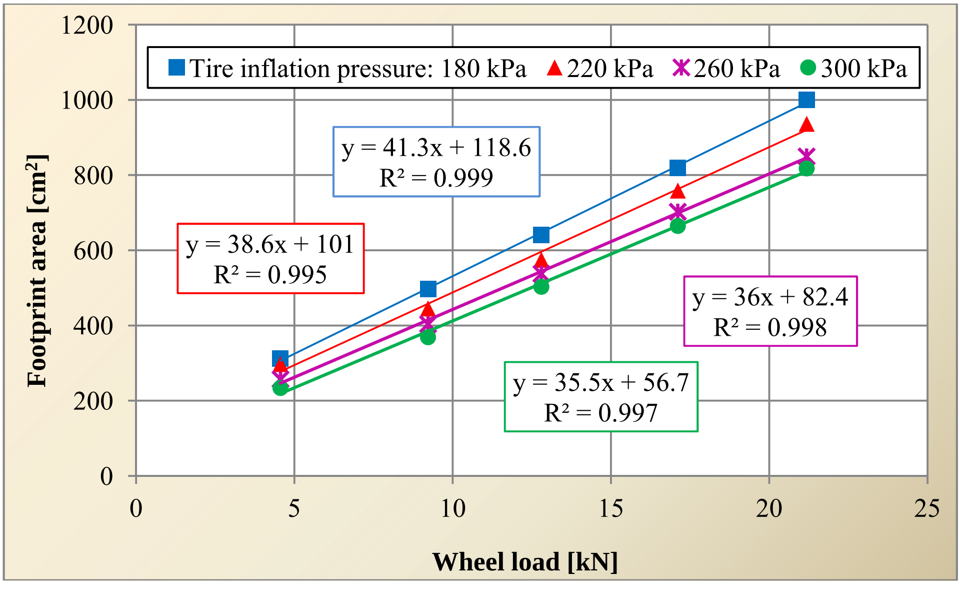

Fig. 7 Variation of footprint area with wheel load, for various tire inflation pressures

Figure 8 presents the variation of the footprint area depending on tire inflation pressure, for various wheel loads. It can be seen that the footprint area decreases proportionally with increasing tire inflation pressure, but this decrease is quite slow. Regression analysis shows a decreasing linear distribution, with high correlation coefficients (R^2 = 0.971 – 0.992). For tire inflation pressure of 180 kPa, were obtained footprint areas from 310 cm^2 for a wheel load of 4.56 kN, to approximately 1000 cm^2 for a wheel load of 21.18 kN. At tire inflation pressure of 180 kPa, footprint area increases with about 700 cm^2 (from wheel load of 4.56 kN to 21.18 kN), and with about 500 cm^2 at tire inflation pressure of 300 kPa (for the same range of wheel loads).

In Figure 9 is presented the graphical variation of footprint area depending on the contact pressure, for five wheel loads. Regression analysis obtained in Excel program shows very high correlation of experimental data with the linear variation law ($R^2 \geq 0.992$). The variation line of footprint area depending on the contact pressure, for a wheel load of 4.56 kN, is arranged to the bottom left side of the graphic, indicating low contact pressures and footprint areas. The range of footprint areas values for a wheel load of 21.18 kN is found in the top right corner of the graphic, with a wide range of values of contact pressure and footprint area, showing higher values of contact pressure and footprint area. Experimental results show that the contact pressure varies from 194 to 146 kPa for a wheel load of 4.56 kN, corresponding to footprint areas between 230 - 310 cm^2. For a wheel load of 21.18 kN and for contact pressures from 259 to 212 kPa, the footprint area varies between 810 - 1000 cm^2. In this case of variation, regression lines have slightly decreasing slope, and slope values are still different from one wheel load to another (regression lines are not parallel).

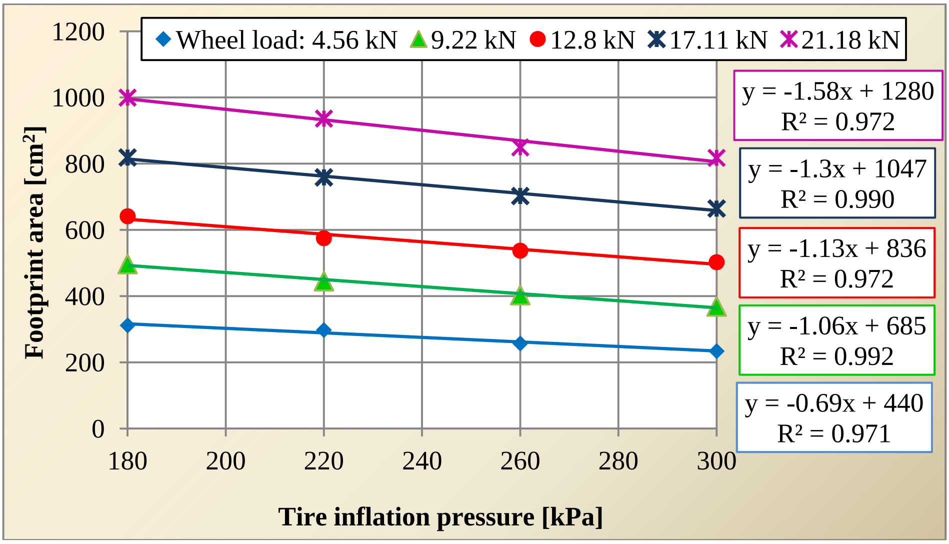

Fig. 8 Variation of footprint area with tire inflation pressure, for various wheel loads

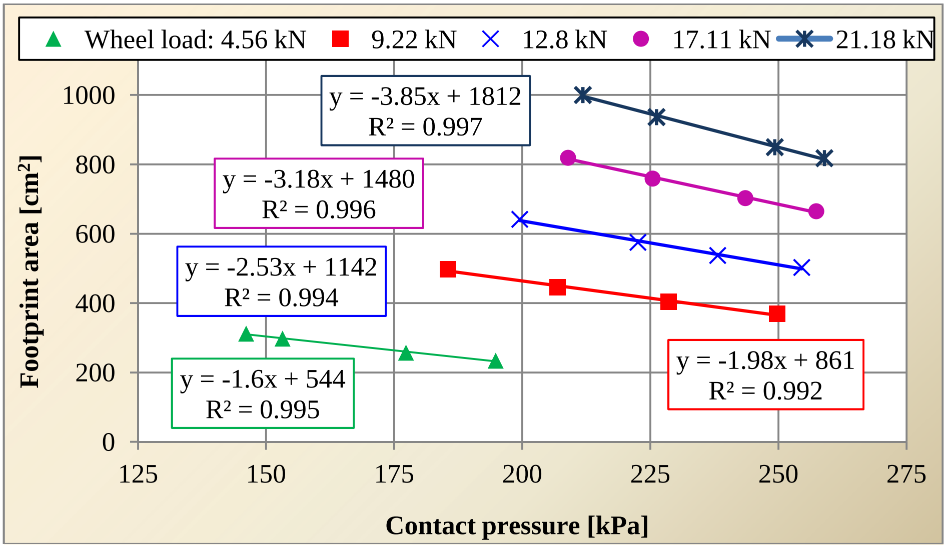

Fig. 9 Variation of footprint area with the contact pressure, for various wheel loads

CONCLUSIONS

The size and shape of footprint between tire and soil are strongly determined by tire inflation pressure and by the size of wheel load. Contact pressure is determined by tire size, tire inflation pressure and wheel load.

Although tire size and tire inflation pressure have a major influence on the footprint area, this does not influence in the same way the variation of the footprint area, and particular attention must be paid to the wheel load (determined by vehicle weight and tire size). Experimental results proved that the footprint area has an approximately linear distribution, proportional to the wheel load, regardless the value of tire inflation pressure.

It was found that by increasing tire inflation pressures between 180 kPa and 300 kPa, at 4.56 kN wheel load, footprint area decreased from 310 cm^2 to 230 cm^2. Also, by increasing wheel load to 21.18 kN, and for tire inflations between 180 kPa and 300 kPa, footprint area decreased from approximately 1000 cm^2 to 820 cm^2. Hence, at constant wheel load, increasing tire inflation pressure results in decreased footprint area, however this decrease is quite slow.

In terms of the contact pressure, it varied between 146-195 kPa for a wheel load of 4.56 kN and for the highest tested wheel load (21.18 kN) were obtained contact pressures between 212-259 kPa.

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44. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

UDC 631.31
Stručni rad
Expert paper

STRESS AND STRAINS DISTRIBUTION IN THE FRAME OF AGRICULTURAL CULTIVATORS USING THE FINITE ELEMENT METHOD

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SUMMARY

In this paper is presented a working methodology for the analysis of stress and strains in the frames of agricultural cultivators. The geometric model of the frame was achieved in Catia V5 format and it was transferred to SolidWorks format, where were made the necessary corrections to achieve static analysis by the Finite Element Method. The CAD (geometric) model was then transferred to the Finite Element Analysis software (ANSYS) through which was performed the resistance calculation in the linear static range. Adaptive meshing of the CAD model was made progressively, more iterations being performed in order to determine an optimum number of nodes and elements to be able to obtain the highest possible accuracy of the calculations. From the analysis of the equivalent stress distribution was able to observe the overloaded areas, which require strengthening, and the less loaded areas in which can be made a weight reduction of the material used. Also, the model of analysis with finite elements enables the identification of possible areas where frame structure deforms plastically under the effect of the applied external loads.

Key words: *Agricultural cultivator, frame, tillage tool, finite element method*

INTRODUCTION

Following the expansion of soil degradation processes due to conventional agriculture and technological mistakes, over the years, the so-named conservative agricultural technologies have been studied and implemented in practice. These technologies have contributed substantially to the improvement of soil fertility and productivity and, thus, of other environmental resources. The most important component of conservative technological systems, as in the case of conventional ones, is soil tillage – loosening and processing – and the introduction of seed into the soil [7]. Switching from conventional tillage systems to the conservative ones was not easy and it has generated a lot of questions that needed relevant answers, scientifically based, some of them being obtained through fundamental and applied research carried out under local specific conditions. Conservative systems are based on the less intense loosening of soil, made by different methods, without furrow return and only while maintaining a given amount of crop residues on soil surface, for this reason being considered as environmental protection strategies [7].

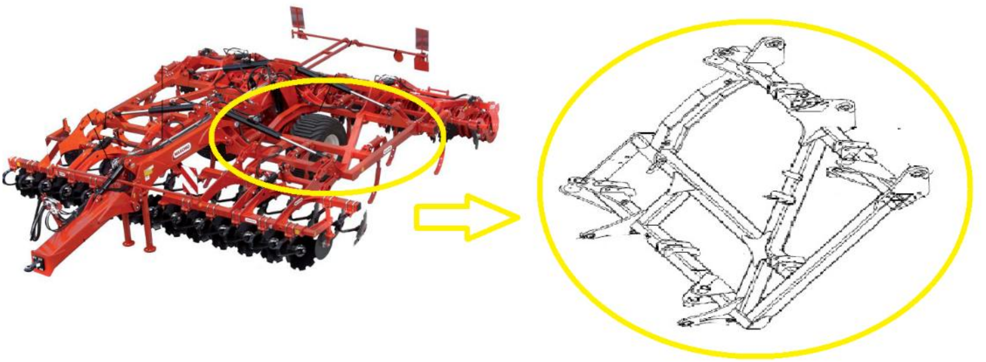
Agricultural cultivators are increasingly widespread equipment used for seedbed preparation in order to establish crops, especially in the current conservative cultivation technologies. Besides the fact that these equipment must achieve a soil processing with higher qualitative and energy indexes, their weight must be as small and their reliability to be as good as possible [7]. Currently, it is possible to shorten spectacularly the cycle of design concept - test - production of this type of equipment by using the Finite Element Method to analyze the distribution of stress and strains of their resistance elements (frames, tool holders, working bodies, etc.) [1, 5].

The finite element method is based on the principle of the overall potential energy, which states that a structure or a body is deformed or displaced in a position that minimizes the potential energy (overall potential) [2]. The principle of the minimum potential energy has many applications in solid bodies mechanics and in structure analysis. In these cases, the principle of the minimum overall potential is a special case of the principle of virtual mechanical work applied to systems being under the action of conservative forces. The principle of the virtual mechanical work states that the virtual mechanical work of the exterior forces is equal and opposed to the virtual mechanical work of the interior forces (normal stress, shear stress, torsion and bending stress). It is assumed that forces and stresses remain constant and only the variations of strains are taken into account; only the strains that satisfy the internal compatibility of the body and the boundary conditions (resulting from the connections to other bodies) are accepted [4].

The finite elements method was imposed by the need to solve complex problems in the mechanics of deformable bodies. Finite elements analysis (FEM) [2, 3, 6] of structures emerged as a necessity [1] to simplify and reduce the cost of testing in operation or under simulated and accelerated regimes, it can approximate to within acceptable precision the areas of maximum (critical) stress [4], the maximum tensions and even the lifetime of a structure.

MATERIAL AND METHODS

The technical equipment analysed within this paper is a prototype of Dracula type cultivator of Maschio Gaspardo Company, which is designed for seedbed preparation in conservative system. The equipment (Fig. 1) is semi-mounted type and operates in aggregate with tractors of 330-550 HP [1].



a) *b)*

Fig. 1 Agricultural cultivator

Lateral frames (left / right) are welded structures of rectangular pipes and sheet profiles and are provided with connecting elements with the central frame, connecting elements with the previous modules and posterior modules, with fixation plates of the working bodies with a prestressed spring and lugs of the hydraulic cylinders [7]. The lateral-left frame (Fig. 1.b) is the subject of analysis in this paper, due to its importance.

The geometric model of the frame was achieved in Catia V5 format and it was transferred to SolidWorks format, where were made the necessary corrections to achieve static analysis by the Finite Element Method. The CAD (geometric) model was then transferred to the Finite Element Analysis software (ANSYS) through which was performed the resistance calculation in the linear static range (Fig. 2). Adaptive meshing of the CAD model (Fig. 3) was made progressively, more iterations being performed in order to determine an optimum number of nodes and elements in order to obtain the highest possible accuracy of the calculations.

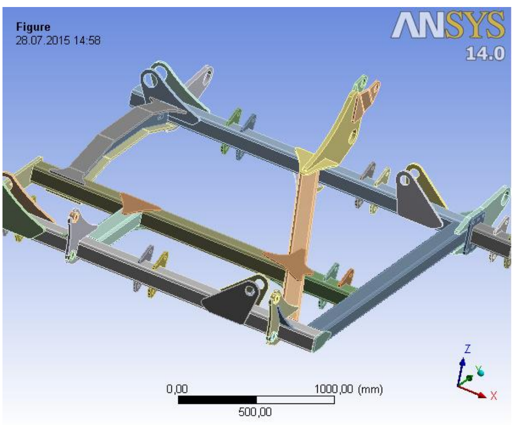
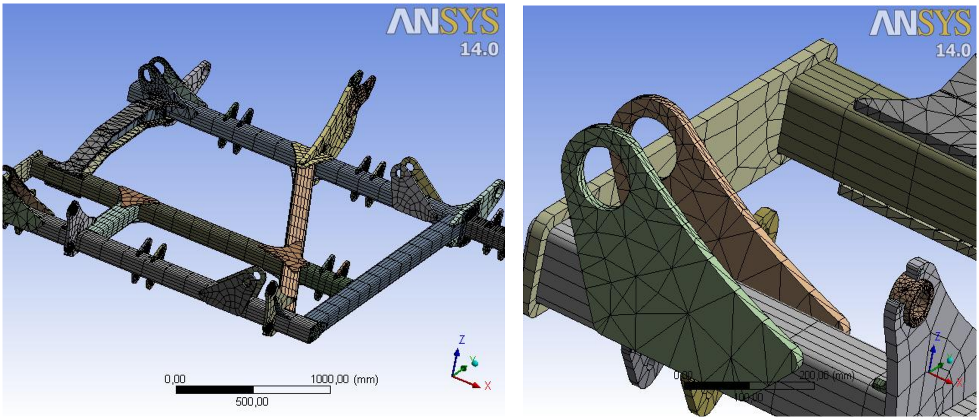


Fig. 2 Geometrical model of the frame



a) *b)*

Fig. 3 Overview of the mesh used for the frame

Given that the investigated structure was modeled three-dimensional geometrical, in the meshing process it was chosen to use a 3D finite element, of Solid type. This is a three-dimensional element, of rectangular shape, with 20 nodes (on each corner and at each mid side) with three degrees of freedom on each node: nodal translations in the directions of OX, OY and OZ axis (Fig. 4) [2]. The element supports the theory of plasticity, hyper plasticity, large specific displacements and strains. In Figure 4 is presented the geometrical shape of the finite element, used in the meshing process. The rectangular shape of the finite element represents the native shape, whereas the other shapes, found in the right side of the Figure, represent degenerated forms, that may arise in the case of complex geometries as shapes (in areas in which are found junction radius, thickness variations etc.). The welded frame is made of S355OL52 steel.

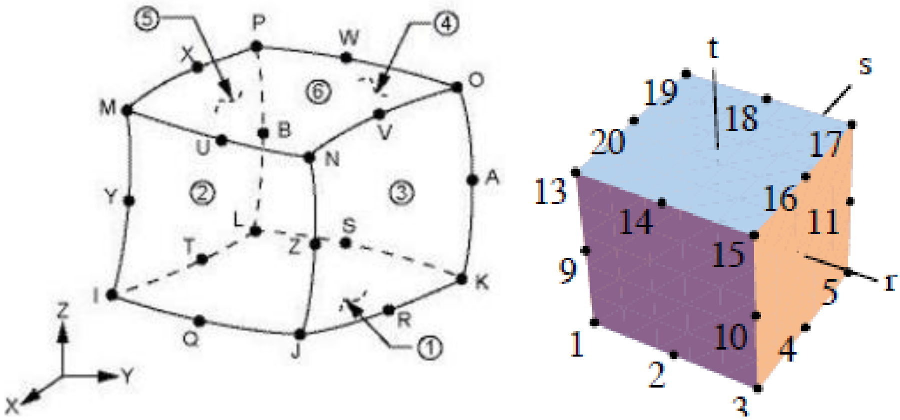


Fig. 4 Geometry of the finite element [2]

The partial derivatives of the interpolation functions with respect to x, y, and z are evaluated using chain rule as follows [2]:

$$\begin{pmatrix} \frac{\partial N_i}{\partial r} \\ \frac{\partial N_i}{\partial s} \\ \frac{\partial N_i}{\partial t} \end{pmatrix} = \begin{pmatrix} \frac{\partial x}{\partial r} & \frac{\partial y}{\partial r} & \frac{\partial z}{\partial r} \\ \frac{\partial x}{\partial s} & \frac{\partial y}{\partial s} & \frac{\partial z}{\partial s} \\ \frac{\partial x}{\partial t} & \frac{\partial y}{\partial t} & \frac{\partial z}{\partial t} \end{pmatrix} \cdot \begin{pmatrix} \frac{\partial N_i}{\partial x} \\ \frac{\partial N_i}{\partial y} \\ \frac{\partial N_i}{\partial z} \end{pmatrix} \tag{1}$$

Applying the principle of sub-structuring, in Figure 5 are presented the forces reduced in the coupling points of the frame with the working bodies and the bearings and its restrictions of bearing. The effect of resulting forces at the interaction of the working bodies with the soil is reduced in the coupling points of the working bodies with the frame by applying the theory of forces reducing tensor in a point.

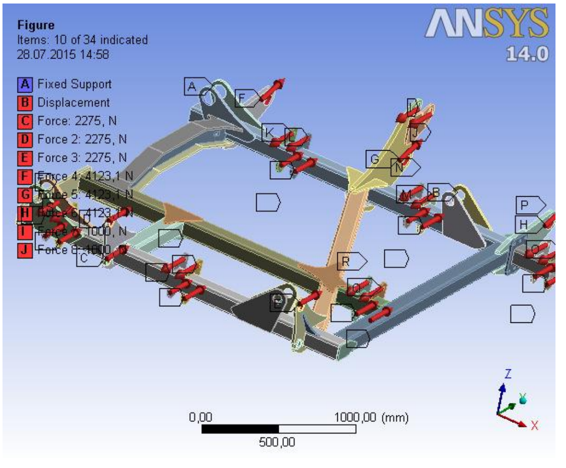


Fig. 5 Bearings and forces acting on the analysed frame

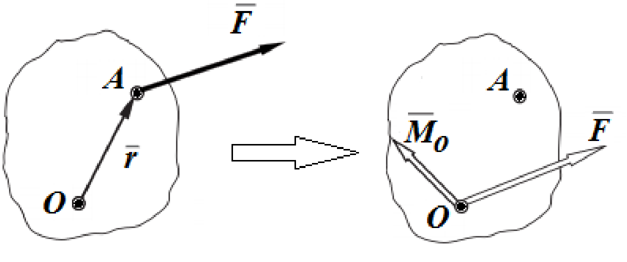


Fig. 6 Principle of force reduction in a point

According to this theory of force reducing tensor (Fig. 6), in point A (belonging to the working body) if the resistant force *F* resulting from the interaction with the soil is applied, the effect of this force on the frame, in the point of coupling O consists in a torso of reduction of force F relative to point O, respectively [3]:

$$\tau_O(\bar{F}) = (\bar{F}, \overline{M_O}) \tag{2}$$

respectively:

$$\tau_O(\bar{F}) \begin{cases} \bar{F} \\ \overline{M_O} = \bar{r} \times \bar{F} \end{cases} \tag{3}$$

RESULTS AND DISSCUSSION

The results of static analysis of the cultivator frame are presented in the following figures. They consist of the distribution of equivalent stress according to the Von-Mises criterion, and the distribution of total deformations.

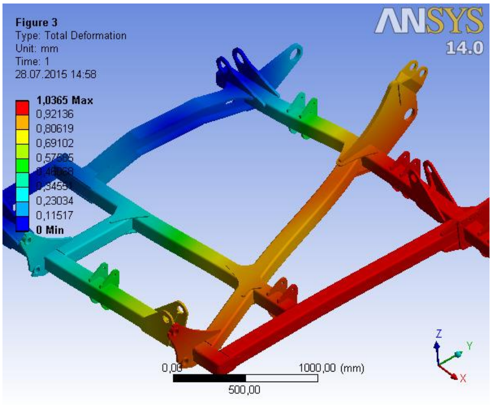


Fig. 7 Total deformation

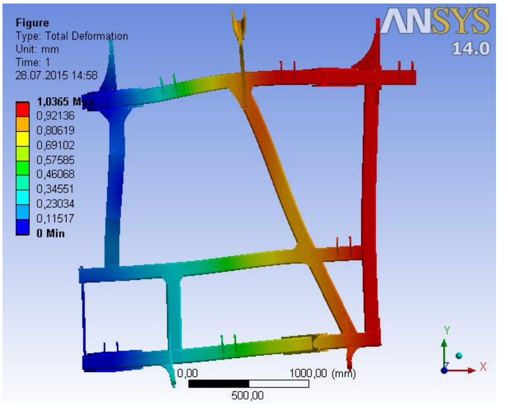


Fig. 8 Total deformation in horizontal view

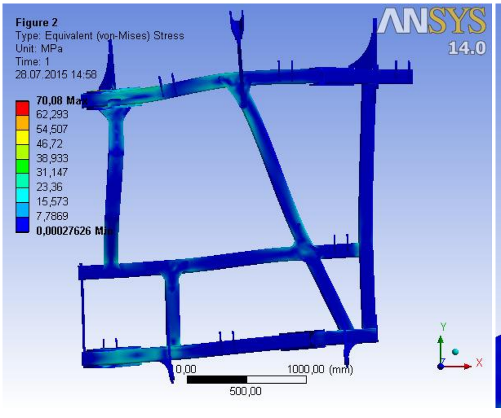


Fig. 9 Von Mises equivalent stress

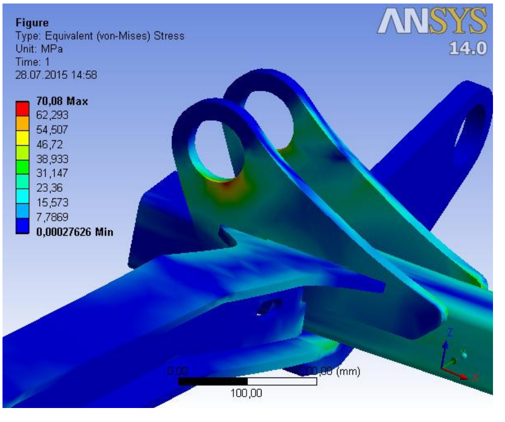


Fig. 10 Detail of stress distribution

From Figures 7 and 8 it can be seen that the greatest displacements (deformations) of the cultivator frame are found in the farthest area from the points of coupling to the central frame. The maximum values of total deformations are of about 1 mm. From Figures 9 and 10 it results that the highest values of equivalent stress are of about 70 MPa, being smaller than the value of allowable stress corresponding to the material of the frame. As it can be seen from these figures, the greatest stresses are located in the area of the connecting points of the analysed frame to the central frame.

CONCLUSIONS

- From this study it also results that the finite element method can be successfully used to perform analysis on the distribution of stresses and deformations in resistance structures (frames) of agricultural machinery, in order to optimize their construction.
- These methods allow the spectacular shortening of the time needed for the design and manufacture of resistance structures of agricultural cultivators.
- From the analysis of equivalent stress it can be observed that under the effect of the applied external loads, the structure of the frame does not deform in the plastic domain.
- The analysed frame of the cultivator is reliable in terms of mechanical strenght.
- In the areas of contact between components does not occur effects of overlapping, slippage.

ACKNOWLEDGEMENTS

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44. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

UDC 631.374:631.565
Izvorni znanstveni rad
Original scientific paper

SIMULATION OF TRANSPORTATION STRESS OF AGRICULTURAL IMPLEMENTS WITHIN LABORATORY

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SUMMARY

One of the many reasons for agricultural implements resistance failures is represented by stress caused by transportation conditions. A safe way to assess the transportation stress influence on the agricultural machinery fatigue life is to record and to reproduce it within laboratory, in simulated and accelerated regime. Within the paper we present the real transportation stress measured in different conditions for a heavy duty combiner and the procedure followed for creating an accelerated test in simulated regime based on that real stress. The accelerated test was performed on a custom designed testing rig which allowed the accelerated reproduction of the recorded stress without dynamic stress amplification. We have applied a rainflow cycle counting algorithm on the transportation recorded stress and we constructed a testing program in accelerated regime which to account for the implement's entire life span in terms of transportation stress.

Key words*: transportation stress, accelerated test, rainflow counting*

INTRODUCTION

At the beginning of XIX century it has appeared the agriculture's mechanization concept [3], which was rapidly applied by the majority of the world's states. The agriculture's mechanization was performed through development of a very diverse range of agricultural machines or implements, development which continues even nowadays.

The machine represents generically a technical system made up from parts and mechanisms with determined movements, with the purpose of turning energy into mechanical work.

Agricultural machines or implements are self-propelled working machines or driven by an alternative power source [3], destined to do a series of works within processes from agriculture, according to agricultural-biological and technical-economical requirements imposed.

According to Negrus et al. [6], testing of agricultural machines or implements could be defined as a collection of diverse types of tests. Importance of testing agricultural machinery resides from the fact that different types of tests, as an self-contained part of the research-development, fabrication, exploitation and maintenance processes contribute decisively to permanent enhancement of those, in every stages mentioned before [7].

Most of the times, tests performed on agricultural machinery resolve the next critical tasks: determination of parameters which characterize the functioning of the machine, determination of wear resistance in exploitation conditions, research of processes which take place in different assemblies and mechanisms of the machine as also identification and correction of failure mechanisms.

One of the failure generation means for the agricultural implements from their structure of resistance point of view, besides exploitation loads, are the transportation loads. These are generated by gravity forces amplified by the road bumps and holes, inertia forces, vibrations and so on. It is a known fact that agricultural and forestry roads have many more bumps than national roads meaning a more dynamic gravity loads and vibrations variation. Also within the transportation process there are specific sectors of road with different characteristics: tarmac, gravel, dirt or sandy roads, even transportation jobs which occur directly in field terrain. All these generate different load amplitudes, which mean that by mission profiling [4] of this process one could identify their real distribution and so could predict their influence on the fatigue life. Also one could use them as real data inputs for an accelerated test [2].

Road tests are performed for assessing of the implements road behavior (safety, maneuverability, comfort). These tests are realized on special proving grounds or on segments of road which have unleveled profiles (holes and bumps) so that to correspond to real exploitation conditions. Within this process, the implement is subjected to real transportation loads, commonly found in transportation operations. If choosing of testing routes, elaboration of testing methods and right equipment election have been done properly, the recorded data precision is satisfying. Tests performed on proving grounds could reduce the testing period, which still represents a big amount of testing time. For further reducing testing time one should perform accelerated tests within laboratory. In [1], accelerated testing is defined as a way to compress testing time using different methods: usage rate acceleration, stress amplification, step stress testing, etc. Thus accelerated testing within laboratory conditions using real stress data as inputs represents a substantial alternative for acceleration of tests [8]. Input data for testing in laboratory of agricultural implements is obtained from records of relevant loads at which the machine is subjected in exploitation, which are then simulated on specialized stands, usually in simulated and accelerated regime [4,9].

In the current paper there is presented a method for testing of agricultural implements in transportation conditions, simulated and accelerated within laboratory, in view of reducing conventional testing period.

METHOD

For experiment realization we chose an agricultural combination implement with a total weight of 6500 kg and a transportation height of 4 m. This had a total length of 6 m and was semi-carried, having also its maximum allowed transportation speed of 25 km/h, adapted to the road conditions. Because of this high values parameters (weight, height, length) the transportation loads tend to be dangerous so that a thoroughly testing is imposed. We chose to measure the vertical acceleration on the agricultural machine's drawbar in one strategic point, taking into consideration the testing stand that was at our disposal with one hydraulic actuator.

For taking measurements we used a piezoelectric accelerometer, produced by PCB, with analog conditioner and USB data acquisition card produced by National Instruments. The software used for data acquisition was developed in LabView. We mounted the accelerometer on the combination implement drawbar using a magnet, in order to record the vertical acceleration at which it was subjected. The accelerometer was calibrated using a calibration exciter of 10 m/s^2 RMS value at 159.2 Hz before performing the measurements on the road.

Fig. 1 Accelerometer mounted on the combinator's drawbar

Fig. 2 Aggregate tractor-combinator

Sampling frequency was set up at 2500 Hz. Test results were recorded on ASCII files which were afterwards processed off-line.

The machine was used in aggregate with a 150 HP tractor for carrying out road transportation tests.

We carried out transportation tests covering the entire range of road conditions: tarmac, gravel, bumpy road in the field. Loads on the drawbar were recorded as accelerations (m/s^2). After performing these tests, we processed experimental data with nCode Glyphworks software. The used acquisitions were those related to normal exploitation conditions. The processing methodology respected the following stages:

- File importing in nCode Glyphworks format;
- Naming of measured channels corresponding to the recorded data as time and acceleration;
- Graphical editing [5] of acceleration channel for elimination of flat segments of signal with low amplitudes which corresponded to stationary moments or even leveled road;
- Double integrating of the vertical acceleration signal for obtaining of vertical displacement of the drawbar, relative to the equilibrium position in stationary regime; this signal was used as input for the syntheses of controlling signal of the actuator’s stroke on the testing stand;
- Counting of load cycles using a Rainflow algorithm for estimation of stress accumulation in time;
- Synthesizing (from the vertical displacement signal) the reference control signal of the testing stand; we achieved this by sample rate adjustment of the vertical displacement signal (dividing the original frequency by 10 and so comprising the testing time ten times);
- Exporting of the newly created reference signal as a file compatible with the control system of the hydraulic actuator which represents the execution element of the testing stand.

Afterwards, the combination implement was tested in accelerated regime with loads which had the same shape as the real transportation ones, in mounted state on a testing stand according to figure 3. The combination implement structure was positioned on a testing platform, with its wheels left to move freely and its drawbar laid down on top of a 100 kN hydraulic actuator, which had its stroke controlled after the reference signal previously synthesized. A load cell of 100 kN was mounted on the actuator’s rod in order to measure the reaction forces on vertical direction on actuator-drawbar coupling. The drawbar was excited in vertical direction, simulating the real transportation loads. Hence we simulated real displacement on vertical direction of the combination implement’s entire structure, having as pivot point its transportation axle. We imposed the application of 4000000 cycles of loading in these conditions according to the previously counted cycles from the real acceleration signal.

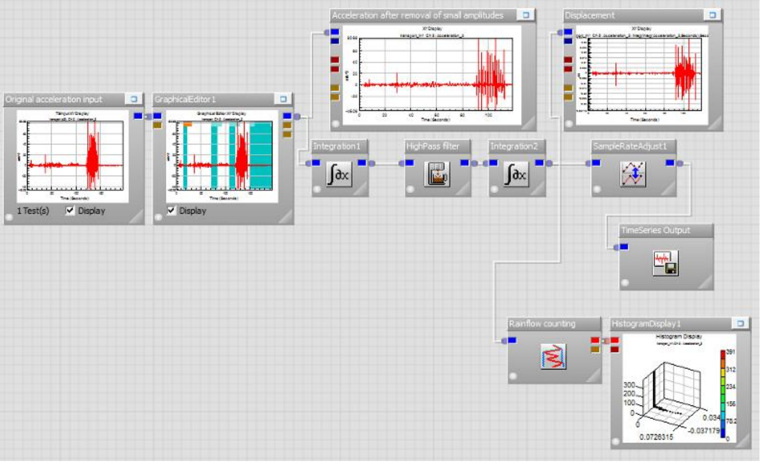

Fig. 3 Data processing methodology

Fig. 4 Stand for testing in simulated and accelerated regime of agricultural combination implementin transportation conditions (left – in front view, right – view from behind)

RESULTS AND DISCUSSION

As a result of the performed measurements we obtained diagram from figure 5 which represents the evolution of vertical acceleration, measured on top of the drawbar, along 2.91 km of transportation in different road conditions. The observed length of time was of 2241 seconds. The recorded values were between -7.6 m/s^2 and 6 m/s^2 with the extremes measured in areas with bumpy roads. The measured values demonstrate that against the structure in dynamic regime there are acting supplementary forces which are superimposed on the gravity force.

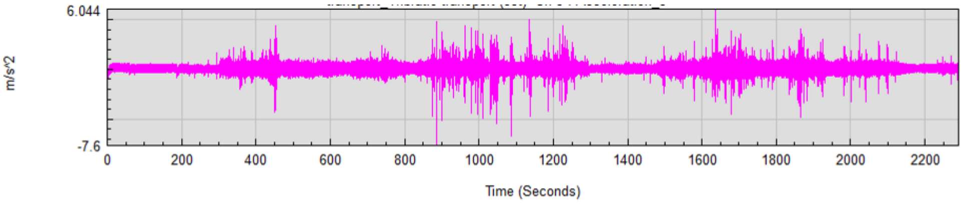

Fig. 5 Original acceleration recorded in transportation graphically edited

The original acceleration signal was digitally integrated twice, in order to obtain the displacement signal. Thus the reference signal for controlling of the hydraulic actuator had the shape of figure 6, before sample rate adjustment.

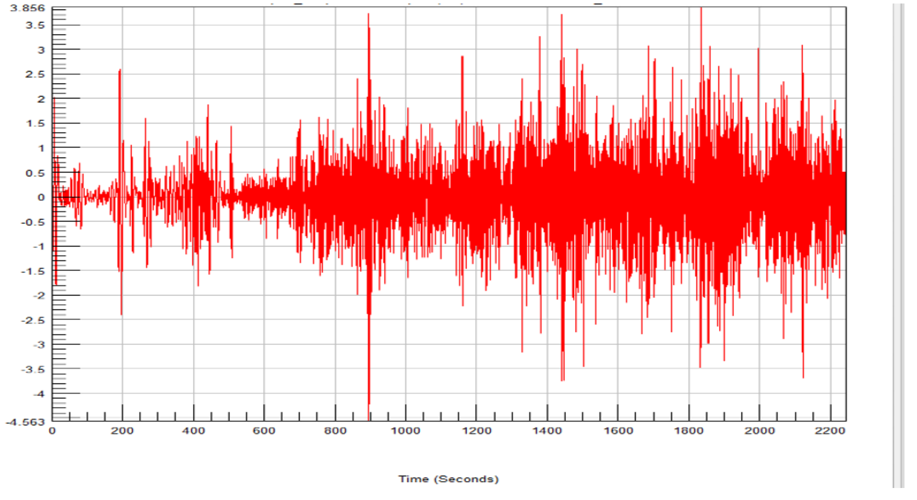

Fig. 6 Vertical displacement diagram obtained after digitally integration of the original acceleration signal

By applying a rainflow type counting algorithm to the signal from figure 6 we obtained the diagram of figure 7, totalizing a number of 2325 cycles of solicitation during 2241 seconds, recorded along 2.91 km of road track. Thus this sequence had to be repeated 1720 times to achieve the 4000000 imposed loading cycles. The real transportation work which accounted for 4000000 cycles was calculated by multiplying the initial solicitation duration of 0.622 hours (2241 seconds) with the number of repetition of the original sequence, so that we obtained a total number of 1070.7 hours. Also by multiplying the initial recorded length of the road track with the number of repetition of the original sequence we obtained a total length of road transportation of 5056.8 km. So our accelerated test of 4000000 loading cycles simulated transportation work on a distance of 5056.8 km which normally would be achieved within 1070.7 hours. Using an acceleration factor equal to 10 on the original signal, after sample rate adjustment we obtained a compressed testing time in accelerated regime of 107.07 hours.

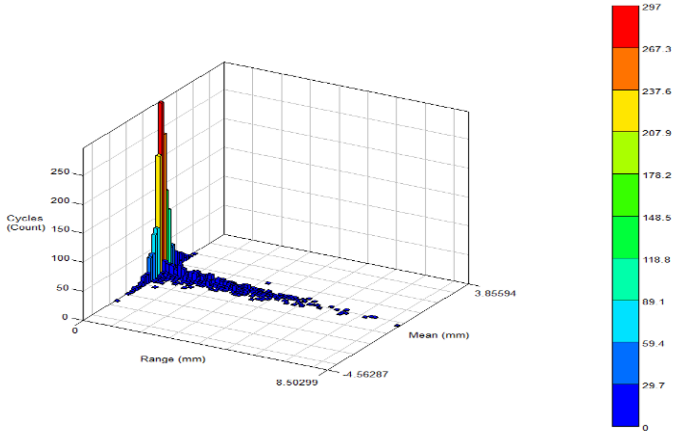

Fig. 7 Cycles counting diagram

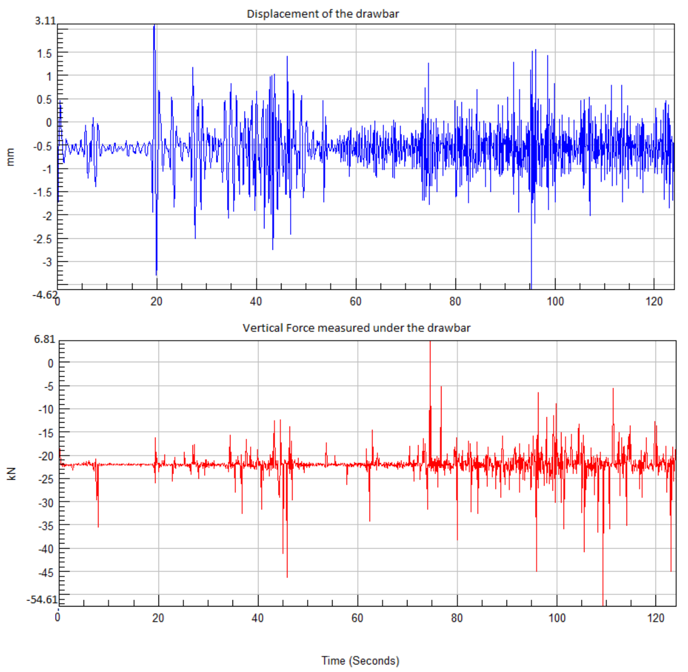

Fig. 8 Imposed displacement of the drawbar (blue) and its force responce (red)

The diagram of figure 7 suggests a Gaussian distribution of the loads centered on the mean value of zero which accounts for their random occurrence. Added to this we can observe a very high density of small amplitude loads which are created by the moving parts, characteristic to road with even surface. The really high amplitude loads occur seldom because of the bumps and holes and unleveled surface of the road.

We placed the combination implement on the testing stand and we applied the reference signal after sample rate adjusting by a factor of 10. In figure 8 we present the imposed displacement of the drawbar through the actuator’s stroke and the reaction force measured on the vertical direction.

In table no. 1 we present the extreme values recorded by the drawbar: displacement and reaction force.

Table 1 Results of accelerated test

No crt	Drawbar vertical displacement (mm)	Vertical reaction force (kN)
Minimum value	-4.62	-54.61
Maximum value	3.11	6.81
Peak to peak value	7.73	61.42

Positive and negative values of the displacement (figure 8) represent oscillations around the virtual zero point considered as the initial position of the actuator’s rod before tests beginning, on vertical direction. Positive values of the reaction force represent traction values while negative ones represent compressive forces. The mean value of around 22 kN represent the compression force due the combination implement own weight. We observe that the reaction force value achieve 54.61 kN compression force. There is a difference of approximately 23 kN between the mean value and the top compressive force value, which is explained by dynamic amplification of gravity force because of the bumps on the road. Actually the forces which act in vertical direction against the drawbar and implicit against the entire structure double their amplitude on discrete moments in time as a result of road characteristics.

After applying 4000000 cycles of solicitation we simulated road transportation on a distance of approximately 5000 km without appearance of any cracks or fissures.

CONCLUSIONS

Agricultural machines for which we estimate a high degree of mechanical stress during transportation presume a large amount of testing time in normal conditions. Thus we could choose an accelerated testing method based on the real transportation stress reproduction within laboratory. This test performed at quicker rate compared with the real stress allows shorter testing period in the same time keeping the original stress pattern. The chosen acceleration factor allowed us to achieve a testing period 10 times shorter than the original reference signal.

For realization of accelerated tests of an agricultural implement in transportation conditions we propose to follow the next stages: recording of real transportation stress in different conditions, analysis of recorded data, reference signal generation from real data by shortening the period of signal application and laboratory tests on a testing stand which should simulate the real transportation conditions and carrying out tests within laboratory.

Tests performed within laboratory will not simulate totally the real transportation conditions due to limitations of the testing stands, although this type of testing is useful for agricultural implements developers, which can validate in shorter time their designs.

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44. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

UDC 631.354
Prethodno priopćenje
Preliminary communication

TANGENTIAL THRESHING SYSTEM WITH VENTILATOR EFFECT AT THE COMBINE HARVESTERS

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SUMMARY

The working capacity of a combine harvester depends mainly on the working capacity of the tangential threshing system. Its increase depends on the feeding with vegetal mass made by the conveyor with chains and scrapers of the feederhouse. Reality has demonstrated the technological limits of the conveyor in terms to achieve optimum feeding and, therefore, we decided to study a tangential threshing system transformed so that it has a ventilator effect to improve the feeding with vegetal mass provided by the conveyor or even the possibility to remove it. The article presents how to make this new tangential threshing system and the suction speed calculation with vegetal mass depending on various technical and functional parameters.

Key words: *combine harvester, tangential threshing system, transversal ventilator*

INTRODUCTION

The combine harvesters have a history of slightly more than a hundred years, their appearance being a consequence of the need to harvest cereals on surfaces increasingly greater in a time as small and with a minimum of labour. It is interesting to note that their emergence did not happen in Europe, where it was only natural because the potential human and technical existing, but in North America and Australia. These combines were pulled by horses or mules and carried out in a single technological process the cutting of straw cereals, threshing, separating and collecting grains of harvested culture. The first self-propelled combines were produced in North America before the World War II, the main components being as the present combines.

Figure 1 presents the main components of a conventional combine harvester, the tangential threshing system being highlighted with red color.

This study refers to a new concept of a tangential threshing system. It is designed to solve the problems of the conventional combine harvesters, such as: the threshing capacity smaller of the tangential threshing system compared to axial threshing system capacity, the feeding speed reduced of the tangential threshing system and the loading uneven with vegetal mass of the threshing cylinder, because of the technological limits of the conveyor with chains and scrapers of the feederhouse. The drive speed of this conveyor must be correlated with the speed of the threshing cylinder and characteristic to vegetal mass harvested. [5]

The idea of the study appeared in 1981, when, being in front of a combine harvester in running-in (the feederhouse was not mounted on this combine), I noticed that the rotation of threshing cylinder was generating an air suction. This combine was equipped for harvesting corn, and the threshing cylinder had 8 angle irons in addition to the threshing cylinder for harvesting cereals. I believe that these angle irons generated the air suction.

Figure 1 presents this tangential threshing system for corn harvesting.

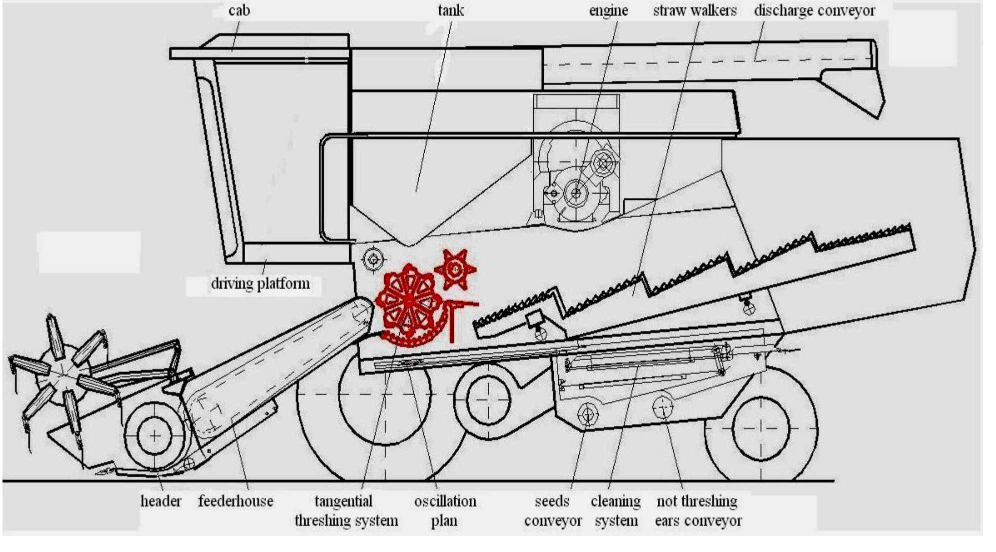

Fig. 1 The main components of a conventional combine harvester [4]

The threshing cylinders for cereals harvesting have only grooved bars provided with flat areas, and the air suction turned into air discharge. (Fig. 3)

Based on this finding, we propose a new tangential threshing system. The new system has, besides the current components, a number of ventilator blades, which will give of the system an effect of air suction (ventilator effect), several plastic disks and a capote. (Fig. 4)

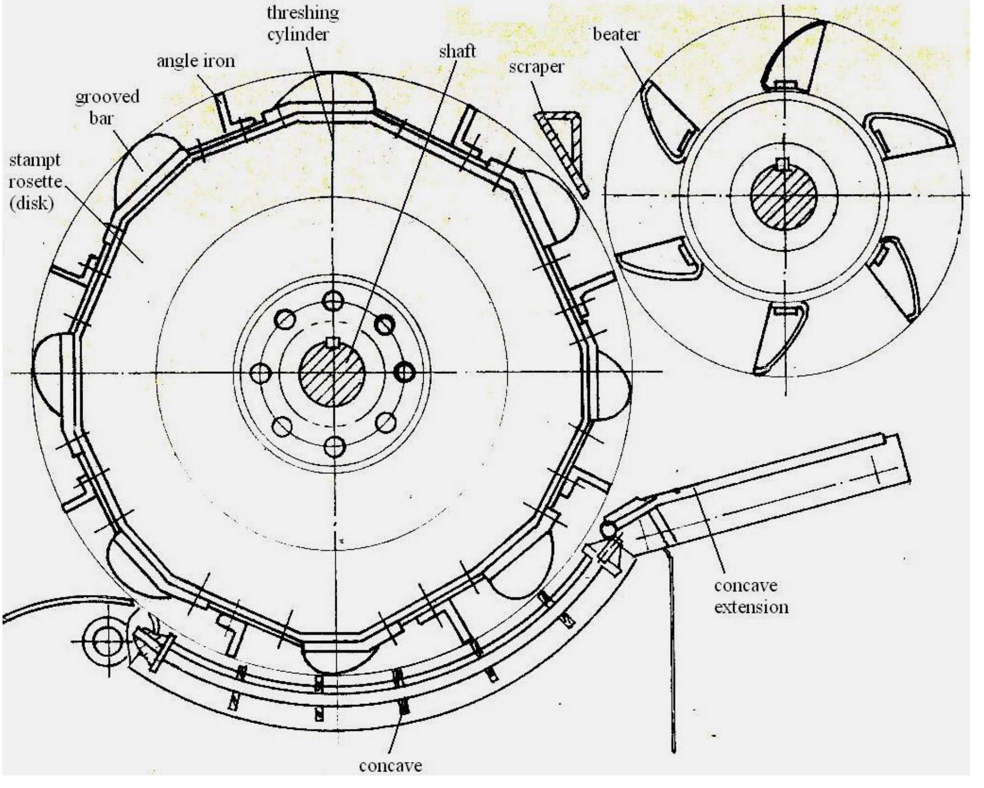

Fig. 2 Tangential threshing system for corn harvesting [8]

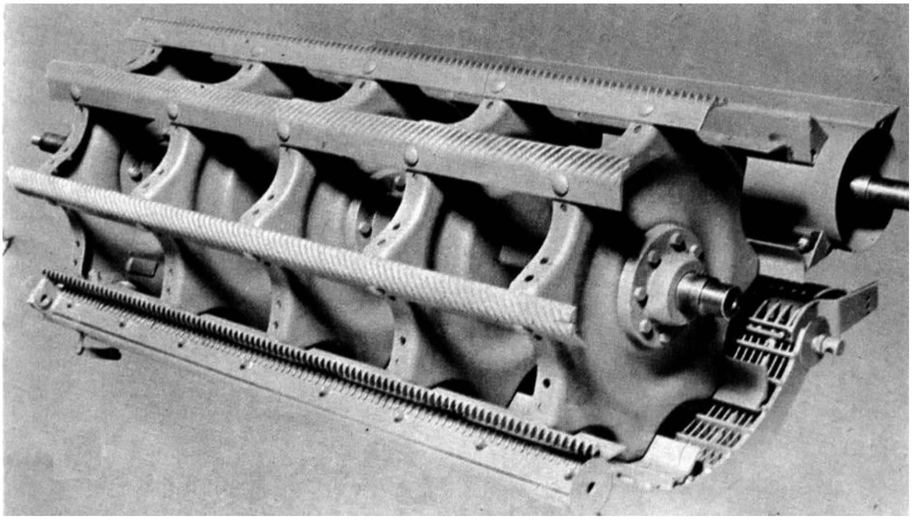

Fig. 3 Tangential threshing system for cereals harvesting [8]

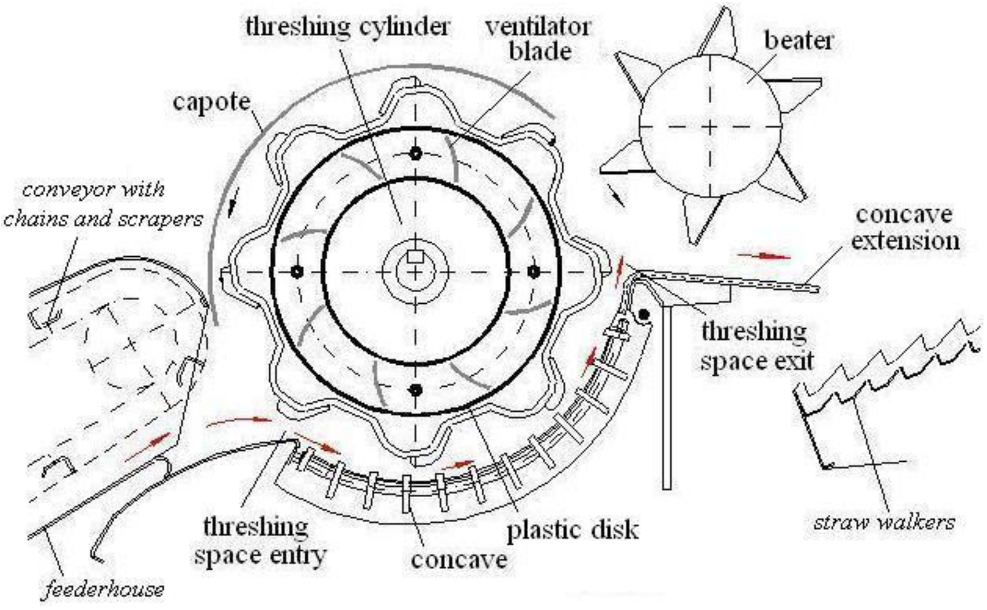

Fig. 4 The new tangential threshing system components (variant 1)

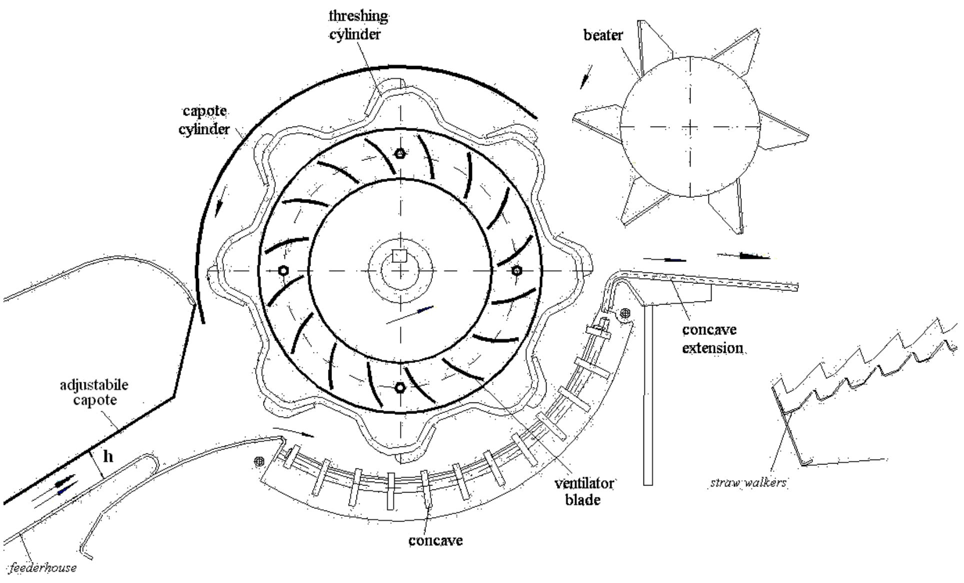

Fig. 5 The new tangential threshing system components (variant 2)

The plastic disks have holes for the ventilator blades and for fixation on the stamped or molded rosettes.

All of these new components gives to the tangential threshing system characteristics of a transversal ventilator. The number and the size of ventilator blades can be bigger to increase the air suction flow, the ventilator pressure, so that, with a montage as in Figure 5, the conveyor with chains and scrapers may be removed.

The concave and the capote of cylinder will act as a transversal ventilator housing and the adjustable capote of feederhouse is designed to increase the suction speed of vegetal mass, the conveyor with chains and scrapers being sent off. It should be noted that the position of feederhouse capote must be adjustable, so that, various types of cereals harvested can be transported completely without the help of conveyor.

METHODS

It should be noted from the start the important in this study of the new threshing system:

1. The feeding with vegetal mass (called short material) of the tangential threshing system determines the threshing capacity, by the uniform entraining a big quantities of material at a full rotation of the threshing cylinder. [5]
2. For reducing the energy consumption of the tangential threshing system, the entry speed of the material in the threshing space must be higher than 6 m/s. [4]
3. The theoretical studies and experimental researches effected confirm that the transversal ventilator is the ideal ventilator type, by the structures and the quality of aerodynamic field which is generated. The studies confirm the discharge uniformity of transversal ventilator and we hopefully as the aerodynamic field of air suction to be the same.[3]

Figure 5 presents the mounting of ventilator blades and plastic disks on the rosettes of the new threshing cylinder.

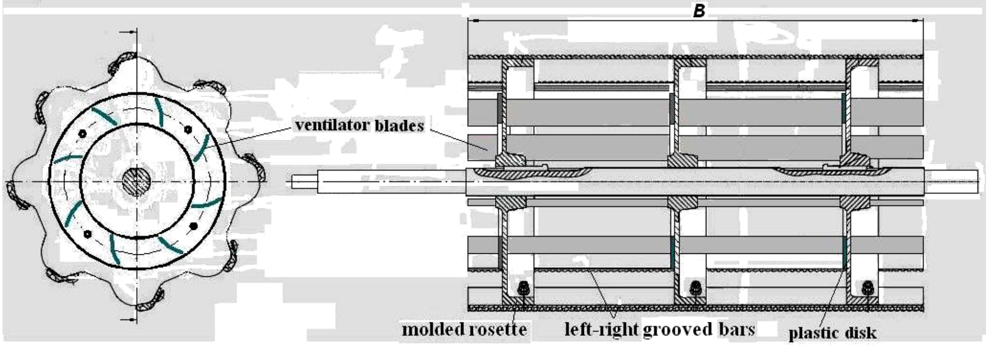

Fig. 6 The new threshing cylinder

The plastic disks are mounted on the outside of the molded rosettes (this surface is processed after molding) using the screws, so that, the eight ventilator blades to pass through the existing holes of the molded rosettes [4]. After this assembling, the threshing cylinder will be dynamically balanced.

The configuration of the ventilator blades and their arrangement in relation to the rotation axis of the threshing cylinder is shown in Figure 7 and the values of ventilator blade characteristics in Table 1.

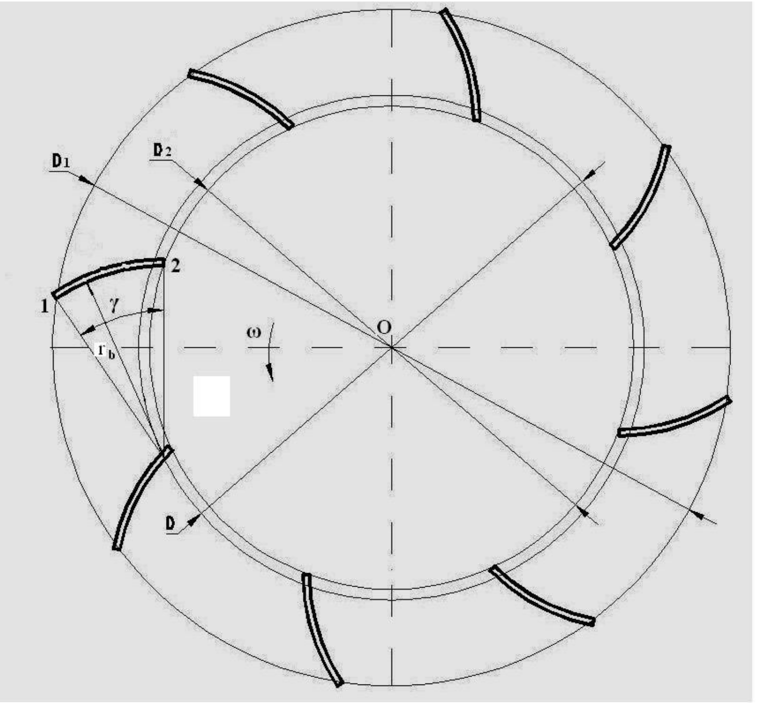

Fig. 7 Configuration of the ventilator blades

Table 1 Values of the blade characteristics

Blade characteristics	z	B [m]	D_1 [m]	D_2 [m]	D [m]	r_b [m]	γ
Values	8	1.08	0.428	0.306	0.320	0.120	35º

where: z is number of the blades ventilator; B – length of the ventilator; D_1 –outer diameter of the ventilator; D_2 –inner diameter of the ventilator; D – diameter of the blades radius center; r_b – radius of the blades; γ – angle of the blades.

We present below the calculation method for the pressure and the airflow rate who passing through the threshing cylinder modified.

The theoretical pressure equation of a transversal ventilator, requires a ventilator with an infinite number of blades, with ω rotational speed. The air passes twice through the ventilator blades of the threshing cylinder.

Figure 8 presents the air entry scheme into transversal ventilator and Figure 9 presents the air exit scheme from the transversal ventilator.

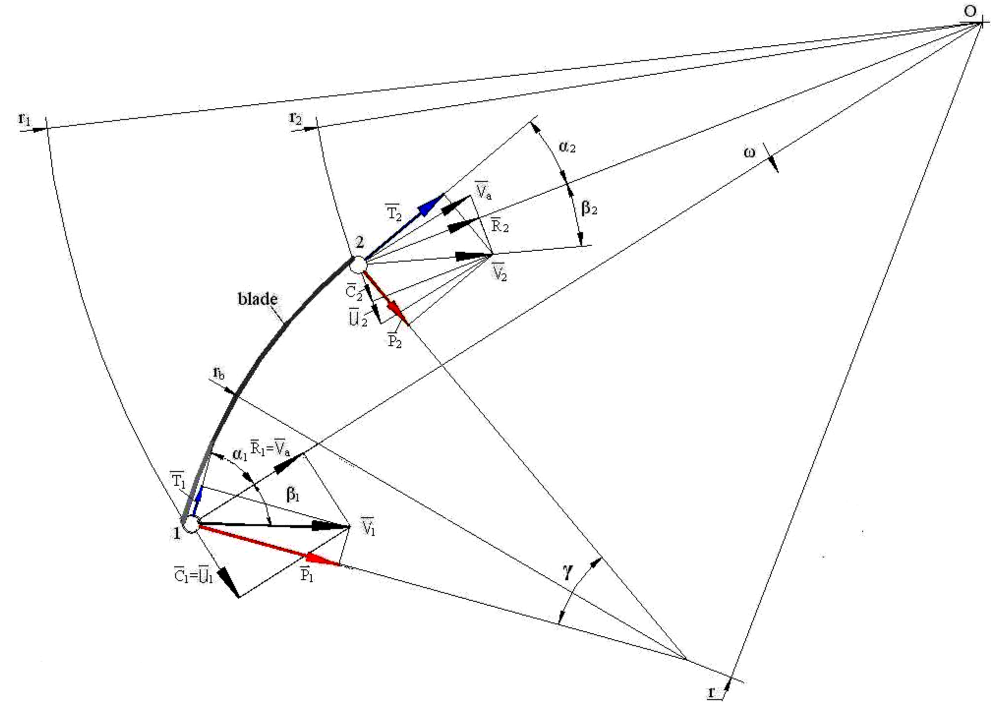

Fig. 8 The air entry scheme into the transversal ventilator

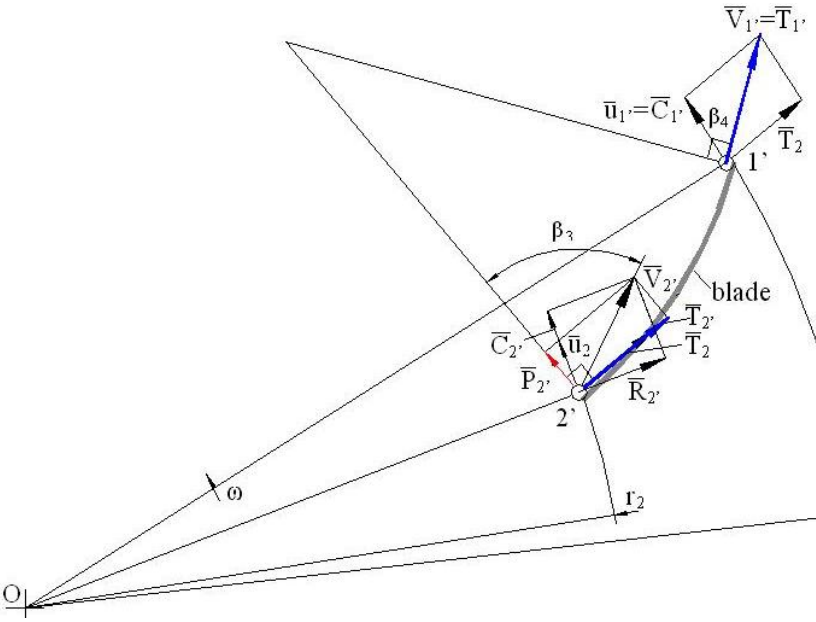

Fig. 9 The air exit scheme from the transversal ventilator.

The motion direction of air particles in ideal rotor coincides with the tangents to the blades. The air particle enters under the action of the ventilator blade in point 1, the particle speed being the resultant of the blade peripheral speed in point 1 and of the airspeed from entering the rotor, according to the relationship 1.

$$\overline{v}_1 = \overline{u}_1 + \overline{v}_a \tag{1}$$

where:

v_1 is the air particle speed;

u_1 – peripheral speed of the blade in point 1;

v_a – the airspeed from entering the rotor.

The peripheral speeds of the blade in point 1 and 2 is given by the relationship 2:

$$u_1 = \omega r_1 = \frac{\pi n}{30} r_1 \qquad u_2 = \omega r_2 = \frac{\pi n}{30} r_2 \tag{2}$$

where:

ω is the angular speed of threshing cylinder;

n – rotation speed of the threshing cylinder (for cereals *n= 640-1100 rpm*, for the threshing cylinder with the diameter 0.6 m);

r_1 – radius of the point 1;

r_2 – radius of the point 2.

The air speed at the entrance in rotor has a value that ensures the optimum feeding with material of the threshing system and the speed direction for our combines is radial. For the transport of the cut plants through the feederhouse, it is necessary an airspeed $v_a > 11\ m/s$ [1].

The movement quantity moment of the air mass m_a is given by relationship 3.

$$M = m_a v r \sin\beta \tag{3}$$

where:

M is moment of the movement quantity;

m_a – air mass transported by the blade;

v – particle air speed;

r – distance to the rotor center;

β – angle between radius r and direction speed v.

The components of particle air speed *v* on the tangent to the trajectory of a blade point and on the radius, are *C* and *R*, respectively, C_1, R_1 and C_2, R_2 (Fig.8), according to the relationship 4.

$$C = v\sin\beta\,; R = v\cos\beta \tag{4}$$

From relations 3 and 4, results the relationship 5.

$$M = m_a C r \tag{5}$$

The air mass who is moving into the unit of time near a point of the blade, can be given by the relationship 6.

$$m_a = \rho Q \tag{6}$$

where:

ρ is the air density;

Q – real airflow rate of the ventilator.

From relations 5 and 6, results the relationship 7.

$$M = \rho Q C r \tag{7}$$

For the two points 1 and 2 of the transversal ventilator blade, we will have two moments of the movement quantity, according to the relationship 8.

$$M_1 = \rho Q C_1 r_1 ; M_2 = \rho Q C_2 r_2 \tag{8}$$

where:

C_1 is the tangential component of the particle air speed V_1;

C_2 – the tangential component of the particle air speed V_2;

r_1 – distance of point 1 to the rotor center;

r_2 – distance of point 2 to the rotor center.

The difference is the variation moment of the movement quantity, according to the relationship 9.

$$\Delta M = M_2 - M_1 = \rho Q\left(r_2 C_2 - r_1 C_1\right) \tag{9}$$

where: ΔM is the variation moment of the movement quantity.

The energy transmitted to the air at the pass through the first stage rotor blades, will be according to the relationship 10.

$$L_1 = \omega \Delta M = \rho Q (u_2 C_2 - u_1 C_1) \tag{10}$$

where: L_1 is the energy transmitted to the air at the pass through the first stage rotor blades.

The energy of the unit volume or the theoretical pressure (H_{T1}), at the pass through the first stage rotor blades, will be according to the relationship 11.

$$H_{T_1} = \frac{L_1}{Q} = \rho (u_2 C_2 - u_1 C_1) \tag{11}$$

where: H_{T1} is the theoretical pressure at the pass through the first stage rotor blades.

Similarly, the second air passage through the rotor blades, the air theoretical pressure will be according to the relationship 12.

$$H_{T_2} = \rho (u_1 C_{1'} - u_2 C_{2'}) \tag{12}$$

where: H_{T2} is the theoretical pressure at the pass through the second stage rotor blades.

Summing the two theoretical pressures is obtained the theoretical pressure of transversal ventilator, according to the relationship 13.

$$H = H_{T_1} + H_{T_2} = \rho (u_2 C_2 - u_1 C_1 + u_1 C_{1'} - u_2 C_{2'}) \tag{13}$$

where: H is the theoretical pressure of transversal ventilator.

Dynamic pressure of the transversal ventilator is calculated using the relation 14.

$$\Delta H_d = \frac{\rho}{2} u_1^2 \tag{14}$$

where: ΔH is dynamic pressure of transversal ventilator.

The theoretical airflow of transversal ventilator is calculated with relationship 15.

$$Q_{th} = u_1 \frac{\pi D_1^2}{4} \tag{15}$$

where:

Q_{th} is theoretical airflow of transversal ventilator;

u_1 – peripheral speed of the rotor;

D_1 – outer diameter of the transversal ventilator.

The real airflow of transversal ventilator is calculated with relationship 16.

$$Q = \varphi u_1 \frac{\pi D_1^2}{4} \tag{16}$$

where:

Q is real airflow of transversal ventilator;

φ – airflow rate coefficient.

According to some authors, the cross-sectional area can not be a reliable parameter and therefore they proposes to calculate the real flow rate of the transversal ventilator with the relationship 17. [1]

$$Q = \varphi_d u_1 D_1 B \tag{17}$$

where:

φ_d is an other airflow rate coefficient;

B – length of the ventilator.

RESULTS

For the calculation of the parameters used in this analysis, the following values:

- the airspeed from entering the rotor: $v_a=30\ m/s$;
- rotation speed of the threshing cylinder: $n= 640\text{-}1100\ rpm$ for cereals, for the threshing cylinder with the diameter 0.6 m;
- radius of the point 1: $r_1=0.214\ m$;
- radius of the point 2: $r_2=0.153\ m$;
- angle between radius r and direction speed v: $\beta_1=33^o, \beta_2=16^o, \beta_3=65^o, \beta_4=90^o;$
- radius of the blade: $r_b=0.12\ m$;
- diameter of the blades radius centers: $D=0.32\ m$;
- angle of the blades: $\gamma=35^o$;
- length of the ventilator: $B=1.08\ m$;
- outer diameter of the ventilator: $D_1=0.428\ m$;
- air density: $\rho=1.21\ Ns^2/m^4$;
- channel width of the feederhouse: $B_f=1\ m$;
- height channel of the feederhouse: $h=0.05...0.1\ m$. (Fig. 5)

According to the mathematical model presented, the results are:

- theoretical airflow rate: $Q=3\ m^3/s$;
- real airflow rate: $Q=1.5\ m^3/s$, for $\varphi=0.5$;
- the airspeed from entering the ventilator: $v_a=15...30\ m/s$, $v_a=30\ m/s$ for grain;
- height channel of the feederhouse for grain: $h=0.05\ m$;
- particle air speed in point 1: $v_1=35.9\ m/s$;
- particle air speed in point 2: $v_2=30.7\ m/s$;
- particle air speed in point 2': $v_{2'}=32.7\ m/s$;
- particle air speed in point 1': $v_{1'}=33.9\ m/s$;
- peripheral speed of the blade in point 1 and 1' for wheat: $u_1=20.2\ m/s$;
- peripheral speed of the blade in point 2 and 2' for wheat: $u_2=14.4\ m/s$;
- tangential component of the particle air speed v_1: $C_1=20.2\ m/s$;
- tangential component of the particle air speed v_2: $C_2=8.7\ m/s$;
- tangential component of the particle air speed $v_{2'}$: $C_{2'}=22.3\ m/s$;
- tangential component of the particle air speed $v_{1'}$: $C_{1'}=33.9\ m/s$;
- theoretical pressure of transversal ventilator: $H=97\ Pa$;
- dynamic pressure of transversal ventilator: $\Delta H=246.8\ Pa$.

CONCLUSION

The study presents how to make a tangential threshing system with ventilator effect at a conventional combine harvester and the calculation method for the pressure and the airflow rate who passing through the threshing cylinder modified.

The study also shows the calculation method of air suction speeds at the new threshing system to improve the feeding with material to increase its working capacity.

The new threshing system could revolutionize the threshing process of conventional combine harvester, in the conditions in which this combine would be more simple and effective. Experimentation of the new threshing system could eliminate or modify (in the sense of simplicity) and other important components of the combine, such as beater, straw walkers or cleaning system.

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44. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

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Izvorni znanstveni rad
Original scientific paper

COMBINE HARVESTER THRESHING CYLINDER CONSTRUCTIVE PARAMETERS

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SUMMARY

For the purpose of finding the optimal shape of filler plates, laboratory trials were performed that involved threshing of corn ears. Total 8 sets of threshing cylinder filler plates (each containing 8 plates) were produced for the purpose of investigation. Research was done with fixed tangential threshing cylinder which was 0.6 m in diameter and 1.2 m in width, and had eight rasp bars. It was surrounded in concave by angle of 146º. Threshing process was recorded using high-speed video recording camera Photron 1024 PCI (at the speed of 2000 frames per second).

Threshing of individual corn ears showed that corn ears tend to move faster during the process of threshing when linear speed of rasp bars is increased. Moreover, corn ear travel speed was found to be higher in first part of the concave when compared to its part two. Increasing linear speed of rasp bars was found to result in increased number of impacts suffered by each corn ear. Threshing studies showed that grain separation through the concave is affected by design of threshing cylinder filler plates. Grain separation through the concave is most intensive when cylinder filler plates are made with working plane angle of 36° to radius of the cylinder. Laboratory tests of individual corn ear threshing suggest that further research of rational filler plates design should be carried out with filler plates with passive plane angle to the cylinder radius should change from 51° to 67°, while working plane angle should be kept 36°.

Key words: *corn, ear, separation, cylinder, filler plates, concave*

INTRODUCTION

Corn is one of the most widely grown agricultural plant species throughout the world. The total land area cultivated with corn amounts for 178 million ha worldwide, and total corn grain production annually amounts for approximately one milliard tons. EU countries produce approx. 75 million tons of corn grains annually. In Lithuania, corn has been cultivated for the purpose of grain production only since 1995. Corn occupied areas kept growing over the last decade. Nowadays, in Lithuania land area cultivated with corn amounts for 17.2 thousand ha. The average corn grain yield amounts for 7.4 t ha^{-1} (Statistical Yearbook of Lithuania, 2014).

Harvesting of corn requires for specific conditions and fine-tuning of combine-harvester threshing apparatus. To achieve minimum loss during corn harvesting, the combine-harvester threshing apparatus, cleaning shoe and other mechanisms must undergo particular reconstructions and adjustments (Poničan et al., 2009). Performance of threshing apparatus depends on the feed rate, the concave clearance and the cylinder speed (linear speed of rasp bars). Setting well-balanced technological parameters for adjustment of the threshing apparatus not only increases throughput of the combine harvester but also improves quality indicators of threshing process: leads to reduced grain loss, grain damage and threshed grain crushing as well as improved grain separation through the concave (Špokas et al, 2013). When inside the threshing apparatus and while "floating" in the airflow caused by threshing apparatus within the concave clearance, grain suffer damage due to extra impacts (Petkevichius et al., 2008). When investigating influence of the structure of threshing cylinder on the airflow within the threshing apparatus, a rational structure of filler plates can be designed (Karitonas et al., 2013). Fitting cylinder with filler plates was found to have a positive effect on wheat grain separation through the concave and enables to reduce grain damage (Kuzin, 2005). However the shape of filler plates appropriate for corn ear threshing must be optimized. For this reason it's worth undertaking investigation of corn ear threshing enabling to find out the influence of the structure of cylinder filler plates on threshing performance and to justify further avenues of research in search for well-balanced shape of cylinder filler plates.

The aim of this work is to finding out the influence of the design of cylinder filler plates of the combine harvester on the corn ear threshing performance.

MATERIALS AND METHODS

Experimental trials were carried out in 2013–2015 at laboratory for investigation technological processes of agricultural machinery using the stationary tangential single-cylinder threshing unit (Fig. 1) containing tangential threshing cylinder (4) of 1.2 m in width and 0.6 m in diameter with eight rasp bars attached to it. It was wrapped in the concave (5) at the angle of 146º. Threshed grain was diverted to the grain collection tank (10) by the back-beater (25). Parts of the threshed grain-chaff separated through individual sections of the concave were collected in tanks (7, 8, and 9). A tray (1) equipped with the feed lever (3) was fitted to the frame of the threshing unit at 45° angle. Investigation was carried out in the threshing apparatus equipped with the concave having surface of 0.96 m^2, out of which the active separation area (that of concave grate) amounted for 69.19%. The concave clearance was set based on the determined biometric parameters of the corn ears used for the purpose of research (34 mm in front, 26 mm in the midways, and 22 mm at the end).

Working parts of the threshing units are rotated by 15 kW electric motor. Cylinder speed was controlled using a frequency transducer *Delta VFD-C2000 SERIES* and belt variator. Speed of cylinder shaft rotation was measured using a digital tachometer *Chauvin® Arnoux C.A. 1727* with the measurement range of 100÷1000 min^{-1}, and measurement error $\pm 1 \cdot 10^{-4}$ of the measured value.

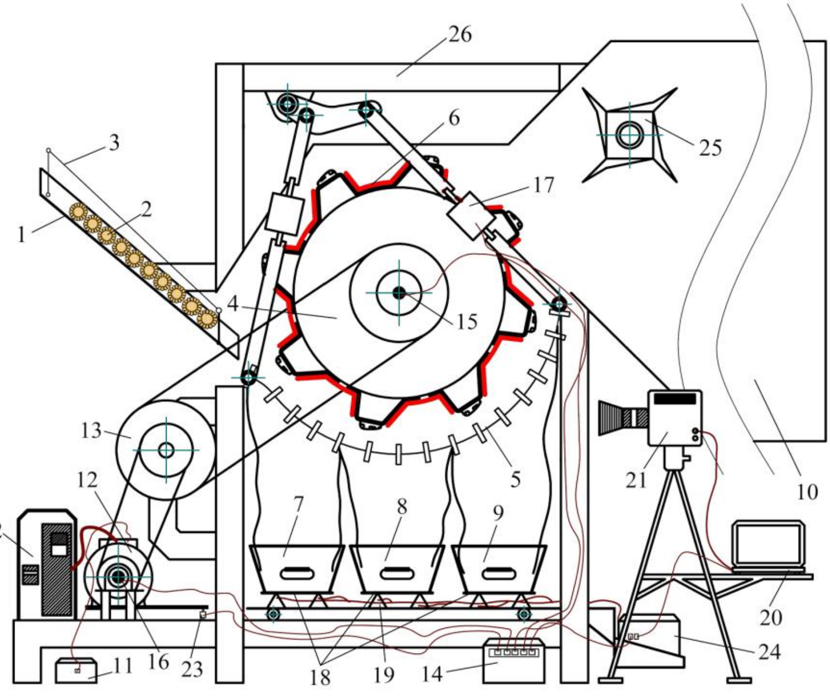

Fig. 1 The scheme of the stationary unit used for threshing corn ears: 1 – tray; 2 – corn ears; 3 – feed lever; 4 – threshing cylinder; 5 – the grate-bar type concave; 6 – threshing cylinder filler plates; 7, 8, 9, – tanks for collecting grains separated through individual sections of the concave; 10 – threshed grain collection tank; 11 – the device for measuring electric current, voltage and wattage; 12 – electric motor (15 kW); 13 – belt variator; 14 – signal inverter PIC18F2553; 15 – optical sensor of cylinder rotation frequency *Autonics E40H*; 16 – optical sensor of electric motor rotation frequency *Autonics E40H*; 17 – sensor of pressure force at the end of the concave; 18 – electronic weighing scale; 19 – tensoresistor load sensors; 20 – computer; 21 – high-speed video recording camera *Photron 1024*; 22 – frequency transducer; 23 – locking torque sensor *Scaime ZFA* 200; 24 – signal amplification and power supply unit for weighing scale; 25 – back beater; 26 – frame of the stationary threshing unit

Total 8 sets of threshing cylinder filler plates (each containing 8 plates) were produced for the purpose of investigation (Fig. 2–9). Laboratory trials were performed at different frequency of rotation of the threshing cylinder (350 and 450 min^{-1}).

For the purpose of comparative trials, stainless-steel filler plates of 8 different shapes were used with thickness of 1.5 mm, and with the mass of 2.54±0.21 kg each. They were attached by means of steel rivets. First for the purpose of investigation into corn ear threshing, the filler plates with the shape resembling the standard shape of the cylinder spaces between adjacent rasp bars (Fig. 2), the filler plates with the working planes having angles of 55° to the radius of the cylinder (Fig. 3), and the filler plates with the working planes having angles of 36° to the radius of the cylinder (Fig. 4) were made.

Fitting threshing cylinder with filler plates with the shape resembling the standard shape of the spaces between rasp bars increases its mass resulting in increased moment of inertia: from 8.49 kg m^2 to 9.62 kg m^2. The threshing unit concerned (Fig. 2) uses standard cylinder with the cross-section area of one space between rasp bars amounting for 95.94 cm^2, whereas the same cross-section area amounts for only 87.05 cm^2 after the filler plate is fitted (Fig. 2), meaning the area is reduced by 9.27%.

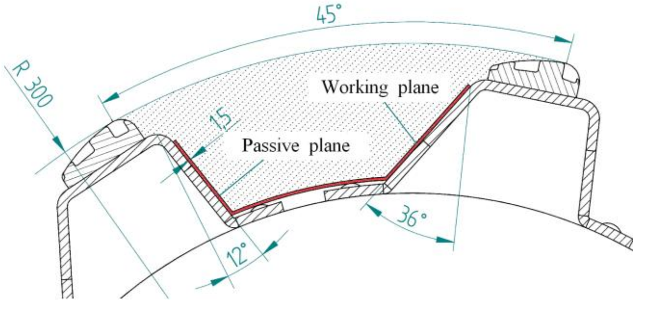

Fig. 2 Fragment of the threshing cylinder fitted with filler plates with the shape resembling the standard shape of the spaces between rasp bars (spaces between rasp bars covered with filler plates 0)

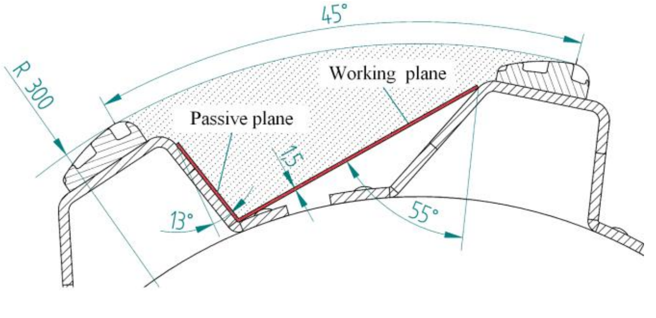

Fig. 3 Spaces between threshing cylinder rasp bars covered by filler plates I

Fitting threshing cylinder with filler plates, working plane whereof formed 55° angle to the cylinder radius, the cross-section area of one space between rasp bars was found to decrease from 95.94 cm^2 to 79.13 cm^2, i.e., by 17.52%. The passive surface of threshing cylinder filler plate formed 13° angle to the cylinder radius (Fig. 3).

Fitting threshing cylinder with filler plates, working plane (contact surface) whereof formed 36° angle to the cylinder radius, the cross-section area of one space between rasp bars was found to decrease from 95.94 cm^2 to 75.69 cm^2, i.e., by 21.12% (Fig. 4).

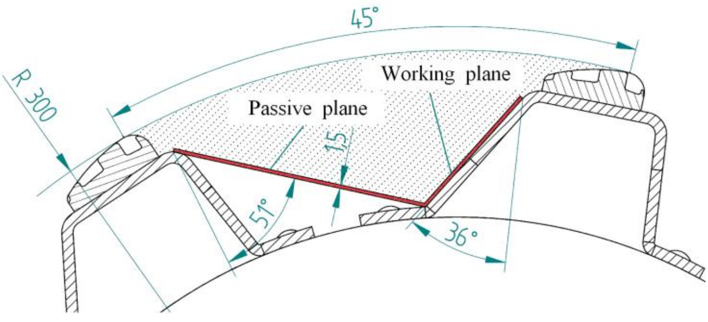

Fig. 4 Spaces between threshing cylinder rasp bars covered by filler plates II

Another 5 novel sets of threshing cylinder filler plates were produced with variable angles of working (contact surface) and passive planes to the cylinder radius and widths of planes. Variation of these parameters caused significant changes in cross-section areas of a single space between rasp bars. The length of filler plates was matched to the threshing cylinder length, i.e., amounted for 1.2 m.

Fitting threshing cylinder with filler plates, working plane (contact surface) whereof formed 36° angle to the cylinder radius, and width of the plane amounted for 42 mm, the cross-section area of a single space between rasp bars was found to decrease from 95.94 cm^2 to 64.68 cm^2, i.e., by 32.58% (Fig. 5). The passive plane of the threshing cylinder filler plate formed 60° angle to the cylinder radius, width of the plane amounted for 127 mm.

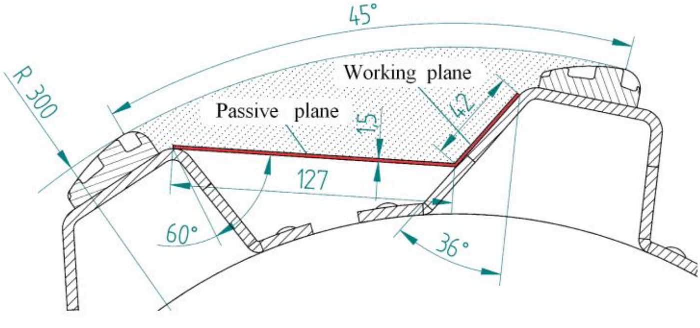

Fig. 5. Spaces between threshing cylinder rasp bars covered by filler plates III

Fitting threshing cylinder with filler plates, working plane (contact surface) whereof formed 36° angle to the cylinder radius, and width of the plane amounted for 21 mm, the cross-section area of a single space between rasp bars was found to decrease from 95.94 cm^2 to 54.22 cm^2, i.e., by 43.49% (Fig. 6).

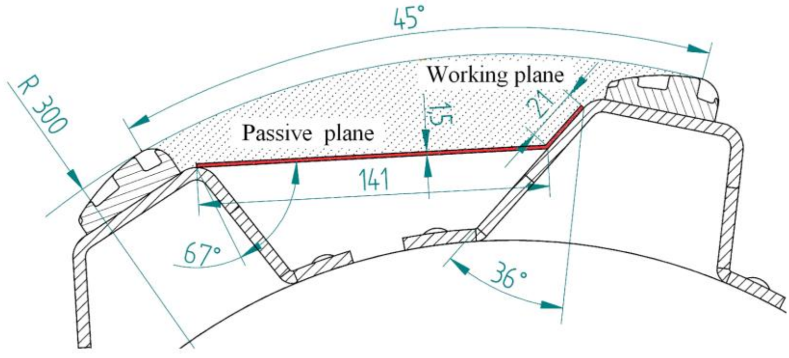

Fig 6 Spaces between threshing cylinder rasp bars covered by filler plates IV

Fitting threshing cylinder with filler plates, working plane (contact surface) whereof formed 55° angle to the cylinder radius, and width of the plane amounted for 86 mm, the cross-section area of a single space between rasp bars was found to decrease from 95.94 cm^2 to 66.72 cm^2, i.e., by 30.45% (Fig. 7).

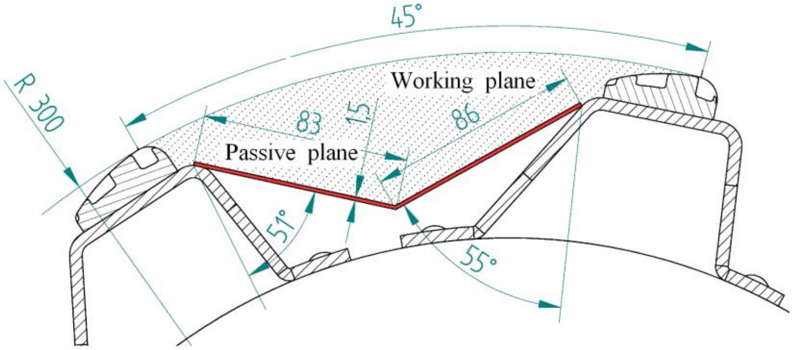

Fig 7 Spaces between threshing cylinder rasp bars covered by filler plates V

Fitting threshing cylinder with filler plate, working plane (contact surface) whereof formed 45° angle to the cylinder radius, and width of the plane amounted for 73 mm, the cross-section area of a single space between rasp bars was found to decrease from 95.94 cm^2 to 71.67 cm^2, i.e., by 25.30% (Fig. 8).

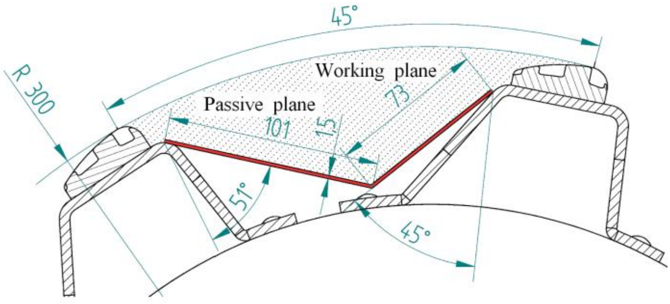

Fig. 8 Spaces between threshing cylinder rasp bars covered by filler plates VI

Fitting threshing cylinder with filler plates, working plane (contact surface) whereof formed 45° angle to the cylinder radius, and width of the plane amounted for 50 mm, the cross-section area of a single space between rasp bars was found to decrease from 95.94 cm^2 to 62.71 cm^2, i.e., by 34.64% (Fig. 9).

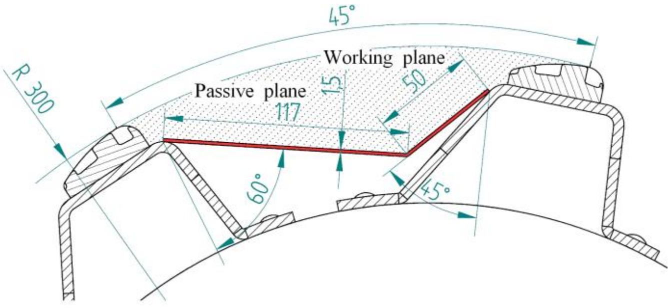

Fig. 9 Spaces between threshing cylinder rasp bars covered by filler plates VII

For the purpose of finding the optimal shape of filler plates, laboratory trials were performed that involved threshing of corn ears in series of 10 units. During trial a tray with the feed lever raised was filled with 10 pre-selected and weighed corn ears. After turning the threshing unit on and setting pre-defined threshing cylinder speed, lever is lowered causing corn ears to run into the threshing unit (Fig. 1). When corn ear threshing is completed, non-threshed individual grains are separated from ear piths and weighed separately. Afterwards, all the ear piths and leaves are weighed altogether. Knowing total mass of corn ears prior to threshing, mass of non-threshed grains and mass of threshed-out corn ear piths and leaves, enables to find out the percentage of non-threshed grains. Each threshing trial under pre-define threshing cylinder speed is performed for 5 times with each of 8 sets of custom-produced threshing cylinder filler plates. Trials served to find out the percentage of non-threshed grains.

Threshing process was recorded using high-speed video recording camera *Photron 1024 PCI* (at the speed of 2000 frames per second), and photos obtained during each trial were saved to the computer and analyzed afterwards while calculating number of impacts suffered by the corn ear at the first and part two of the concave by length. Corn ear travel speed over the surface of the concave was found in these parts as well.

Analysis of corn ear travel over the surface of the concave was performed having the threshing cylinder fitted with filler plates of the shape resembling the standard shape of the spaces between adjacent rasp bars (filler plates 0) (Fig. 2), and with filler plates the working plane whereof formed 36° angle to the cylinder radius (filler plates II) (Fig. 4). Each trial was repeated 5 times. Measurement data was assessed through computing a confidence interval on the mean under the 95% probability

RESULTS AND DISCUSSION

Corn ears featuring similar biometric properties were selected for the investigation (Table 1). Corn ears of *Rodni* species were threshed in the threshing unit concerned at their physiological maturity stage with the grain moisture content of 22.99±0.60%, of ear piths of 48.02±6.11%, of corn ear covering leaves 23.09±6.71%, and of panicles 29.95±8.33%. Total mass of ten corn ears was in range of 2097.6±20.4 g during entire investigation.

Table 1 Biometric parameters of corn ears

Parameters	Total ear weight g	Max ear diameter mm	Ear length mm	No of vertical line	No of horizontal lines	Grain number per ear	Grain weight g
Mean with confidence interval	225.14 ±12.36	46.89 ±0.79	173.56 ±3.55	13.77 ±0.41	35.47 ±0.98	476.70 ±18.36	159.61 ±10.78

The speed of crop flow movement over the surface of the concave depends on cylinder speed, i.e., on linear peripheral velocity of threshing cylinder (Miu and Kutzbach, 2007). Moreover, corn ear travel speed over the surface of the concave and number of impacts suffered within the threshing unit depends on feed rate and orientation of ears (Petkevichius et al., 2008). Different cylinder speed as well as linear peripheral cylinder velocity is recommended for threshing different types of crops. Experimental research shows that linear peripheral velocity of threshing cylinder must amount for 24–35 m s^{-1} when threshing wheat, 14–24 m s^{-1} for rapeseed, and 10–20 m s^{-1} for corns (Miu, 2015).

To find the speed of corn ear travel over the surface of a concave and number of impacts per corn ear suffered during the threshing process trials were performed that involved threshing of corn ears in series of 10. These trials were performed at the rasp bar linear speeds of 11.0 m s^{-1} (cylinder rotation speed n=350 min^{-1}), 14.1 m s^{-1} (n=450 min^{-1}) and 17.3 m s^{-1} (n=550 min^{-1}). Statistical processing of data captured by high-speed video recording camera resulted in observation that in majority of cases, during the process of threshing, corn ears tend to move faster through first part one of the concave when compared to its part two (Fig. 10). It also revealed the speed of corn ear travel to be lower when filler plates II are used when compared to covered spaces between rasp bars with filler plates 0. However, for most cases this difference was negligible.

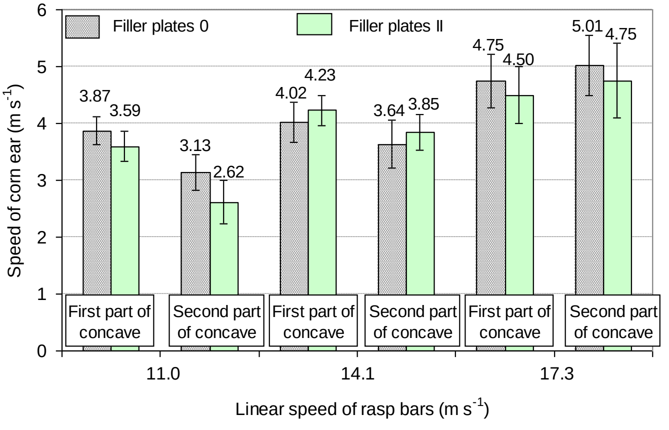

Fig. 10. The speed of corn ear travel over the surface of the concave depending on the linear speed of rasp bars

Trials showed that corn ears tend to suffer more impacts in the part one of the concave when compared to the second one (Fig. 11). This tendency was found to persist even under varied shape of filler plates and cylinder speed (i.e. linear speed of rasp bars). The number of impacts per corn ear was found to increase together with the increasing linear speed of rasp bars.

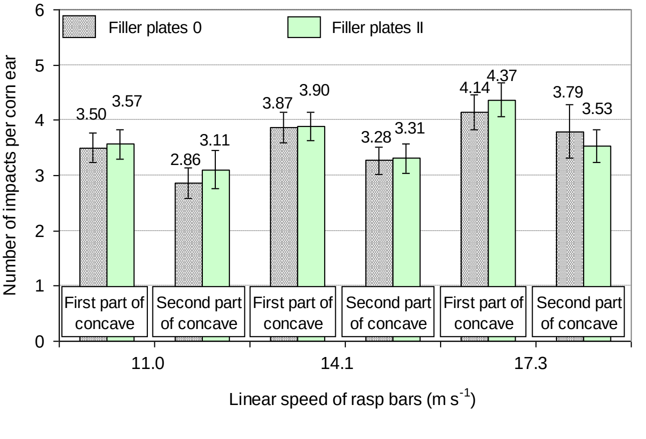

Fig. 11. The number of impacts per corn ear at different linear speeds of rasp bars

When trials were performed at threshing cylinder speed of 350 min^{-1}, percentage of non-threshed grains was found to increase significantly. With spaces between cylinder rasp bars being covered with filler plates I and V, and using filler plates of the shape resembling the standard shape of rasp bars (filler plates 0), the grain loss from threshing exceeded the limit of 6%. In these cases grain losses were as follows: 6.69±0.64%, 6.16±0.41% and 6.45±0.45%, respectively. Using the rest of filler plates for threshing resulted in lower grain losses; however they still amounted for approximately 4.5%.

Corn ear threshability trials at cylinder speed of 450 min^{-1} showed that the highest threshability of corn ears was achieved when using threshing cylinder with filler plates III and IV (Fig. 12). They showed no critical reciprocal difference, whereas percentage of non-threshed grains amounted for as little as 0.40±0.11% and 0.26±0.17%, respectively.

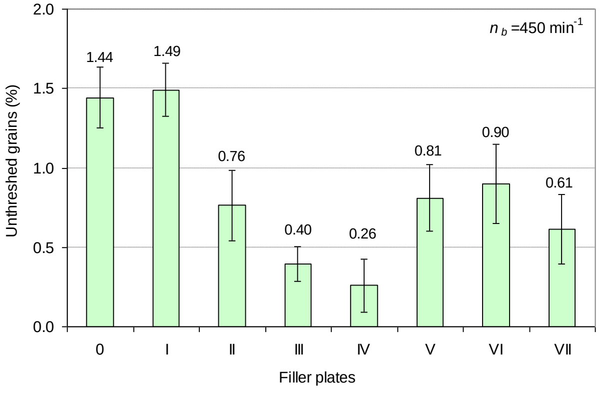

Fig. 12 The influence of filler plates design on corn threshability

The lowest threshability of corn ears was achieved using threshing cylinder with filler plates I and using threshing cylinder with filler plates resembling standard shape of spaces between rasp bars (filler plates 0). For the latter cases percentage of non-threshed grains was above one percent and amounted for 1.49±0.17% and 1.44±0.19%, respectively (Fig. 12).

CONCLUSIONS

1. Trials of threshing individual corn ears showed that corn ears tend to move faster during the process of threshing when linear speed of rasp bars is increased. Moreover, corn ear travel speed was found to be higher in part one of the concave when compared to its part two. Increasing linear speed of rasp bars was found to result in increased number of impacts suffered by each corn ear.
2. Maintaining the angle of working plane to the radius of the concave constant (36°), and increasing angle of the passive plane from 13° to 67°, while at the same time reducing cross-section area of each filler plate from 95.94 cm^2 to 54.22 cm^2 (of individual space between rasp bars) results in better threshability of corn ears.
3. Based on the findings of laboratory trials that involved threshing of individual corn ears, it’s true to state that further studies in search for optimal shape of cylinder filler plates should involve filler plates with the passive plane at angle to cylinder radius being in range of 51° to 67°, while maintaining angle of working plane constant (at 36°).

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44. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

UDC 633.333
Stručni rad
Expert paper

MATHEMATICAL MODELLING OF GRANULATED FERTILIZERS DISTRIBUTION BY CENTRIFUGATION

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SUMMARY

This paper presents a mathematical model for process management, based on researches in the field performed at world level and models used up to present for identifying the uniformity function of distribution, that can be considered as main element in modelling the working process of distribution apparatus; thus three hypotheses were established first the fertilizer particle material was considered as a non-particle "point"; second hypotheses there are two trajectories considered as having the greatest influence on the process: moving the disc along the blade and moving in the air until the particle leaves the disc; and last when the radial coordinate value in relation to the Cartesian coordinate system, Oxyz, becomes equal to the disk radius distribution. Based on these hypotheses was established the mathematical model which takes into consideration the relationships between design parameters of the machine distribution and the material used for administration, these relations having logical-mathematical and theoretical foundations in classical mechanics; the model allows to establish the size distribution of apparatus and the operating parameters, increase the coefficient of friction leading to longer stopping particle disk. The initial position of the particle before reaching the separation distance influences the position of particles on soil, directly influence the distribution of chemical fertilizers.

***Key words**: fertilizers, distribution, uniformity, soil, quality*

INTRODUCTION

Worldwide there is an increasing human consumption of organic products, free of harmful compounds. Organic production is an overall system of farming management and food production that combines best environmental practices and use of natural resources, ensuring a high level of biodiversity.

In order to reduce the polluting effects, substantial efforts are taken both for safely storing fertilizers products, maintaining their initial physicochemical characteristics and achieving performance technical distribution equipment.

Because Romanian agricultural equipment needs to be in accordance with internal and external market, it must have competitive technical characteristics and be manufactured at a high quality level, these objectives being a forefront issue in obtaining a high economic efficiency. [10, 11]

The equipment for distribution of granulated fertilizers by centrifugation is being subjected to continuous changes, even at the present, due to ongoing research on rationalizing the fertilizer applying, in order to ensure the requirements of nutrients of plants, so as to stop the excessive distribution which, over the time, is detrimental to the environment and therefore to the health of people and animals. [9,10, 11]

To ensure the distribution of various types of granulated fertilizer with different physical and chemical characteristics, recommended by the agro-qualitative conditions, specific to each crop, and to provide a wide range of distribution rules, the machine that carries out the fertilization work comprises constructive elements with adjustment possibilities (for example, disc blades, adjustable metering flap, etc.). [6,12, 13]

The movement of material particles on the disk surface is influenced by the structural characteristics of devices with centrifugal distribution, by their shape (a disc and blades) and the area where the particles fall on the disk. [8,9]

The uniformity of distribution of the material particles on the surface of the ground is only achieved if the particles are transmitted by the disc elements a certain initial launching speed of different directions in comparison with the aggregate direction of travel. The speed of particles leaving the disc and their launching directions depend on the position of the feeding disc, as well as, the duration of material particles movement on the surface of the spreader disc [5,8,9].

The mode of movement of the particles on the surface of the disc and the duration of movement of the material particles depend on the following factors [5]:

- The design of the distribution apparatus: one or two discs;
- Diameter disc (s) and the inclination of the disc surface;
- Structural characteristics of the blades (length, radius of curvature, profile), the number of blades and their position relative to the disk radial direction.

Another influencing factor is the height above ground of the disks in the composition of the distribution apparatus.

For the carried equipment the unit height can be adjusted in comparison with the soil by acting the 3-point linkage mechanism of the tractor, thus changing the distribution parable.

Quality of work is influenced by the following disturbing factors:

- The unevenness of the land and / or changes in the speed of the unit.
- Weather conditions, namely wind speed> 5 m / s and humidity> 90% which over these limits do not allow to obtain a high quality work;

- Operator who must maintain a constant engine speed, the forward direction on the ground surface (defined by landmarks placed at each end of the parcel) has to make appropriate adjustments concerning the parts of the machine in order to achieve the optimal spreading uniformity of the material on soil surface;
- Physical and mechanical properties of fertilizers such as natural slope angle, aggregation state, wettability etc. They are taken into account in the design and construction of hopper, agitator and distribution apparatus for choosing technical solutions able to ensure a constant flow and steady distribution of fertilizers, utilization of technologies based on GPS according to EU standards/regulations (ex: D 2009/128/EC).

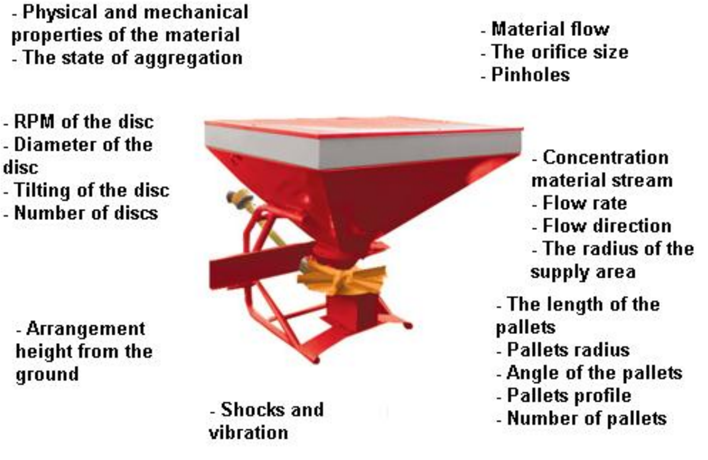

Fig. 1 - Factors that influence the working process executed by mineral fertilizer spreaders by centrifugation

MATERIALS AND METHODS

Simplified mathematical model for the distribution of particulate matter is the material point, which first moves on fixed surface, having guidance role (blade disks) and then on upper surface, after which it moves freely in the gravitational field in the air. Obviously, approximation of a fertilizer particle to a material point is accompanied by an abstraction that automatically leads to errors. Material particles applied have, in our case a fairly regular shape, namely spheroid, which is an argument used to approximate the dynamics of material point in the movement of these particles. In addition, their sizes are quite small (0.001 ... 0.007 m) and this is another argument in favour of the election, their rotation in space being negligible for now. If the fidelity of the mathematical model is not good enough in relation to the physical model we can study higher models in terms of complexity: model of rigid solid, deformable solid or fluid models with certain properties.

Therefore, a movement of fertilizers on rotation crop land is accompanied by random phenomena: the fall in fixed surface of the disc from feeder on random positions and at different speeds, collisions between particles, clashes between particles and land surface, forms and masses more or less different, phenomena related to state fertilizer (humidity, cohesion, natural slope angle etc). This high level of uncertainty has led to the idea of choosing a simplified mathematical model for the beginning.

Following the above reasoning, we used for mathematical modelling equations of material point dynamics. For simplicity we divided the path of the material point (particle of fertilizer) into two parts: the first part consists of a curved surface to run (disc with blades), the second part consists of a parabolic one described in the air. The two movements are studied separately considering that particle position and speed at the end of motion should be the initial conditions of motion for the second path.

In this way, through the mathematical model chosen it was possible to establish relationships between the input parameters of the process (speed work, mass of distributed particles, angular velocity of the disk, speed, friction coefficients between particles and surfaces of distribution and output parameters (coordinates of locations where particles lay in the soil), data which will constitute the starting elements for assessing the uniformity of material spread. In this study phase, mathematical model will be extended to all areas distributing material (two discs) as the final distribution of the material after the passage of fertilizer applying machine results from the interaction of distribution areas of material scattered by each distribution surface.

To validate the mathematical model and capitalize it for defining relationships between input parameters and some output parameters, it is used a so-called simulation program, namely a numerical analysis based on the mathematical model developed in Mathcad; not all the equations can be solved analytically, thus numerical solutions are required by simulation. In this case the equations of motion on disc are solved analytically and those in gravitational field are to be solved numerically by a Runge-Kutta scheme.

The simplest theoretical model of particles motion in the process of the distribution of chemical fertilizers in the field can be obtained using the dynamics of the material point. This type of modelling is not new, as noted, tests of this type being numerous in the area [1, 2, 6, 13, 14]. This model is based on the set of initial data defining the particles containing at their turn, information about the geometry of the distribution / release apparatus (the diameter of the disc, the lengths of blades, the height to the ground of the disc) information on its kinematics (angular velocity of the disc) data on machine travel regime(working speed), information on the characteristics of the material spread (mass, geometry) and data on this material contact with the distribution apparatus of the machine (friction between particle and disk, blades, air friction air, air density).

RESULTS AND DISCUSSION

According to the literature we shall use the following assumptions:

I1) fertilizer particle can be considered as material point (we neglect its rotational movements in space);

I2) trajectory can be studied on two distinct portions where the particle is influenced by different resistance forces to forward movement: moving on the disc along the blade, moving in the air until reaching the soil;

I3) it is considered that the particle leaves the disc when its radial coordinate value in relation to the Cartesian coordinate system, Oxyz becomes equal to the distribution disk radius (criterion of escaping the particle from the disk)

In order to monitor the fertilizer particle in space it is considered the absolutely fixed system Oxyz , originated somewhere on the ground, initially on the machine rear axle at the intersection of the longitudinal axis of the machine and the ground projection of line of rotors / discs centres, the Ox axis being oriented to the longitudinal axis of the machine and with the positive sense in the direction of travel of the vehicle; Oy-axis, parallel to the axis of rotors centres has the direction towards left of the machine as seen from the rear, and the OZ axis is perpendicular to the two and has the direction opposite to gravity acceleration.

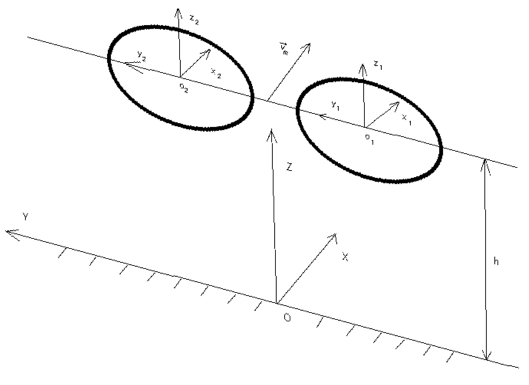

Fig. 2 Representation of Oxyz coordinate system

It is considered the reference systems which are mobile cohesive united to the machine, with origins O1 and O2 in distribution discs and axes O1x1 and O2x2 permanently parallel to the Ox axis of the absolute reference system and axes O1y1 and O2y2 permanently parallel to the axis Oy of absolute reference system O1z1 and axes O2z2 permanently parallel to the axis Oz of absolute reference system.

Reference links between local and global system are:

$$\begin{cases} X = x_1 + v_m t \\ Y = -\delta + y_1 \\ Z = h + z_1 \end{cases} \tag{1}$$

wherein v_m is the working speed; t is the travel time; δ is the distance from the hub to the machine axis; h is the height of the centre of the disc to the ground.

For the right rotor seen from the rear of the machine (Figure 2)

$$\begin{cases} X = x_2 + v_m t \\ Y = \delta + y_2 \\ Z = h + z_2 \end{cases} \tag{2}$$

For simplifying, the dynamic equations will be studied for a particle thrown by the distributor to the right (disc 1) to the left (disk 2) the trajectories being simply obtained by translation along and a mirror conversion to the plane XOZ.

According to the hypothesis 12 we shall study in the first stage the particle movement on the disc. I2 hypothesis is taken from [2.6] and particle motion can be described according to parametric equations of motion on each axle:

$$\begin{cases} x = r(t)\cos\omega t \\ y = r(t)\sin\omega t \\ z = \phi \end{cases} \tag{3}$$

wherein: ω - angular velocity ϕ - the particle diameter of the spheroidal

The differential equation of fertilizer particle motion along the blade is a radial movement mathematically modelled by differential equation of a material point in a durable medium under the influence of centrifugal force and simultaneously the action of the Coriolis force [2.6]

$$\ddot{r} + 2\mu\omega\dot{r} - \omega^2 r = -\mu g \tag{4}$$

wherein: μ - coefficient of friction between the material and the disk surface particle: 0.42 ... 0.81, g - *gravitational acceleration.*

Initial conditions:

$$\begin{cases} r(0) = R \\ \dot{r}(0) = 0 \end{cases} \tag{5}$$

By integrating the general solution is obtained for radial displacement:

$$r(t) = C_1 e^{\lambda_1 t} + C_2 e^{\lambda_2 t} + \frac{\mu g}{\omega^2} \tag{6}$$

The radial velocity:

$$\dot{r}(t) = C_1 \lambda_1 e^{\lambda_1 t} + C_2 \lambda_2 e^{\lambda_2 t} \tag{7}$$

Taking into account the initial conditions (5) and (6) and (7) equations (8) and (9) are obtained

$$r(0) = C_1 + C_2 + \frac{\mu g}{\omega^2} = R_1 \tag{8}$$

$$\dot{r}(0) = \lambda_1 C_1 + \lambda_2 C_2 = 0 \tag{9}$$

wherin: R - Minimum and maximum range of the blade

Solving equations (8) and (9), the solution for the equation of radial movement of the fertilizer particle is:

$$r(t) = \frac{R_1 - \frac{\mu g}{\omega^2}}{1 - \frac{\lambda_1}{\lambda_2}} e^{\lambda_1 t} + \frac{R_1 - \frac{\mu g}{\omega^2}}{1 - \frac{\lambda_2}{\lambda_1}} e^{\lambda_2 t} + \frac{\mu g}{\omega^2} \tag{10}$$

in which:

$$\lambda_{1,2} = \frac{-2\mu\omega \pm \sqrt{4\mu^2\omega^2 + 4\omega^2}}{2} = -\mu\omega \pm \omega\sqrt{1+\mu^2} = \omega(-\mu \pm \sqrt{1+\mu^2}) \tag{11}$$

(11) is obtained for example by algebraically using Laplace transformation technique for the differential equation (4), [12]

Then the movement of particle on the disk under absolute reference coordinate system is:

$$\begin{cases} X = r(t)\cos\omega t + v_m t \\ Y = -\delta + r(t)\sin\omega t \\ Z = h + \phi \end{cases} \tag{12}$$

According to the hypothesis 13) the condition of leaving the disc can be written:

$$r(t) = R_2 \, . \tag{13}$$

Solving equation (13) where the function r (t) is given by equation (10) the time t* moment is obtained, when the particle leaves the disc. Given that the initial moment of movement on the disc is t = 0, t* will be movement duration on disk.

Graphs of the movement components on disk in local reference system

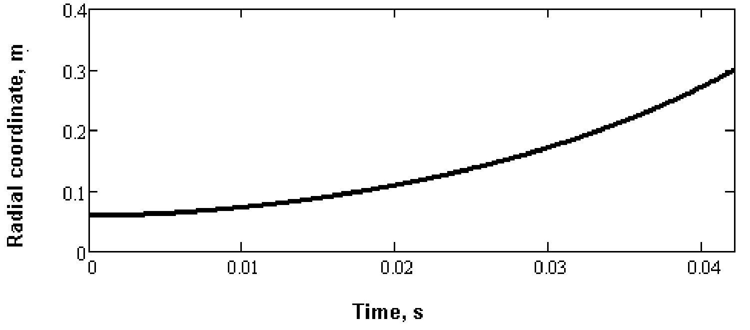

Fig. 3 Time variation of radial coordinates on disc [16]

In figure 3 it is shown the time variation of the coordinate on disk within the time interval between initial moment and detaching moment from the disc, t_{des}, calculated as provided in I3 and having value for machine dimensions MIA 10 [11,15] 0,043 s.

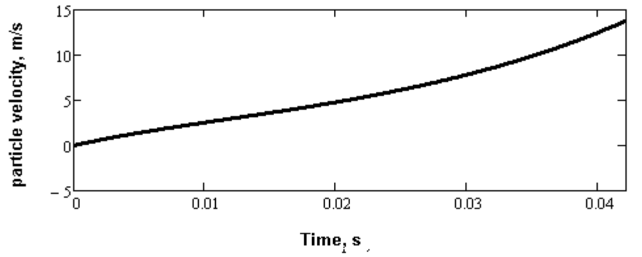

Fig 4 Time variation of particle velocity disk

In Figure 4 is represented the time variation of particle on the disk within the interval between the initial moment and the moment of separation, t_{des}.

It is noted that both radial coordinate and radial velocity are monotonously increasing and have nonlinear growth, and which is interesting is that the particle velocity increases more in the last part of the curve. This observation is obvious if one appeals to plotting the radial acceleration of the particle given in Figure 5.

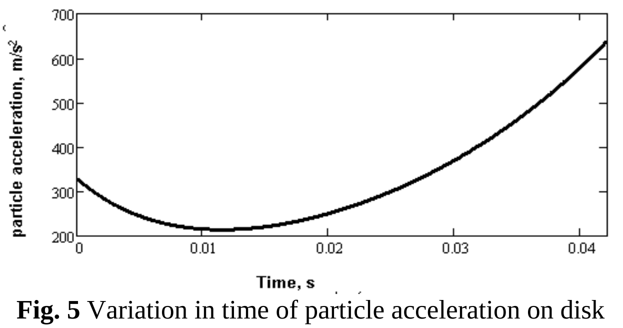

Fig. 5 Variation in time of particle acceleration on disk

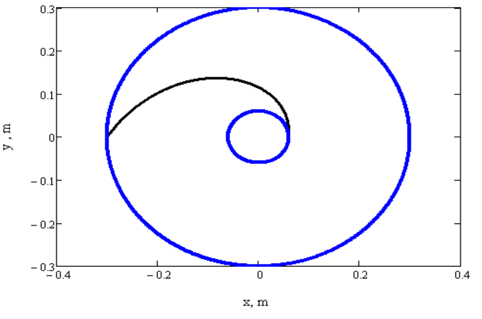

Fig. 6 The trajectory of a fertilizer particle on Disc 1

In Figure 6 is shown the trajectory of the fertilizer particles on the disc 1, whose coordinates are given in Fig. 2.

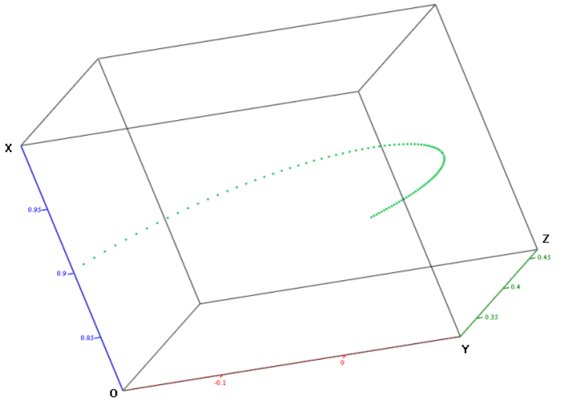

Fig. 7 The particle trajectory from a disk in space

CONCLUSIONS

Besides the knowledge of the design of the existing equipment, improving the capacity of specialists who experience new products for determining the properties of the materials used, working parameters of the machinery, working conditions, requirements prescribed by agro-technique, all are of a particular importance.

In construction of the machines manufactured worldwide the control of working process is automatically performed by means of control systems, which enable establishing the working parameters (speed, level of fertilizer in hopper, flow of fertilizer) and monitor the area worked (based on forward speed and working width).

In our country perspective objectives on construction of machinery of fertilizer applying are in accordance with those of the world.

Factors which influence the working process of the centrifugal distribution with discs of machines applying mineral granulated fertilizers, are: diameter of the disk, the radius of the minimum power, the length and shape of the blade (straight or curved), the angle of inclination of the blade to the radial direction, the flatness or cone-shaped character of the disc surface.

Among the numerical simulations presented in this article, the structural and functional parameters which directly influence the distribution of chemical fertilizers are to be mentioned:

- Size of distribution apparatus and the operating parameters (disc diameter and length of the blades, the distance from the ground to disc, disc rotation frequency, the coefficient of friction between the material and disc, material starting position).
- Increase of friction coefficient has led to longer stopping the particle on disk;
- The initial position of the particle before the separation has influenced the distance reached by particles on soil;
- Friction coefficient to some extent has influenced the distribution, but less than expected;
- Mathematical model may undergo improvements over the time, sometimes initial conditions having errors because the process of taking over the fertilizer particles by disc has a random character.

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44. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

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VERTIKALNA RASPODJELA ZRAČNE STRUJE KOD RASPRŠIVAČA AGP 200 ENU I TIFONE VENTO 1500

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SAŽETAK

U radu su prikazani rezultati testiranja vertikalne raspodjele zraka po visini usmjerivača na lijevoj i desnoj strani kod dva raspršivača. Ispitivanja su obavljena na raspršivačima tvrtke Agromehanika AGP 200 ENU i raspršivača Tifone Vento 1500. Raspršivač tvrtke Agromehanika AGP 200 ENU posjeduje aksijalni ventilator promjera 585 mm, a Tifone Vento 1500 ima promjer ventilatora 810 mm. Kod oba raspršivača ventilatori posjeduju 8 lopatica koje se mogu postaviti u 5 različitih zakošenja. Raspršivač AGP 200 ENU pri brzini vrtnje vratila traktora od 180 min^{-1} i pri ukošenju lopatica na položaju „1“ ostvario je prosječnu brzinu zraka po visini usmjerivača na lijevoj strani od svega 2,81 m/s dok je raspršivač Tifone Vento 1500 ostvario je prosječnu brzinu zraka od 2,17 m/s. Na desnoj strani raspršivača AGP 200 ENU pri istim uvjetima utvrđena je prosječna brzina zraka od 2,46 m/s, a kod raspršivača Tifone Vento 1500 iznosila je 2,36 m/s. Povećanjem broja okretaja vratila traktora na 540 min^{-1} uz isto zakošenje lopatica (položaj 1) ostvarena je prosječna brzina zraka kod AGP 200 ENU, na lijevoj strani od 7,99 m/s i 9,84 m/s na desnoj strani stroja. Raspršivač Tifone Vento kod 540 okretaja vratila traktora uz maksimalno zakošenje lopatica na položaju „5“ ostvario je prosječnu brzinu zraka na izlaznom sustavu od 16,02 m/s na lijevoj strani i 16,72 m/s na desnoj strani. Raspršivač AGP 200 ENU pri 540 okretaja vratila traktora ostvario je prosječnu brzinu zraka na lijevoj strani usmjerivača od 17,46 m/s. Na desnoj strani utvrđena je prosječna vrijednost od 17,96 m/s.

Ključne riječi: *raspršivač, aksijalni ventilator, brzina zraka, vertikalna raspodjela zraka*

UVOD

Razvoj strojeva i uređaja u suvremenoj aplikaciji pesticida direktno doprinosi povećanju proizvodnje hrane, ali i značajno doprinosi narušavanju ekosustava. Tehnološki napredak tehničkih sustava u zaštiti bilja ponekad ne doprinosi smanjenju narušavanja ekosustava radi sve veće potrebe za hranom rastućeg svjetskog stanovništva u slaborazvijenim dijelovima svijeta. Ograničena aplikacija pesticida podjednako je važan čimbenik također i iz ekonomskih razloga, kao udio u smanjenju inputa u uvjetima intenzivne proizvodnje. Da bi smo podigli razinu preciznosti aplikacije, a time i potpune djelotvornosti postupaka zaštite, tehnički sustavi (prskalice, raspršivači) moraju biti konstrukcijski i eksploatacijski ispravni. S obzirom na navedene činjenice, u zemljama EU uvedeni si pravilnici obaveznog pregleda tehničkih sustava u zaštiti bilja direktivom *2009/128/EC i 2006/42/EC*, kojima je temelj standard *EN 13790.* Ni Republika Hrvatska u tome pogledu ne zaostaje, a sve je to pravno popraćeno donošenjem Zakona o održivoj uporabi pesticida (*NN14/2014*) i pravilnika o održivoj uporabi pesticida (*NN 142/2012*). Republika Hrvatska već dvije godine uspješno provodi obavezno testiranje tehničkih sustava sa 11 službeno odobrenih ispitnih stanica. Njihovim radom osim eksploatacijske neispravnosti kod većeg broja tehničkih sustava za zaštitu bilja uočen je veći broj nedostataka u samoj konstrukciji radi starosti sustava koji i te kako utječu na cjelokupni postupak zaštite bilja. Kako cjelokupna svjetska tehnologija napreduje tako napreduju i tehnički sustavi u zaštiti bilja. Dostupni su različiti oblici raspršivača sa različitim tehničkim izvedbama ventilatora, usmjerivača zraka, položaja mlaznica i ostalog. Isto tako koriste se raspršivači sa aksijalnim i radijalnim ventilatorom, raspršivači sa tangecijalnim usmjerivačima, raspršivači sa fleksibilnim vodovima i drugim novijim tehničkim rješenjima. Uz eksploatacijsku i tehničku ispravnost radnog stroja u zaštiti bilja posebice je važno pravilno podesiti parametre prskanja kao brzinu rada stroja, radni tlak, količinu zraka, količinu tekućine po jedinici površine i tip mlaznice. Samo sinergija pravilno podešenih čimbenika prskanja i konstrukcijska odlika stroja daju adekvatne rezultate. Često se dešava da iako poznajemo čimbenike prskanja, ali radi loše izvedbe u konstrukciji nekih sustava prihvatljivu aplikaciju ne možemo ostvariti. Najčešća konstrukcijska neispravnost uočena je kod sustavu vertikalne raspodjele zraka u usmjerivačima. Neravnomjerna vertikalna raspodjela zraka znatno utječe na smanjenu pokrivenost površine lista, pojavu zanošenja kapljica, povećane potrošnje zaštitnog sredstva, povećanu potrošnju vode po jedinici površine, slabo prodiranje zaštitnog sredstva u krošnju te niz drugih negativnih utjecaja koje dovode do opetovane pojave bolesti.

Zadatak ispitivanja je primjenom standardnih metoda utvrditi vertikalnu raspodjelu zračne struje kod raspršivača *AGP 200 ENU* i raspršivača *Tifone Vento 1500.* Na temelju dobivenih znanstvenih rezultata doći do saznanja koje su to vrijednosti te njihova raspodjela po visini usmjerivača zračne struje kako bi se u radu ostvarila najbolja površinska i vertikalna raspodjela škropiva u trajnom nasadu.

DOSADAŠNJA ISTRAŽIVANJA I TRENUTNO STANJE

Protok i brzina zraka raspršivača važni su tehnički čimbenici zaštite u trajnim nasadima. Oni direktno potpomažu dezintegraciju mlaza te omogućuju stvaranje sitnijih kapljica (hidropneumatska dezintegracija), koje potpomažu u transportu te ih usmjeravaju prema cilju prskanja. Randall (1971) navodi da brzina zraka ventilatora pri zaštiti trajnih nasada mora biti veća od 12,2 m/s. Isto tako Svensson (2001) navodi da je povećana brzina zraka na izlaznom dijelu usmjerivača raspršivača preduvjet za bolji depozit i pokrivenost lisne površine unutar krošnje. Kod mladih trajnih nasada gdje je mala lisna površina povećavanje brzine zraka kako navodi Landers i sur., (2004) ne ostvaruje se povećanje pokrivenosti objekta prskanja nego dolazi do povećanja zanošenja kapljica (drift). Navedeni autor također navodi da se smanjivanjem brzine zraka za 25% kod mladih trajnih nasada povećava srednji volumni promjer kapljica za 31%. Na taj se način osigurava optimalna pokrivenost lisne površine te smanjeno zanošenje kapljica. Za nasade koje imaju bujnu krošnju i za one koji su u kasnijim razvojnim stadijima, treba koristiti strojeve koji mogu proizvesti veću brzinu i protok zraka. Banaj i sur. (2010) preporučuju testiranje strojeva prema maksimalno ostvarenoj brzini i protoku zraka za pojedini trajni nasad. Isti autori navode kod testirana tri različita aksijalna raspršivača *Tifone Vento, Myers N1500 i Hardi Zenit,* da je *Hardi Zenit* ostvario najveći protok zraka od 44.590 m^3/h. Jedan od problema, kako navodi Fox i sur., (1992), kod brzine zraka je u tome što energija zračne struje slabi udaljavanjem od izlaza ventilatora pa je na udaljenosti do 3,5 m manja za oko 60 %. Često se događa da kod uzgojnih oblika koji su visine 3 do 4 m optimalna brzina zraka ne dolazi do vršnih grana. Pokrivenost lisne površine vršnih dijelova krošnje je relativno mala te štetnici prežive djelovanje upotrijebljenih pesticida. Razlog navedenom je nepravilno podešena brzina zraka na usmjerivačima ili korištenje neadekvatnog raspršivača. Ovi problemi mogu se riješiti kako navode Manktelow (1998), te De Moor i sur., (2000). pravilnim optimiranjem brzine zraka po cijeloj vertikalnoj osnovici kulture ili korištenjem radijalnih raspršivača s tangencijalnim usmjerivačima. Naravno, moguće je korištenje i posebnih tehničkih izvedbi aksijalnih raspršivača s visinskim usmjerivačima zraka. Brzina zraka često se kombinira sa čimbenicima brzine kretanja raspršivača i normom raspršivanja. Tako su Marucco i sur. (2008) naveli da je najbolji rezultat pokrivenosti površine i depozita ostvaren pri brzini rada raspršivača od 7 km/h uz ostvarenje brzine zraka od 14 m/s s normom raspršivanja 400 l/ha. Panneton i sur. (2005) navode pojam specifičnog protoka zraka u postotku koji se utvrđuje pomoću brzine rada stroja (km/h) i ukupnog protoka zraka kroz usmjerivače (m^3/s). Isti autor navodi da se smanjenjem brzine rada sa 5,8 na 4,4 km/h pokrivenost tretirane površine u vinogradu povećala sa 9 na 18%. Barčič (1999) navodi da je za depoziciju kapi od posebnog značaja brzina rada stroja i brzina zračne struje. Male kapi u laminarnoj struji slijede strujnice zraka i zaobilaze prepreku (bitno za pokrivenost površine unutar krošnje), dok velike kapi zbog svoje inercije ne zaobilaze prepreke nego se deponiraju na njima (na vanjskim listovima krošnje). Ova tvrdnja govori u prilog malim kapljicama jer probijaju duboko u krošnju i ostvaruju dobre depozite i pokrivenost površine unutar krošnje.

MATERIJAL I METODE

Ventilator rotacijom lopatica stvara brzinu i protok zraka koji je jedan od važnijih tehničkih čimbenika raspršivanja. Brzina i protok zraka direktno djeluju na dezintegraciju mlaza, te nanošenja škropiva na cilj zaštite. Ventilator stvara struju zraka s turbulentnim vrtloženjem čija je uloga pomicanje grana i listova (tzv. „otvaranje krošnje“) čime se omogućuje nesmetan prolaz škropiva do unutrašnjosti krošnje i pokrivanja škropivom obje strane lista. Ugrađeni aksijalni ventilatori stvaraju veliki turbulentni protok s malim radnim tlakom i malom brzinom kretanja zraka na izlaznom sustavu raspršivača. U sustavu zaštite značajno je da optimalna brzina zraka dolazi do cilja prskanja, tj. da cijeli predmet zaštite po visini bude izložen podjednakom brzinom zraka na vanjskim rubovima krošnje ili listovima loze. Uslijed navedene ujednačenosti ostvaruje se zadovoljavajuća pokrivenost tretirane površine jer će upućeni zrak omogućiti ravnomjerno „otvaranje krošnje". Glavne tehničke odlike ventilatora prikazuju se kroz protok zraka u m^3/h, brzinu zraka, m/s i vertikalnu distribucija zraka na izlazu ventilatora. U tvrđivanje vertikalne raspodjele zračne struje raspršivača *AGP 200 ENU* i raspršivača *Tifone Vento 1500* obavljeno je u praktikumu za mehanizaciju Poljoprivrednog fakulteta u Osijeku uporabom meteorološke postaje postavljene na vertikalni sustav za pomicanje po visini.

Raspršivači AGP 200 ENU i Tifone Vento 1500

Raspršivač *AGP 200 ENU* nošeni je uređaj, izuzetno je kratak što je posebice važno za primjenu na nagnutim terenima te manjim traktorima. Ventilator s usmjernim sustavom koji je napravljen od polietilenskih vlakana, smješten je na zadnji dio stroja koji usmjerava zrak ravnomjerno na lijevu i desnu stranu pri čemu je gornji dio podesiv s obzirom na vrstu i bujnost nasada. Raspršivač *Tifone Vento 1500* vučeni je uređaj s kružnim usmjernim sustavom u koji je ugrađen ventilator s pogonom od vratila crpke.

Slika 1 Raspršivači *AGP 200 ENU* (lijevo) i *Tifone Vento 1500* (desno)
Figure 1 Mistblowers *AGP 200 ENU* (left) and *Tifone Vento 1500* (right)

Tablica 1 Tehnički podaci ispitivanih raspršivača
Table 1 Technical scpecification of tested mistblowers

	AGP 200ENU	*Tifone Vento 1500*
Volumen spremnika / Tank Volume (l)	200	1500
Traktorski priključak / Tractor hitch category	I. kategorije / cat. I	I. kategorije / cat. I
Dimenzije raspršivača (š-v-d) / Dimensions (w-h-l) (m)	960x1200x1320	1540x1320x3500
Promjer ventilatora / Fan blower diameter (mm)	585	810
Broj lopatica / No. of fan blades	8	8
Površina lopatica / Fan blades surface area (cm^2)	2016	3136
Izlazna brzina zraka / Output air speed (m/s)	< 40	< 40
Maks. broj okretaja ventilatora / Fan max. rpm (min^{-1})	1600	1600
Kapacitet zraka / Air flow (m^3/h)	12000 do 32000	> 40000

REZULTATI

Iz tablica 2 i 3 možemo vidjeti da je ispitivani raspršivač *AGP 200 ENU* pri brzini vrtnje vratila traktora od 180 min^{-1} i pri ukošenju lopatica na položaju „1“ ostvario prosječnu brzinu zraka po visini usmjerivača na lijevoj strani od svega 2,81 m/s dok je raspršivač *Tifone Vento 1500* ostvario prosječnu brzinu zraka od 2,17 m/s.

Na desnoj strani raspršivača *AGP 200 ENU* pri istim uvjetima utvrđena je prosječna brzina zraka od 2,46 m/s, a kod raspršivača *Tifone Vento 1500* iznosila je 2,36 m/s. Povećanjem broja okretaja vratila traktora na 540 min^{-1} uz isto zakošenje lopatica (položaj 1) ostvarena je prosječna brzina zraka kod *AGP 200 ENU*, na lijevoj strani od 7,99 i 9,84 m/s na desnoj strani stroja. Raspršivač *Tifone Vento* kod 540 okretaja vratila traktora uz zakošenje lopatica na položaju „1“ ostvario je prosječnu brzinu zraka na izlaznom sustavu od 7,6 m/s na lijevoj strani i 7,29 m/s na desnoj strani.

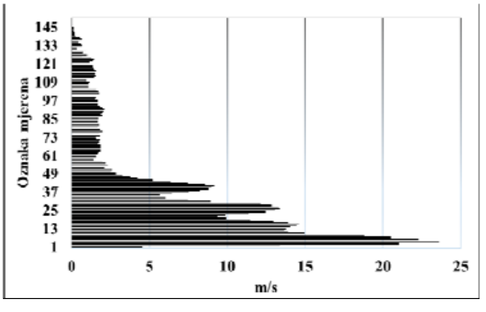
Raspršivač *Tifone Vento* pri 540 okretaja vratila traktora uz maksimalno zakošenje lopatica na položaju „5“ ostvario je prosječnu brzinu zraka na izlaznom sustavu od 16,02 m/s na lijevoj strani i 16,72 m/s na desnoj strani. Raspršivač *AGP 200 ENU* pri 540 okretaja vratila traktora ostvario je prosječna brzina zraka na lijevoj strani usmjerivača od 17,46 m/s i 17,96 m/s na desnoj strani.

Tablica 2 Prosječna brzina zraka na izlaznom usmjerivaču raspršivača *AGP 200 ENU*
Table 2 Mean air speed at air duct output of *AGP 200 ENU* mistblower

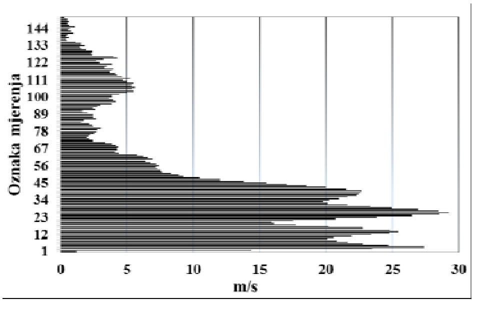
Broj okretaja vratila traktora / PTO rpm (min^{-1})	Prosječna brzina zraka / Mean air speed (m/s)			
	Lijeva strana / Left side		Desna strana / Right side	
	Položaj 1 / Adjustment 1	Položaj 5 / Adjustment 5	Položaj 1 / Adjustment 1	Položaj 5 / Adjustment 5
180	2,81	5,52	2,46	5,97
540	7,99	17,46	9,84	17,96

Tablica 3 Prosječna brzina zraka na usmjerivaču raspršivača *Tifone Vento 1500*
Table 3 Mean air speed at air duct output of *Tifone Vento 1500* mistblower

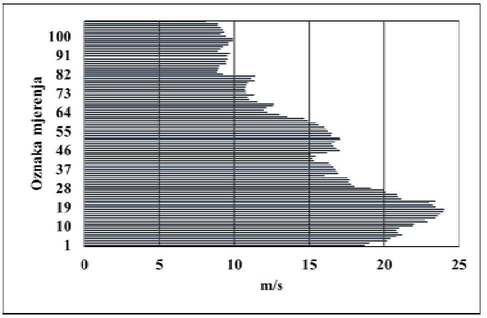
Broj okretaja vratila traktora / PTO rpm (min^{-1})	Prosječna brzina zraka / Mean air speed (m/s)			
	Lijeva strana / Left side		Desna strana / Right side	
	Položaj 1 / Adjustment 1	Položaj 5 / Adjustment 5	Položaj 1 / Adjustment 1	Položaj 5 / Adjustment 5
180	2,17	4,68	2,36	4,65
540	7,6	16,02	7,29	16,72



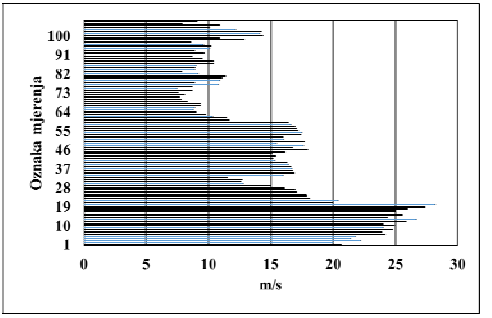
Slika 2 Prosječne izmjerene brzine zraka na lijevoj strani izlaza usmjerivača kod raspršivača *Tifone Vento 1500* (položaj lopatica „1“ pri 540 min^{-1} okretaja priključnog vratila traktora)
Figure 2 Mean air speed measured at left side air duct output of *Tifone Vento 1500* mistblower (Fan blades adjustment „1“ and 540 PTO rpm)



Slika 3 Prosječne izmjerene brzine zraka na desnoj strani izlazu usmjerivača kod raspršivača *Tifone Vento 1500* (položaj lopatica „1“ pri 540 min^{-1} okretaja priključnog vratila traktora)
Figure 3 Mean air speed measured at right side air duct output of *Tifone Vento 1500* mistblower (Fan blades adjustment „1“ and 540 PTO rpm)



Slika 4 Prosječne izmjerene brzine zraka na lijevoj strani izlaza usmjerivača kod raspršivača *Tifone Vento 1500* (položaj lopatica „5“ i pri 540 min^{-1} okretaja priključnog vratila traktora)
Figure 4 Mean air speed measured at left side air duct output of *Tifone Vento 1500* mistblower (Fan blades adjustment „5“ and 540 PTO rpm)



Slika 5 Prosječne izmjerene brzine zraka na desnoj strani izlaza usmjerivača kod raspršivača *Tifone Vento 1500* (položaj lopatica „5“ i pri 540 min^{-1} okretaja priključnog vratila traktora)
Figure 5 Mean air speed measured at right side air duct output of *Tifone Vento 1500* mistblower (Fan blades adjustment „5“ and 540 PTO rpm)

ZAKLJUČCI

Na temelju provedenih istraživanja i polučenih rezultata vertikalne raspodjele zračne struje raspršivača *AGP 200 ENU* mougu se donijeti slijedeći zaključci;

- raspršivač *AGP 200 ENU* pri brzini vrtnje vratila traktora od 180 min^{-1} i pri ukošenju lopatica na položaju „1“ ostvario prosječnu brzinu zraka po visini usmjerivača od 2,81 m/s na lijevoj strani i 2,46 na desnoj strani stroja,
- raspršivač *Tifone Vento* pri 180 okretaja vratila traktora uz zakošenje lopatica na položaju „1“ ostvario je prosječnu brzinu zraka na izlaznom sustavu od 2,17 m/s na lijevoj strani i 2,36 m/s na desnoj strani,
- kod raspršivača *AGP 200 ENU* pri brzini vrtnje vratila traktora od 540 min^{-1} i pri ukošenju lopatica na položaju „5“ ostvarena je prosječna brzina zraka po visini usmjerivača od 17,46 m/s na lijevoj strani i 17,96 na desnoj strani stroja,
- raspršivač *Tifone Vento* pri 540 okretaja vratila traktora uz maksimalno zakošenje lopatica na položaju „5“ ostvario je prosječnu brzinu zraka na izlaznom sustavu od 16,02 m/s na lijevoj strani i 16,72 m/s na desnoj strani.

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VERTICAL DISTRIBUTION OF AIR FLOW WITH AGP 200 ENU AND TIFONE VENTO 1500 MISTBLOWERS

SUMMARY

In this paper the results of vertical air flow distribution on both sides of two different mistblowers are shown. Researches are conducted with Agromehanika AGP 200 ENU and Tifone Vento 1500 axial mistblowers. Agromehanika mistblower is equipped with axial fan, 585 mm in diameter, while fan diameter of Tifone mistblower is 810 mm. Both mistblower fans have 8 blades with the possibility of setting in 5 different bevels. AGP 200 ENU (with 180 rpm of PTO and with fan blades on position 1) has achieved the average air velocity on the left side of machine of 2.81 m/s, while Tifone Vento 1500 had 2.81 m/s. On the right machine side with the same conditions, AGP 200 ENU had average air flow velocity of 2.46 m/s, Tifone Vento 1500 had 2.36 m/s. With increasing of rpm of PTO at 540 (same position of blades) AGP 200

ENU on the left machine side had achieved average air flow velocity of 7.99 m/s and 9.84 m/s with the right side of machine. Tifone Vento at 540 rpm of PTO (maximal bevelling, position 5), on the left side, has achieved the average air flow velocity of 16.02 m/s and 16.72 m/s on the right side. AGP 200 ENU at 540 rpm of PTO (maximal beveling, position 5), on the left side, has achieved the average air flow velocity of 17.46 m/s and 17.96 m/s on the right side.

Key words: *mistblower, axial fan, air velocity, vertical air flow distribution*

44. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

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Review paper

SUVREMENA TEHNIKA ZA PRIKUPLJANJE OREZANE BIOMASE U SVRHU ENERGETSKOG ISKORIŠTENJA

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SAŽETAK

Sve prisutnija globalna i ekološka pitanja, ograničenost zaliha fosilnih goriva, nesigurnost isporuke plina te potreba za većom samostalnošću i neovisnošću u vođenju energetske politike, utječu na razvoj i primjenu novih sirovina za dobivanje energije. Dio navedenih problema može se postići korištenjem energije iz obnovljivih izvora, pod kojime podrazumijevamo i poljoprivrednu biomasu. Nakon rezidbe trajnih nasada ostaju značajne količine orezane biomase. Kako bi se orezani ostaci kvalitetno i učinkovito prikupili neophodno je korištenje suvremene poljoprivredne tehnike. Cilj ovog rada je prikazati mogućnosti mehaniziranog prikupljanja orezane biomase iz trajnih nasada u svrhu energetskog iskorištenja.

Ključne riječi: *orezana biomasa, prikupljanje biomase , poljoprivredna tehnika*

UVOD

U posljednjih nekoliko godina interes za obnovljive izvore energije, a poglavito iz biomase, znatno je porastao u cijelom svijetu. Postoji nekoliko razloga za to: biomasa je široko dostupna i obnovljiva te ima potencijala za proizvodnju energije kao što su električna i toplinska energija te tekuća goriva, a ujedno se i relativno lako koristi. Nakon ugljena i nafte, biomasa je treća po veličini primarna energija u svijetu. Ona predstavlja glavni izvor energije za više od pola svjetske populacije te osigurava oko 1,25 milijarde tona ekvivalenta nafte (Mtoe) primarne energije što je oko 14% svjetske godišnje potrošnje energije (Di Blasi i sur., 1996; Krička, 2013). Biomasa kao skraćenica pojma biološka masa predstavlja biorazgradivi dio proizvoda, otpada i ostataka proizvedenih u poljoprivredi (uključujući tvari biljnog i životinjskog podrijetla), šumarstvu i srodnim industrijama, kao i biorazgradivi dio industrijskog i komunalnog otpada (2003/30/EC). Pod poljoprivrednom biomasom, među ostalim, podrazumijevaju se i ostaci rezidbe trajnih nasada. Nakon rezidbe trajnih nasada (voćnjaci, vinogradi, maslinici) ostaju velike količine rozgve i granjevina. Orezani ostatak se uglavnom malčira te se na taj način unosi u tlo ili se iznosi iz nasada te se potom spaljuje. Povećanjem ekološke svijesti, ali i povećanom potrebom za obnovljivom energijom, razvijena je specijalizirana mehanizacija za prikupljanje i doradu orezane biomase. Međutim, orezana biomasa mora biti kvalitetno prikupljena i dorađena, što je moguće primjenom suvremene tehnike. Prosječne količine orezane biomase u trajnim nasadima prikazani su u tablici 1.

Tablica 1 Prosječne količine orezane biomase u trajnim nasadima (Bilandžija i sur., 2012.)

Kultura	Orezana biomasa (kg/kulturi)	Orezana biomasa (kg/ha)	Energetski potencijal (MJ ha^{-1})
Jabuka	2,34	5.557,5	94.814,75
Kruška	2,45	5.818,7	97.498,50
Breskva i nektarina	7,23	2.870,3	50.881,10
Marelica	5,79	1.621,2	24.981,88
Trešnja	5,90	1.988,3	33.315,82
Višnja	5,37	2.169,5	37.167,19
Šljiva	7,34	2.055,2	35.092,40
Orah	3,43	538,5	8.781,01
Ljeska	3,05	1.848,3	32.287,68
Badem	5,81	1.626,8	28.678,72
Smokava	4,58	1.282,4	20.006,28
Maslina	9,08	2.524,2	42.672,16
Vinova loza	0,89	4.255,1	72.546,89

POLJOPRIVREDNA TEHNIKA

Suvremenu poljoprivrednu tehniku za prikupljanje orezane biomase možemo podijeliti na: strojeve za prikupljanje i iznošenje orezane biomase, strojeve za usitnjavanje orezane biomase, strojevi za rezidbu i usitnjavanje orezane biomase

Strojevi za prikupljanje i iznošenje orezane biomase

U strojeve za prikupljanje i iznošenje orezane biomase ubrajamo balirke za orezanu biomasu i traktorski utovarivač s priključkom. Preše za biomasu (slika 1) se podjednako učinkovito mogu koristiti u svim trajnim nasadima. Jednostavan princip rada temelji se na namatanju orezane biomase u bale povezane uzicom. Postupak baliranja je u potpunosti automatiziran, a manje od minutu je kvalitetnoj preši dovoljno za cjelokupan proces sakupljanja, oblikovanja i istovara bale izvan stroja. Masa same bale je od 25 do 40 kg. Bala svojim dimenzijama (širina 60 cm, promjer 40 cm) ne predstavlja značajnije probleme tijekom manipulacije. Preše mogu prikupljati i balirati grane debljine do 4 cm uz radni zahvat sakupljačkog uređaja od 1,5 do 2,0 m. Neposredno baliranu biomasu s ciljem poboljšanja energetskih svojstava preporučeno je sušiti. Kako bi cijeli postupak peletiranja bio što rentabilniji i ekološki prihvatljiviji, preporučuje se sušenje bala prirodnim putem. Prirodno sušenje se najčešće provodi na otvorenom prostoru bez pokrivanja ili sa pokrivanjem (plastičnim prekrivačima ili ceradama) te u skladišnim prostorima.

Slika 1 Različiti tipovi preša za orezanu biomasu (www.caebinternational.it; www. poljoinfo.com)

Prednji traktorski utovarivač s priključkom, kao što su vile može jednostavno prenašati bale (slika 2). Međutim, ukoliko preše nisu opremljenije „metlicama" namijenje-nih za oblikovanje zbojeva, taj se zahvat mora obaviti zasebnim uređajem (slika 3.).

Slika 2 Bala nošena vilama (www.asiancorrespondent.com)

Slika 3 Uređaj za oblikovanje zbojeva biomase (www.ledgardpruning.com)

Strojevi za usitnjavanje orezane biomase

Strojevi za usitnjavanje biomase dijele se prema mjestu rada, stoga oni mogu biti namijenjeni za rad u ili izvan trajnih nasada. Strojevima takvog tipa priprema se biomasa za daljnju tehnološku doradu bilo u vidu sječke, peleta ili briketa. Današnja tehnika nudi veliki izbor spomenutih strojeva različitih tehničkih karakteristika koji se jednako kvalitetno mogu koristit u voćnjacima i vinogradima.

Strojevi za usitnjavanje orezane biomase izvan trajnih nasada dijele se na stacionarne (slika 4) i mobilne (traktorski nošene – slika 5 ili vučene – slika 6). Pogon strojeva može se ostvariti putem priključnog vratila traktora, zasebnog diezel motora ili električne energije. Navedeni strojevi se kod relativno manjih količina orezane biomase opskrbljuju manualnim putem, međutim, postoje i izvedbe koje omogućuju strojno umetanje biomase (slika 7.).

Slika 4 Stacionarni stroj za usitnjavanje biomase (www.rajkumaragromachines.com)

Slika 5 Nošeni stroj za usitnjavanje biomase (www.teknamotor.co.uk)

Slika 6 Vučeni stroj za usitnjavanje biomase (www.teknamotor.co.uk)

Slika 7 Usitnjivač s mehaničkim dobavljanjem biomase (www.comerc.pl)

Orezana biomasa se ubacuje u usipni koš, gdje se pomoću dva nezavisno pogonjena valjka (fiksnog i samonivelirajućeg) ili noževa/čekića usitnjavaju biomasu. Usitnjena biomasa potom dolazi do cijevi za izbacivanje koja ima mogućnost rotacije od 360°. Postoje različite izvedbe i tipovi navedenih strojeva, a dimenzije im se uglavnom kreću od 1 do 4,5 m širine, od 1,5 do 3,1 m visine, od 2,3 do 4,7m dužine te mase od 50 do 2000 kg. Ovisno o tipovima strojeva imamo i različite učinke koji se kreću približno od 2 do 15 m^3/h, a uobičajeno preporučene debljine orezane biomase su od 3,5 do 20 cm.

Strojevi za prikupljanje i usitnjavanje orezane biomase unutar trajnih nasada mogu se podijeliti na dvije osnove grupe, i to obzirom na tehniku spremanja usitnjene biomase u:

- spremnike na vlastitoj konstrukciji (hidraulički spremnik, promjenjive vreće)
- prateće agregate (malčeri s puhajućom cijevi) (Spinelli i sur., 2010).

Kako i kod strojeva za prešanje i usitnjavanje tako i kod specijalnih malčera sa spremnikom za usitnjenu biomasu, na tržištu se nudi široki spektar različitih izvedbi i tipova. Princip rada im je sličan klasičnom malčeru čekičaru (16 - 24 čekića), samo što u navedenom slučaju usitnjena orezana biomasa ne ostaje u nasadu u vidu malča već se doprema u za to predviđene spremnike. Specijalni malčeri imaju mogućnost učinkovitog prikupljanja orezanih ostataka i to pomoću takozvanog *pick-up* sistema koji izbjegava ulazak trave, kamenja i grudica tla u spremnik (vreću/prikolicu). Širina samih uređaja je prilagođena međurednom razmaku unutar trajnih nasada (1,40 – 2,50 m) a kapaciteti spremnika su uglavnom od 0,80 do 1,86 m^3. Manji kapaciteti se uglavnom odnose na malčere sa promjenjivom vrećom, dok kapaciteti najsuvremenijih malčera sa hidrauličnim spremnikom mogu imati zapremninu i do 7,8 m^3. Masa im se kreće od 600 do 3500 kg, a prihvatljiva debljina orezane biomase je od 5 do 8 cm uz radni učinak od približno 0,5 do 1 ha/h. Malčeri s hidraulički progonjenim spremnikom (slika 8) dostavljaju biomasu do zasebnih prikolica te imaju mogućnost istovara biomase na visinu od 1,5 do 2,5 m, dok se kod malčera sa vrećom (slika 9) manipulacija istih obavlja viljuškarima.

Slika 8 Malčer s hidraulički progonjenim spremnikom (Spinelli i sur., 2010)

Slika 9 Malčer s vrećom (Spinelli i sur., 2010)

Za razliku od specijalnih malčera sa spremnikom na vlastitoj konstrukciji, malčerima sa puhajućom cijevi se mora osigurati prateći agregat (najčešće prikolica) kao spremnik usitnjene orezane biomase. Obzirom da puhajuća cijev ima mogućnost rotacije, prikolica može biti priključena direktno na malčer (slika 10) ili se može priključiti na zaseban traktor koji se u redu paralelno kreće s malčerom (Velázqez-Martí i Fernández-González, 2009).

Slika 10 Malčer s puhajućom cijevi (www.bertima.it)

Slika 11 „COMBY“ (www.facma.it)

Jedan od suvremenih strojeva za prikupljanje i usitnjavanje orezane biomase je i stroj „COMBY“ (slika 11). Priključuje se na traktor čija je snaga motora najmanje 73KW. Pogon dobiva od traktora preko zglobnog vratila (kardana) s 540 okretaja u minuti. Rotor sitnilica je horizontalno postavljen, a radni organi su čekići-sitnilice, usitnjavaju grane debljine 90 mm. Ovaj podatak je važan kada radimo radikalnu rezidbu gdje ostaje mnogo skeletnih grana. Širina radnog zahvata je 2 m. Kapacitet spremnika je 3-5 m^3, pražnjenje je hidrauličko i zato su potrebna minimalno dva priključka (izvoda) za hidrauliku. Biomasa se ne balira već je u rinfuznom stanju, može se istresati u prikolice jer ima mogućnost hidrauličkog podizanja spremnika ili direktno na deponiju. Uređaj je vučenog tipa, a prednost se očituje u obavljanju dvije operacija u jednom prohodu. Služi za prikupljanje grana u međuredni prostor da se kasnije lakše pokupi nekom od sitnilica ili balirki. Jedan od modernijih tipova je onaj s mogućnosti hidrauličkog podešavanja radnih organa četki. Posjeduje okvir s jednim ili dva hidraulična cilindra za podešavanje visine i kuta rotirajuće četke i priključuje se s prednje strane traktora. Ima mogućnost bočnog izmicanja da je rad što čišći. Elektrohidraulične komande omogućavaju upravljanje palicom (joystickom) iz kabine traktora. Može zahvaćati prostor između redova 280-420 m. Sjeckalica ima širinu zahvata 1,5 m. Radi preko priključnog vratila, a potreban je traktor minimalne snage 59 kW. Uređaj radi tako da prikuplja i usitnjava granje pomoću valjka s noževima. Masu transportira kroz izlaznu cijev u sanduke ili jumbo vreće. Visina sakupljanja se regulira hidraulički pomoću kotača. Traktor treba imati minimalno 2 hidraulička izvoda. Upravljanje je pomoću ručica na uređaju. Vreća se lagano skida tako da se kotači spuste, a vreća sama spadne i ostane na tlu. Na kraju se može ugraditi stol na koji se stavi sanduk. Kada se napuni, također se hidrauličkim upravljanjem odloži na tlo (Marinčević, 2015).

Samokretni strojevi za prikupljanje i usitnjavanje orezane biomase

Do sada većina navedenih strojeva uglavnom potječe od konvencionalnih malčera. Veliki nedostatak takvih strojeva je taj što se nalaze iza traktora te je potrebno prethodno formiranje zboja orezane biomase. Iz toga razloga raste interes za razvojem jakih industrijskih jedinica s prednjim prihvatnim („pick up") uređajem koji ne zahtijeva prethodno formiran zboj. Samokretna mehanizacija se sastoji od prednjeg pick up uređaja te remenski pogonjene kosilice koja usitnjava prikupljeni ostatak. Tako usitnjeni ostatak se otpuhuje u prateću prikolicu. Samokretni strojevi brže obavljaju prikupljanje orezane biomase, brže prelaze iz jednog reda u drugi te imaju dvostruko veći kapacitet od traktorom pogonjenih sakupljačkih jedinica (Spinelli i sur., 2010). Međutim, treba imati u vidu da su navedeni samokretni strojevi prikladani za velike nasade te zahtijevaju intezivno korištenje kako bi se isplatili.

Slika 12 Samokretni stroj (Spinelli i Picchi, 2010)

Strojevi za rezidbu i usitnjavanje orezane biomase

Kako bi proces energetskog iskorištenja orezane biomase bio što rentabilniji, u novije vrijeme se na tržištu nalaze univerzalni strojevi za rezidbu i usitnjavanje biomase (slika 13). Za razliku od svih prethodno spomenutih strojeva, strojevi takvog tipa u jednom prohodu obavljaju rezidbu, usitnjavanje i spremanje biomase u vlastitom spremniku. Prikazani takozvani „*Speedy cut*" stroj obavlja rezidbu pomoću višestrukih diskova koji se nalaze na poluzi. Kako je poluga konstrukcijski povezana s hidrauličkim podizačem, polugu sa diskovima je moguće prilagođavati željenoj visini i kutu reza. Prikupljajuća ploča se nalazi ispod uređaja za rezidbu kako bi sva orezana biomasa, transporterom, bila dopremljena do usitnjivača. Nakon usitnjavanja, biomasa se transporterima dalje doprema u spremnik. Isto kao na primjeru malčera sa hidraulički pogonjenim spremnikom, „*Speedy cut*" stroj ima mogućnost hidrauličkog pražnjena spremnika. Orezivanje i usitnjavanje se obavlja brzinom od 1,2 do 2,8 km/h (Spinelli i sur. 2011)

Slika 13 „*Speedy cut*" stroj (www.speedy-cut.it)

ZAKLJUČAK

Potencijalnu energiju koja se nalazi u orezanoj biomasi moguće je racionalno energetski iskoristiti samo ako se pravilno prikupi i doradi. Nažalost, još uvijek je prisutan trend da se orezana biomasa spaljuje izvan nasada te se na taj način znatan energetski potencijal nepovratno gubi. Prikupljanje orezanih ostataka se provodi specijaliziranom mehanizacijom koja može biti vučena, nošena ili samokretna. Suvremenu poljoprivrednu tehniku za prikupljanje orezane biomase možemo podijeliti na: strojeve za prikupljanje i iznošenje orezane biomase, strojeve za usitnjavanje orezane biomase, strojeve za rezidbu i usitnjavanje orezane biomase. Orezana biomasa se iznosi iz nasada u obliku bala ili sječke te se zatim suši i dorađuje u konačni proizvod, koji može biti u obliku sječke, peleta ili briketa.

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MODERN MECHANIZED METHODS FOR COLLECTING RESIDUAL BIOMASS FROM PRUNING FOR ENERGY PURPOSE

ABSTRACT

All present global and environmental issues: limited supplies of fossil fuels, uncertain gas supplies and the need for greater autonomy and independence in energy policy implementation have influence on development and utilization of new energy raw materials. Part of solution for the mentioned problems can be achieved by utilization of renewable energy, which also includes the agricultural biomass. Significant amounts of pruned biomass remain after pruning permanent plantations. For quality and effective collecting of pruned biomass, it is necessary to use modern agricultural techniques. The aim of this paper is to show the technical possibilities for collecting residual biomass coming from pruning of permanent plantations in order to be used as a source of energy.

***Key words**: pruned biomass, collecting biomass, agricultural enginering*

44. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

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Expert paper

DETERMINATION OF SOIL RESISTANCE RELATED TO WEAR OF A CHISEL SHARE

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SUMMARY

Within the main soil works, the active parts such as: body, ploughshare, disk, chisel, etc., are rapidly subjected to wear out because of abrasive action of soil with which they come into contact. Therefore, active parts have to be checked in terms of wear resistance, in different conditions, so that an average life span should be determined, for ensuring the spare parts in due time. The paper presents the experimental researches performed in the laboratory stand, for finding out the wear resistance of a working part of chisel type, at different depth and working speed, so that a correlation between these parameters should be determined, for enhancing the span of life of this part.

***Key words**:* decompaction equipment, soil, loosening, *active parts, wear*

INTRODUCTION

Soil tillage is performed according to requirements of culture plants and their seeds. In short, by an optimum work, the soil should be broken in particles allowing the air and water free access and their storing [2], [3].

As a general rule, the soil mechanical processing aims at the following objectives:

- soil loosening for increasing pores volume, improving water and air penetrability, eliminating soil compaction;
- soil mixing, redistribution of structure parts, incorporation of chemical and organic fertilizers, covering the waste, natural fertilizers and vegetation;

- soil mechanical processing represents a protection measure against soil erosion;
- breaking the soil surface crust and big clods;
- preparing an appropriate germinating bed.

The interaction system within the mechanical process of working the soil consists in two elements, namely the soil and the tool metal [12]. As the tool moves towards into the soil, a relative movement at the level of the interface between the two elements takes place. Existence of this relative movement represents a discontinuity in the displacement field and is determined by adherence and friction (external friction angles) in interface area, which differ from the cohesion and friction (internal friction angle) from the soil suitable level [8, 9]. Because these working parts are subjected to variable stress of rather high values, the wear intensity being much bigger in comparison with the other parts of the machine, they are also called high wear parts [4, 5, 7, 10].

Harder the soil particles are, more abrasive soil becomes [11], many times the particles hardness being higher than that of tools; thus, are determined the premature wear of the tool, modification of its geometry, especially of its blade, fact that leads to increased working resistance and high energy consumption [6].

Researches performed in [7] have shown that there are 2 main forces acting on active parts: friction and knocking. These forces action determines the appearance of wear, that manifests as two distinct aspects: friction wear (slipping) and impact wear (knocking) [1].

Soil texture and physical and mechanical features directly influence the wear level of machines working (active) parts. The main physical and physico-mechanical properties of soil are the following: density (specific mass), porosity, humidity, cohesion, consistency, adherence, plasticity, friction forces, resistance to compression, shearing resistance, specific resistance to ploughing and physical maturity [13].

Resistance to soil penetration depends on soil density and humidity. The drier and clayeyer the soil is, the smaller is the friction coefficient, and the more humid and sandier the soil is, the greater the friction coefficient is. [13].

MATERIAL AND METHOD

In order to test the soil working tool in laboratory, a testing stand, wholly achieved by Mechanics University from Cluj, was used. It (fig. 1) allows to test in laboratory the different working tools, by changing their functional parameters, respectively the working depth, relief angle, lateral angle to forward direction, rotative speed and respectively, according to necessities, granulation and moisture of testing environment.

By its overall and functional dimensions, the stand allows to test the tools on a circular trajectory with diameter ranging between 1700 and 2000 mm at a maximum depth of 900 mm. Stand achieved comprises the following:

- Electric driving engine (three phase asynchronous, 720 rpm, 3.2 kW);
- Transmission through belts with spare wheels;
- Moment transducer (Hottinger Baldwin Messtechnik (HBM) - T30F N)

- Driving device for four tools;
- System of data acquisition (H BM - Spider 8 or National Instruments - D AQPad 1200);
- Inverter (12V/230V);
- Battery (12 V, 45Ah).

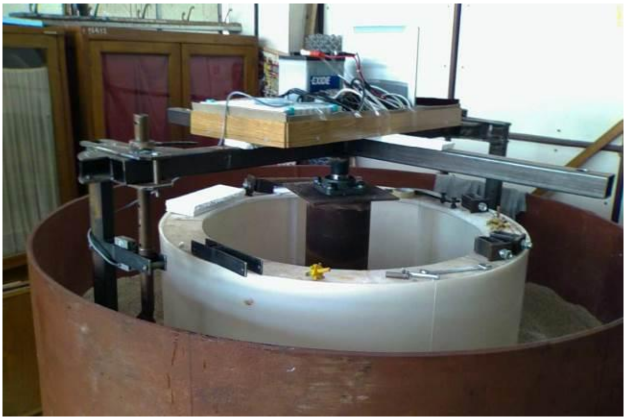

Fig. 1 Testing stand for soil working tools

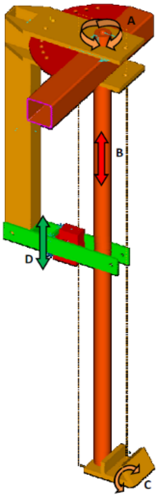

Fig. 2 Port tool assembly

Fig. 3 Port tool

Within the assembly port tool (fig. 2) the following movements are possible [12]:

- Rotation of port tool system reported to driving cross arm-adjustment of lateral angle of tool comparatively to forward direction, ±70° with 5°pace (fig. 2, movement A;

- Vertical movement of port tool bar (adjustment of soil processing depth, maximum 50 0 mm at pace of 50 mm) – figure 2, movement B;
- Rotation of port tool plate – adjustment of tool relief angle (fig. 2, movement C);
- Vertical movement of transducer assembly – adjustment of force ratio between the real one and the measured one (fig. 2, movement D).

In order to test the working tools designed and achieved, a suitable port tool support had to be performed. (fig.3). Device was designed and manufactured so that it allows to mounting it on the existing stand, adjust the working depth within the limits of real working depth and entering angle. In consequence, the port tool (fig. 3, 4) allows the adjustment of the entering angle in 5 steps.

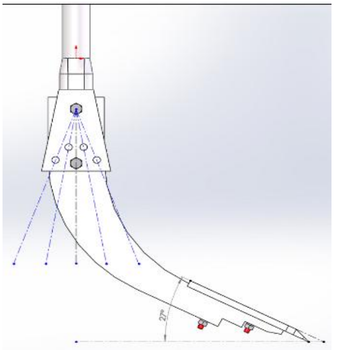

Fig. 4 Adjustment of the port tool entering angle

RESULTS AND DISCUSSION

All the settings on stand allow a good coverage of tools working possibilities, endurance tests for determining the tool wear using specific measuring installations.

For tests, a chisel support (fig. 5) and 3 chisel knives made of different materials OLC 45 (1), OLC 45 thermally treated (2), OL 50 (3) (fig. 6), were used.

Fig. 5. Chisel support

Fig. 6. Chisel type knife

The chisel type knives were mounted in row on the testing stand (fig. 7), where they worked at a depth of 22 cm in sand of stand, so that their wear could be determined after a certain number of operating hours.

Fig. 7 Chisel type knife mounted on experimental stand

These chisel knives were weighed by means of a precision balance before being mounted on testing stand, where they were let to operate for one hour, after which they were weighed and mounted back for another hour, procedure that was repeated 7 times for each knife, monitoring the material losses determined by wear (table 1).

Table 1 List of data obtained for chisel type knives subjected to wear analysis

Timp [h]	Chisel type knife OLC 45 (1)			Chisel type knife OLC 45 thermally treated (2)			Chisel type knife OL 50 (3)		
	Initial weight [g]	Mass difference (effective wear) [g]	Mass difference (effective wear) [100%]	Initial weight [g]	Mass difference (effective wear) [g]	Mass difference (effective wear) [100%]	Initial weight [g]	Mass difference (effective wear) [g]	Mass difference (effective wear) [100%]
0	259.52	0	0	257	0	0	238.16	0	0
1 h	259.1	0.42	0.162	256.47	0.53	0.206	237.89	0.27	0.113
2 h	258.77	0.33	0.127	256.18	0.29	0.113	237.65	0.24	0.101
3 h	258.43	0.34	0.131	255.99	0.19	0.074	237.44	0.21	0.088
4 h	258.12	0.31	0.120	255.78	0.21	0.082	237.3	0.14	0.059
5 h	257.78	0.34	0.132	255.6	0.18	0.070	237.18	0.12	0.051
6 h	257.52	0.26	0.101	255.44	0.16	0.063	237.02	0.16	0.067
7 h	257.27	0.25	0.097	255.3	0.14	0.055	236.84	0.18	0.076
TOTAL		2.25	0.870	-	1.7	0.666	-	1.32	0.557

After the 7 hours of functioning, it has been noticed the evolution of weight loss of the 3 chisel knives. In figure 7 is given the evolution of the 3 chisel knives wear before and after the 7 hours of tests.

At the same time, it can be noticed that at the end of the 7 testing hours, the knife made of OLC 45 of 259.52 g reached 257.27 g being subject of a wear of 0.870 % ; the knife made of OLC 45 thermally treated from 257 g reached 255.3 g being subject of a wear of 0.666 % and the knife made of OL 50 from 238.16 g reached 236.84 g being subject of a wear of 0.557 %.

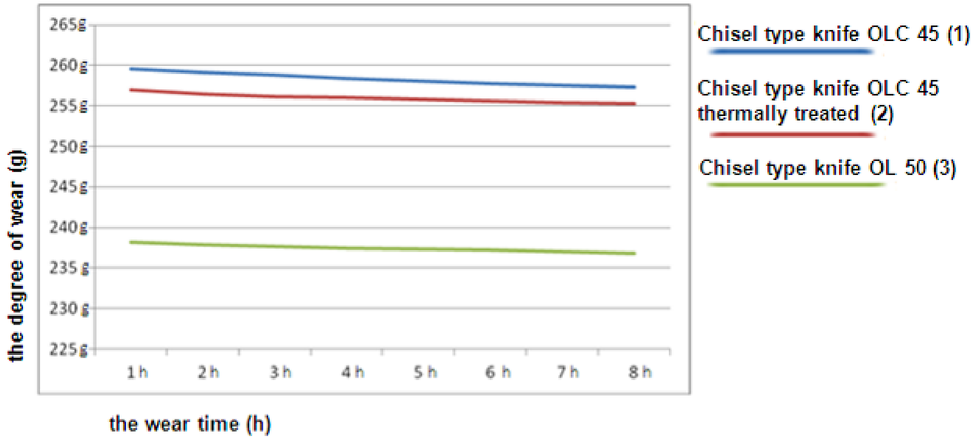

Fig. 8 Evolution of weight loss of the 3 chisle type knives

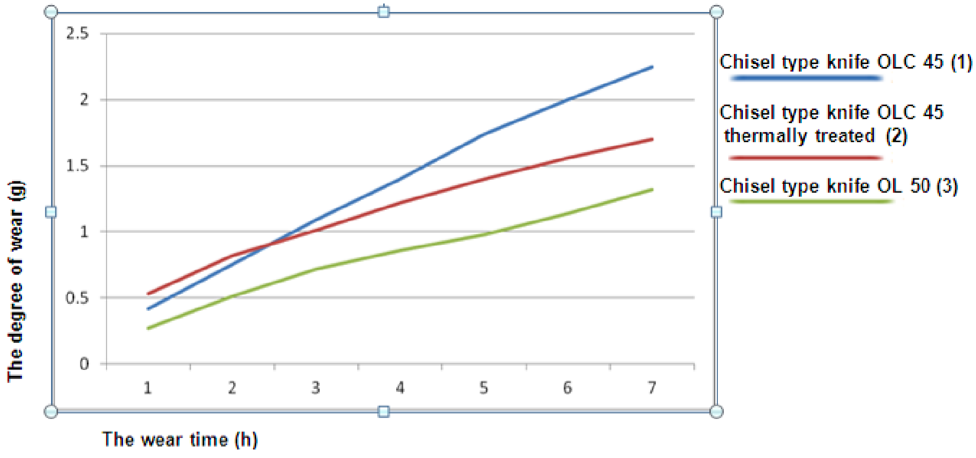

Fig. 8 Evolution of wear increasing of the 3 chisel type knives

In fig 8, we can see the evolution of wear degree growing during the 7 operating hours; thus, it can be noticed that the chisel type knife made of OL50 was subjected to a reduced wear during the operating period, being followed by chisel type knife made of OLC 45 thermally treated, and the chisel type knife from OLC 45 was the most worn up.

At the same time, one can notice that the highest wear level for all the 3 chisel type knives has happened during the first hours of operation, after which, the wear has diminished.

CONCLUSIONS

Soil mechanical processing is a complex process that demands much energy and material consumption because of the resistance to soil breakage and working parts intense abrasive wear. Optimization of this process must take into consideration all the parameters of elements intervening in the process, respectively the soil parameters, tool geometrical parameters and process functional parameters.

Therefore, it is recommended the soil works to be performed when humidity has the values appropriate to minimum resistance to traction.

After using these knives 7 hours each in experimental stand, it has found that the knife made of OL50 was subjected to a smaller wear during the whole operating period, being followed by that made of OLC 45 thermally treated.

Chisel type knife made of OLC 45 has been subjected to the highest wear.

At the end of 7 hours of testing, the knife made of OLC 45 from 259.52 g reached the value of 257.27 g being subject of a wear of 0.870 %, the knife made of OLC 45 thermally treated from 257 g reached 255.3 g being subject of a wear of 0.666 % and the knife made of OL 50 from 238.16 g reached 236.84 g being subject of a wear of 0.557 %.

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44. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

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Prethodno priopćenje
Preliminary communication

ENERGY AND LABOUR EFFICIENCY OF TILLAGE SYSTEMS IN OILSEED RAPE AND BARLEY PRODUCTION

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ABSTRACT

Short-term study of non-conventional soil tillage systems was conducted at the experimental field near Štivica (45° 09' N, 17° 31' E) on hypogley-vertic *type of soil and semi humid climate conditions. Oilseed rape (*Brassica napus L.*) and winter barley (*Hordeum vulgare L.*) were cultivated within four soil tillage systems: CT – mouldboard plough, disc harrow, seed-bed implement, drill, NcT1 – chisel plough, disc harrow, seed-bed implement, drill, NcT2 – chisel plough, rotary harrow integrated with seed drill, NcT3 – mouldboard plough, rotary harrow integrated with seed drill. As the efficiency indicators of different tillage systems the following parameters were observed: energy requirement, work rate and grain yield. Substitution of mouldboard plough with chisel in primary tillage (NcT1 and NcT2) provided substantially lower fuel consumption in those tillage systems than in CT, and in consequence, the specific energy efficiency were improved compared to conventional tillage. Labour requirement comparison also shows that those tillage systems were much more productive than conventional tillage. The average yields in non-conventional systems, with the exception of NcT3 in oilseed rape production, were not impaired by reduction of soil tillage and, therefore, proved that non-conventional tillage systems are not inferior to conventional tillage and could be an important tool to improve energy efficiency and labour productivity in oilseed rape and winter barley production.*

Key words*: soil tillage, specific energy, productivity.*

INTRODUCTION

Soil tillage predominates as the most energy and labour consuming field operation in arable crop production. More than half of direct energy (or fuel consumption) utilised from soil preparation to harvest was accounted to the soil tillage when conventional tillage system practised, in which case the primary tillage require up to 65% of total energy utilised before seeding (Pellizzi et al. 1988). The long term application of conventional tillage showed significant economic and environmental drawbacks. From an economic point of view disadvantages of conventional tillage systems are high energy and labour, large investment and maintenance costs of machinery, and ultimately higher costs of crop production. According to some European researches (Tebrüge et al. 1998, Tebrüge and Düring 1999) conventional tillage system requires 434 kWh ha^{-1} of energy and 4.1 h ha^{-1} human-machine work. In contrast, reduced tillage systems can bring about 30-40% savings of the energy and human-machine work, and direct sowing as much as 90%, compared with conventional tillage (Kosutic et al. 2006). From an ecological point of view disadvantages of conventional tillage systems are increased soil compaction caused by excessive number of machinery passes, systematic reduction of soil organic matter (humus content) as a result of intensive and frequent tillage and the greater the susceptibility to soil erosion. A significant CO_2 emissions from the combustion of large amounts of fuel consumed in the intensive tillage is also an environmental issue (Filipovic et al. 2006).

The leaders in substitution of conventional tillage systems with different variants of reduced tillage and direct sowing in the world are the United States and Canada in North America and Brazil, Argentina, Uruguay, Paraguay in South American where conservation tillage and no-tilll system used on more than half of the total agricultural area (Derpsch and Friedrich 2009). The share of agricultural land in Europe under some system of reduced tillage has not been significantly increased until recent, and it is estimated that there are still less than 20% (ECAF 2013). Despite knowledge of the possibilities of energy and labour savings by means of reducing the soil tillage, conventional tillage system is dominant in Croatia. In the main arable crop production regions in Croatia, Slavonia and Baranja, conventional tillage system is applied on the majority (over 90%) of arable land (Zimmer et al. 2002).

Previous studies suggest that reduced tillage is favourable for high density crops such as wheat, barley and canola, while much worse option for row crops such as corn and soybeans (Kisic et al. 2010, Pospisil et al. 2002, Spoljar et al. 2009). While some authors (Chatskikh and Olesen 2007) have noticed a decrease of yield of some cereals with the degree of tillage reduction (14% lower average yields at a reduced tillage and 27% lower in direct drilling), others claim that there is no significant difference in yields between different tillage systems (Moret and Arrue 2007).

Reduced tillage systems, specific to sustainable agriculture, require productivity at least equal to that of conventional technology, optimized energy efficiency and, at the same time, diminished environmental impact. Taking into account these requirements, the main objective of this study was to determine the opportunities for energy efficiency and labour productivity improvements of soil tillage in arable crop production.

MATERIALS AND METHODS

The experiment was performed at agricultural company “PK Nova Gradiška” near village Štivica, located 150 km south-east from Zagreb (45° 09’ N, 17° 31’ E). Experimental field consisted of 12 plots with dimension length 185 m x width 54 m each, organized as randomized blocks with three replications. Test crops were oilseed rape (*Brassica napus* L.) and winter barley (*Hordeum vulgare* L.).

The tillage with different systems was performed on the Hypogley-vertic type of soil (Skoric 1986) and its texture in ploughed layer belongs to the silty clay loam (Table 1). The climate in this area is semi-humid with a total annual precipitation of 776 mm and an average annual temperature of 11,0 °C (source: Meteorological and hydrological institute of Croatia).

Table 1 Soil particle size distribution

Depth, cm	Particle size, %				Texture[1]
	0.2-2 µm	0.05-0.2 µm	0.002-0.05 µm	<0.002 µm	
0-30	16.0	28.0	22.0	34.0	SiCL
30-60	13.0	32.0	26.0	29.0	SiCL-SiL
60-90	13.0	31.0	28.0	28.0	SiCL

[1] SiCL = Silty clay loam, SiL = Silty loam

Implements, which were included in different tillage systems, are as follows:
Conventional tillage – mouldboard plough, disc harrow, seedbed implement, drill (CT);
Non-conventional tillage 1 – chisel plough, disc harrow, seedbed implement, drill (NcT1);
Non-conventional tillage 2 – chisel plough, rotary harrow with integrated drill (NcT2);
Non-conventional tillage 3 – mouldboard plough, rotary harrow with integrated drill (NcT3).

In this experiment a 4WD tractor with engine power of 136 kW was used for all tillage operations. The working width of the tillage implements (Table 2) was chosen according to the pulling capacity of the tractor.

Table 2 Soil particle size distribution

Field operation	Tractor	Implement	Working width (m)
Ploughing	JD 7820	Kuhn Multimaster 151	1.40
Chiselling	JD 7820	Agram GeoDec SVD-306	3.20
Discharrowing	JD 7820	Kuhn Discover XM 44/660	5.50
Seedbed preparation	JD 7820	Lemken Korund 750L	7.50
Sowing	JD 3650	Tive 901	6.00
Harrowing+Sowing	JD 7820	Kuhn Integra 3000	3.00

Energy requirement of each tillage system was determined based on the tractor's fuel consumption. Energy equivalent of 38.7 MJ L^{-1} was presumed (Cervinka 1980). The amount of fuel consumed was measured for each implement during tillage and sowing on each plot. On plots where chisel was used the primary tillage were done to the same depth as with mouldboard plough (approx. 30 cm). Due to the fact that in NcT2 and NcT3 systems the sowing was done along secondary tillage in single pass, the energy consumption for sowing was also added to CT and NcT1 systems.

Table 3 Date of field operations and application rates

Description	Oilseed rape	Winter barley
	Tillage & Sowing	
Primary tillage	July 7th 2013	October 14th 2014
Soil water content (%) at 5; 15; 30 cm depth	32.3; 34.9; 43,3	39.2; 51.6; 49.8
Secondary tillage	September 3rd 2013	November 15th 2014
Soil water content (%) at 5; 15; 30 cm depth	20.2; 42.0; 41.7	37.7; 54.4; 54.4
Sowing date	September 3rd 2013	November 15th 2014
Crop-cultivar (kg ha^{-1})	Extrom (2.9)	Barun C1 (200)
	Fertilizing	
Application date	August22nd 3013	October 13th 2014
Fertilizer (kg ha^{-1})	MAP 12:52 (200) KCl 60 % (100)	MAP 12:52 (200); KCl 60% (100); Urea 46% (50)
Application date	February 18th 2014	February 20th 20015
Fertilizer (kg ha^{-1})	CAN 27% (250)	CAN 27% (200)
Application date	March 15th 2014	April 4th 2015
Fertilizer (kg ha^{-1})	Urea 46% (300)	Urea 46% (150)
	Crop protection	
Application date	September 3rd 2013	February 22nd 2015
Chemical-rate (l ha^{-1})	metazaklor+klomazon (1.9+0.2)	triasulfuron (0.045)
Application date	October 20th 2013	April 14th 2015
Chemical-rate (l ha^{-1})	quizalifop p tefuril (1.0)	epoksikonazol+krezoksim-metil (0.8)
Application date	March 21st 2014	April 15th 2015
Chemical-rate (l ha^{-1})	klorpirifos+cipermetrin (0.9)	pinoksaden (0.7); tribenuron methyl (0.012)
Application date	April 7th 2014	May 4th 2015
Chemical-rate (l ha^{-1})	boskalida+dimoksistrobin (0.5)	azoksistrobin+klortalonil (2.5)
	Harvest	
Harvesting date	July 1st 2014	June 26th 2015

The labour requirement was determined by measuring the time for finishing single tillage operation at each plot of the known area. The yields were determined by weighing grain mass of each harvested plot, and recalculated according to storage grain moisture content. Schedule of the field operations (tillage, fertilizing, sowing, crop protection, harvesting) and soil moisture content at the moment of tillage are shown in Table 3. On the experimental field previous crop was winter wheat. Fertilization and crop protection was uniform in all systems, determined by crop specific nutrient requirements and pest occurrence.

The climate conditions during these field trials were favourable for growing rapeseed and barley. Mean monthly air temperatures matched the long-term averages, with a sufficient amount of precipitation during the growing season which is evident from Walter climate diagram (Figure 1).

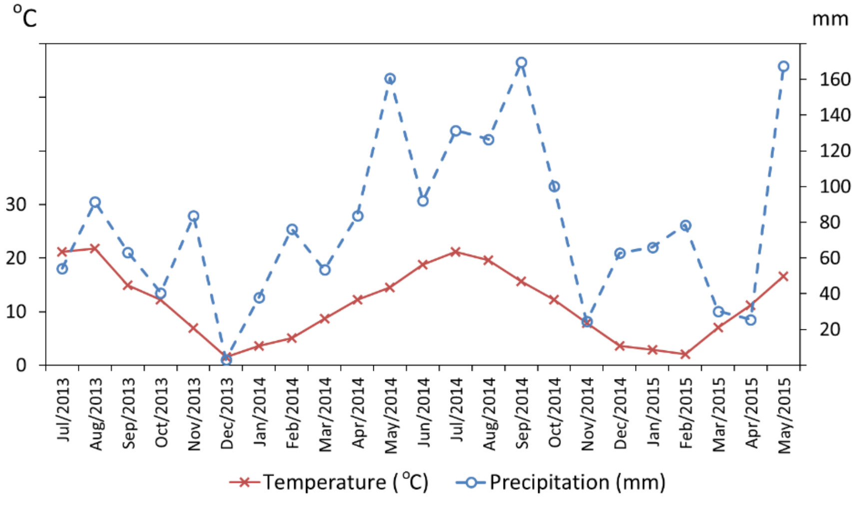

Fig. 1 Walter climate diagram for oilseed rape and barley cropping period.

Statistical analysis of data was done with computer program SAS (SAS Institute 2002) using analysis of variance (ANOVA). The significance of differences between the observed parameters were indicated by F-test at the level of probability p = 0.05.

RESULTS AND DISCUSSION

Yield

In oilseed rape production the greatest average yield of 3.87 t ha^{-1} was achieved by conventional soil tillage system (CT) followed by NcT2 with average yield of 3.61 t ha^{-1} and NcT1 with 3.53 t ha^{-1}. The lowest average yield was obtained with NcT3 system 3.36 t ha^{-1}, which is 13 % lower than CT. According to ANOVA, differences of average oilseed rape yields obtained by different soil tillage systems were statistically significant between CT and NcT3, at probability level of $p<0.05$, while NcT1 and NcT2 yields were not significantly different to other tillage systems. In the cultivation of winter barley there were no significant differences in yields achieved on different soil tillage systems. The highest average yield of 5.47 t ha^{-1} was obtained with NcT1 system, while the lowest average yield of winter barley was on NcT2 system 5.28 t ha^{-1}.

Energy efficiency and labour productivity

Soil tillage with mouldboard plough was expectedly the most energy and labour consuming task, and has largely contributed to high fuel consumption in tillage systems where was applied (Table 4). In oilseed rape production the greatest fuel consumption in soil tillage was recorded in CT system 42.7 L ha^{-1}. NcT3 system enabled 15.2 % saving and NcT1 16.8 % saving of fuel compared to conventional tillage. The greatest energy saving per hectare (24 %) in oilseed rape production was obtained by NcT2 system. Similar trends regarding energy consumption were noticed also in winter barley production where the share of fuel used for primary tillage ranged from 48 % for chiselling in NcT1 to 67 % for ploughing in NcT3 system, of total energy used for tillage and sowing.

Comparing these data to other researches, some variations could be expected due to different soil types, field conditions and machinery and equipment used. For example, Filipović et al. (2004) reported 42.1 L ha^{-1} fuel consumption in conventional tillage system, 30.5 L ha^{-1} in tillage system similar to NcT1 and 36.9 L ha^{-1} in system similar to NcT2 in this research, while Košutić et al. (2005) reported 46.9 L ha^{-1} in CT system and 29.3 L ha^{-1} in NcT1 resembling system. Both mentioned studies were conducted on silty-loam, therefore a somewhat lighter texture soil.

Specific energy requirements for different soil tillage systems varied due to wide range of yields obtained for crops cultivated, but a decrease of energy demands with reduction of soil tillage is clearly noticeable. In oilseed rape production the greatest specific energy consumption of 426.7 MJ t^{-1} was recorded in conventional tillage system as a consequence of highest fuel consumption, in spite of the highest average yields obtained. Tillage system NcT3 with 15.2 % lower fuel consumption provided only 2.3 % lower specific energy, due to significantly lower yields. In contrary, in tillage systems where average yields were on par with conventional system, considerable savings were achieved, 8.6 % less specific energy requirement in NcT1 and 18.4 % less in NcT2 compared to CT. Similar trends regarding specific energy consumption were noticed also in winter barley production where achieved savings varied from 7.4 % in NcT3 tillage system 43.3 % in NcT2 compared to highest specific energy (362.4 MJ t^{-1}) recorded in CT.

Productivity of different soil tillage systems have been calculated both considering the time required per hectare and in respect to obtained yields. Conventional tillage (CT) was the most time consuming system with 2.05 h ha^{-1} spent in oilseed rape production, while in winter barley the highest overall value was recorded in NcT3 system, 2.56 h ha^{-1} or 9.1 % more than for conventional tillage. The most efficient tillage systems were NcT1 and NcT2, in both growing seasons. Achieved saving of time required for soil tillage and sowing of oilseed rape were 37.8 % in NcT1 and 39.7 % in NcT2, while in winter barley production NcT1 system consumed 32.7 % less and NcT2 system 32.0 % less time per hectare compared to conventional tillage.

Similar relations are noticeable in productivity per ton of grain yield, where NcT3 required 0.56 h t^{-1}, or 6.0 % more than CT system in oilseed rape production, and 0.48 h t^{-1} in winter barley, or 9.3 % more than conventional tillage. Again the most efficient systems were NcT1 and NcT2, with 31.7 % (NcT1) and 35.3 % (NcT2) higher productivity than CT in oilseed rape, while in winter barley NcT1 system was 34.2 % and NcT2 31.1 % more productive compared to conventional tillage. Coicu (2010) and Košutić et al. (2007) also highlighted a significant increase in labour productivity with degree of soil tillage reduction, realised through adequate tillage systems where yields were not impaired.

Table 4 Energy and labour requirement of different soil tillage systems

	Oilseed rape				Winter barley			
Tillage system	Fuel L ha^{-1}	Energy MJ t^{-1}	Productivity h ha^{-1}	h t^{-1}	Fuel L ha^{-1}	Energy MJ t^{-1}	Productivity h ha^{-1}	h t^{-1}
CT	**Average yield = 3.87 t ha^{-1} a [(1)]**				**Average yield = 5.355 t ha^{-1} a**			
Plough	24.23	242.1	1.30	0.34	24.96	180.4	1.36	0.26
Disc harrow	9.76	97.5	0.33	0.09	12.82	92.6	0.33	0.06
Seed-bed implement	5.86	58.6	0.17	0.04	7.84	56.7	0.28	0.05
Drill	2.85	28.5	0.25	0.06	4.53	32.7	0.37	0.07
Total	**42.70**	**426.7**	**2.05**	**0.53**	**50.15**	**362.4**	**2.34**	**0.44**
NcT 1	**Average yield = 3.53 t ha^{-1} ab**				**Average yield = 5.474 t ha^{-1} a**			
Chisel	17.07	187.3	0.53	0.15	13.37	94.5	0.66	0.12
Disc harrow	9.76	107.1	0.33	0.09	9.35	66.1	0.27	0.05
Seed-bed implement	5.86	64.3	0.17	0.05	7.84	55.4	0.28	0.05
Drill	2.85	31.3	0.25	0.07	4.53	32.0	0.37	0.07
Total	**35.54**	**390.0**	**1.28**	**0.36**	**35.09**	**248.1**	**1.58**	**0.29**
NcT 2	**Average yield = 3.61 t ha^{-1} ab**				**Average yield = 5.279 t ha^{-1} a**			
Chisel	17.07	183.1	0.53	0.15	13.37	98.0	0.66	0.12
Rotary harrow + drill	15.38	165.0	0.71	0.20	14.64	107.3	0.93	0.18
Total	**32.45**	**348.1**	**1.27**	**0.35**	**28.01**	**205.3**	**1.59**	**0.30**
NcT 3	**Average yield = 3.36 t ha^{-1} b**				**Average yield = 5.348 t ha^{-1} a**			
Plough	24.23	279.0	1.30	0.39	24.96	180.6	1.37	0.26
Rotary harrow + drill	11.99	138.1	0.59	0.17	21.40	154.9	1.19	0.22
Total	**36.22**	**417.1**	**1.89**	**0.56**	**46.36**	**335.5**	**2.56**	**0.48**

[(1)] Different letters indicate significant ($p \leq 0.05$) differences

CONCLUSIONS

The results of this research reveal some important advantages of non-conventional tillage systems over the conventional tillage in arable crop production. Soil tillage systems greatly differ regarding energy requirement. Substitution of mouldboard plough with chisel in primary tillage (NcT1 and NcT2) provided substantially lower fuel consumption in those tillage systems than in CT, and in consequence, the specific energy efficiency was improved compared to conventional tillage. Labour requirement comparison also shows that those tillage systems were much more productive than conventional tillage with mouldboard plough.

Considering that the average yields in non-conventional soil tillage systems, with the exception of NcT3 system in oilseed rape production, were not impaired by reduction of soil tillage this short-term experiment showed that non-conventional tillage systems could be an important tool to improve energy efficiency and labour productivity in oilseed rape and winter barley production. In the selection of preferred soil tillage system, assuming uniform levels of yield, the advantage should be given to a system with lower level of tillage intensity in order to minimise energy and labour requirements.

In order to promote non-conventional tillage systems to a greater percent of acreage, further researches should be carried out to investigate the influence NcT systems in cultivation of spring crops like maize and soybean which are also represented in crop rotation on majority of arable land in Croatia.

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44. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

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PRELIMINARNO ISPITIVANJE VIBRACIJSKOG PODRIVAČA INO VR 500 U VINOGRADU

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SAŽETAK

Rad prikazuje rezultate preliminarnog ispitivanja vibracijskog podrivača INO VR 500 u vinograda agregatiranog s traktorom gusjeničarom nazivne snage motora 44 kW. U ispitivanju su izmjerene velike vučne sile u rasponu F_v= 20 - 28 kN. Zbog relativno male brzine kretanja v= 0,66 – 0,9 km h^{-1} i izračunata vučna snaga nije velika. Potrebna snaga za pogon radnih elementata preko priključnog vratila traktora na vibracijskom podrivaču je < 2 kW.

Ključne riječi: *vibracijski podrivač, višegodišnji nasadi, vučna sila, vučna snaga, snaga za pogon, traktor gusjeničar*

UVOD

U višegodišnjim nasadima broj prohoda traktora sa priključcima je velik i u uvjetima Slovenije iznosi kod integrirane proizvodnje jabuke do 30 ili čak do 40 prelazaka po istim tragovima tijekom cijele godine. Prolazi traktora izvode se i u neprikladnom stanju tla (mokro tlo), pa je djelovanje traktora na strukturu tla odnosno zbijanje u kolotragovima još štetnije. Poboljšanje fizikalnih svojstava tla izvodi se s rekultivacijom nasada i prorahljivanjem sabijenih kolotragova, odnosno traga traktorskih kotača s podrivačima. Ova oruđa imaju pasivne ili aktivne (vibrirajuće) radne organe. Sartori (2003) opisuje različite tipove podrivača, različite radne elemente kao i drugu opremu. Posebnu pažnju ističe i na osiguranju radnih elementa od lomova, odnosno oštećenja. Draghi et al. (2003) proučava različito pokrivena tla u voćnjaku obzirom na intenzitet prohoda u međurednom prostoru. Ustanovio je da učestali prohodi signifikantno utječu na redukciju makropora i otpor tla prodiranju penetrometra, kojeg vrijednost > 2,5 MPa ograničava normalan razvoj korijena. Sito et al. (2002) piše općenito o problematici održavanja plodnosti tla u voćnjaku i pokazuje rješenja za hrvatske uvjete. Filipović i suradnici (1998) ukazuju na štetne posljedice zbijanja tla kotačima standardnog poljoprivrednog traktora, te navode neke mogućnosti smanjenja zbijanja tla. Nenić et al. (1989) proučava učinak, potrošnju goriva i kakvoću distribucije gnojiva dvorednog podrivača s deponatorom mineralnog gnojiva. Poje (2005, 2007, 2008, 2009) piše o problematici i rješavanju zbijanja tla u višegodišnjim nasadima. Poje (2004, 2005) izvještava o utjecaju rada vibracijskog podrivača na mehanička svojstva tla. Tomasone et al (2011) u voćnjaku proučava novu generaciju vibracijskog podrivača s gledišta potrebne snage i ustanovljuje da je za rad podrivača potrebno između 28 i 57 kW pri brzini kretanja između 2,25 i 3,76 km/h. Radite et al (2010) ustanovljuje, da oscilacije vibracijskog podrivača mogu smanjiti potrebnu vučnu silu (snagu) za vuču podrivača. O većoj ukupnu snazi za rad podrivača sa uključenim vibracijskim djelovanjem izvještavaju istraživači (Bandalan et al, 1999, Niyamapa i Salokhe, 2000). Po drugoj strani Shahgoli i suradnici (2010) izvještavaju, da je kod oscilacijskog podrivača moguća redukcija potrebne vučne sile sa 25,8 na 9,3 kN u usporedbi sa podrivačem sa krutim radnim organima.

Namjena ovog preliminarnog ispitivanja je prikazati potrebnu snagu za rad vibracijskog podrivača INO VR 500 u realnim uvjetima u vinogradu.

MATERIJAL I METODE RADA

Uvjeti rada i tehničke karakteristike podrivača

Istraživanje je bilo locirano u vinogradu područja Orešje na Bizeljskem u Sloveniji. Tlo ima 25,5 % gline, 55,1 % praha i 19,4 % pijeska, a u vrijeme ispitivanja imalo je u prosjeku sadržaj vode 20,3 %.

Tablica 1 Tehnički podaci podrivača INO VR 500 (prema proizvođaču)
Table 1 Technical data of subsoiler INO VR 500 (source: producer)

Broj radnih organa Number of working elements	2
Radna dubinaWorking depth	≤ 500 mm Up to 500 mm
Masa stroja Weight of machine	490 kg
Volumen spremnika za gnojivo Volumen of tank for mineral ferilizer	180 l
Minimalna snaga traktora Minimal power of tractor	65 kW
Priključno vratilo PTO – Power take off	540 min^{-1}

Za prorahljivanje sabijenih tala u vinogradu korišten je dvoredni vibracijski podrivač VR 500, proizvod slovenskog proizvođača INO Industrijska oprema. Vibracije radnih organa ostvaruju se pomoću ekscentra koji kružno gibanje priključnog vratila pretvara u oscilacijsko gibanje. Podrivač ima i prigrađen dubinski deponator mineralnih gnojiva sa pneumatskom distribucijom. Za pogon i vuču podrivača korišten je traktor gusjeničar Fiat 55 - 85, nazivne snage motora 40,5 kW (55 KS) i težine 2830 kg.

Slika 1 Dvoredni vibracijski podrivač INO VK 500 priključen o traktor gusjeničar
Picture 1 Two row oscillating subsoiler INO VR 500 coupled with crawler tractor

Mjerni sustav i mjerene veličine

Mjerni lanac bio je sastavljena od tri dijela: senzora, digitalnog mjernog pojačala i računala sa programom CATMAN za prijem i obradu mjernog signala odnosno za mjerenje mehaničkih i drugih veličina. Digitalno pojačalo Quantum Hottinger Baldwin Messtechnik služilo je za pojačanje i obradu signala senzora. Frekvencija uzorkovanja iznosila je 10 Hz dok je dužina pojedinog mjerenja ovisila o vremenskom toku rada sa podrivačem. Za obradu podataka korišten je uobičajeni statistički software.

Vučne sile odnosno njene uzdužne komponente (F_{u1}, F_{u2}, F_{u3}) mjerene su pomoću dinamometarskog tro-zglobnog okvira postavljenog na hidrauličku trozglobnu poteznicu traktora. Vučna sila traktora predstavlja zbroj pojedinačnih komponenti vučnih sila. Iz vrijednosti ukupne vučne sile i brzine kretanja agregata izračunata je snaga za vuču oruđa. Okretni moment i broj okretaja priključnog vratila izmjereni su pomoću dinamometra za mjerenje momenta i prigrađenog senzora za brzinu vrtnje (Lorenz Messtechnik DR 2472 5000 Nm) postavljenog na priključno vratilo traktora. Iz izmjerenog momenta i broja okretaja na priključnom vratilu izračunata je potrebna snaga za pogon podrivača. Na traktor je prigrađen i dodatni kotač za mjerenje prijeđenog puta bez klizanja. Na osnovu prijeđenog puta i vremenske baze izračunata je trenutačna brzina kretanja traktora.

Proračun:

Ukupna vučna sila: $F_u = F_{u1} + F_{u2} + F_{u3}$ (1)

Vučna snaga: $P_v = F_u\, v$ (2)

Snaga za pogon: $$P_p = M\omega \quad (3)$$

$$P_p = M\pi \frac{n}{30} \quad (4)$$

Oznake:

v – brzina kretanja traktora (agregata), m/s

F_v – ukupna vučna sila, N

F_{u1}, F_{u2}, F_{u3} – uzdužne komponente vučne sile, N

P_v – vučna snaga, kW

P_{pv} – snaga potrebna za pogon priključka preko priključnog vratila, kW

M – moment na priključnom vratilu, Nm

ω - kutna brzina, rad

n – broj okretaja priključnog vratila, min^{-1}

Slika 2 Dinamometar (Lorenz Messtechnik DR 2472 5000 Nm) za mjerenje momenta i broja okretaja.

Picture 2 Sensor (Lorenz Messtechnik DR 2472 5000 Nm) for torque and PTO speed measurement

Slika 3 Dinamometarski tro-zglobni okvir za mjerenje vučne sile odnosno njenih uzdužnih komponente.
Picture 3 Three point hitch dynamometric framework for measuring of draft force and its longitudinal components

REZULTATI RADA I DISKUSIJA

U uvjetima vinograda na Bizeljskom obavili smo mjerenja potrebne snage za pogon i vuču dvorednog vibracijskog podrivača slovenskog proizvođača INO. Mjerenja smo proveli na dijelu ravnog terena vinograda, kao i na nagibu pri vožnje niz brdo uzduž vertikalno postavljenih redova trsova. Nagib je bio između 37 i 40 %. Mjerenja su provedena s uključenim priključnim vratilom traktora i bez uključenog priključnog vratila. Time je dobiven podatak za oscilacijski radni organ i kruti radni organ. Dubina rada na ravnoj dionici je bila je 25 cm, a na nagibu 29 cm. Mjerenja potrebne snage sa prvom generacijom vibracijskog podrivača istog proizvođača (Poje i suradnici, 2003) ukazala su na veliku potrebnu vučnu silu. Stoga je kod ovih mjerenja uzet za pogon i vuču traktor gusjeničar sa snage motora 40,4 kW zbog osiguranja većeg koeficijenta vuče na livadi u vinogradu. Traktor gusjeničar ima i veću težinu od traktora s kotačima iste snage.

U tablici 2 prikazani su rezultati mjerenja na ravnom dijelu vinograda, dok su u tablici 3 rezultati mjerenja pri kretanju agregata niz brdo. U tablicama su prikazane izmjerene veličine (moment i broj okretaja na priključnom vratilu, zajednička vučna sila i izračunane veličine (brzina kretanja, snaga na priključnom vratilu, vučna snaga i ukupna snaga) kod rada podrivača sa uključeni priključnim vratilom traktora i bez (sa oscilacijom radnih organa i bez oscilacije – kruti način rada).

Tablica 2 Potrebna snaga za pogon i vuču podrivača na ravnom dijelu vinograda pri dubine rada a= 25 cm

Table 2 Required power for draft and drive of subsoiler on horizontal section of the vineyard at a working depth a= 25 cm

Mjerenje Measurement		Moment Torque of PTO	Broj okretaja Speed of PTO	Brzina Velocity	Ukupna vučna sila Total draft force	Snaga za pogon Oscillating power	Vučna snaga Draft power	Ukupna snaga Total power
		Nm	min^{-1}	km/h	kN	kW	kW	kW
1	Prosjek Average	59,13	303,35	0,81	28,65	1,88	6,48	8,36
	Maksimum Maximum	124,12	323,25	1,27	37,00	3,74	10,06	12,08
2	Prosjek Average	46,79	272,76	0,82	23,53	1,34	5,28	6,61
	Maksimum Maximum	54,01	281,97	1,25	28,52	1,58	6,40	7,91
3	Prosjek Average	-	-	0,66	20,11	-	3,66	3,66
	Maksimum Maximum	-	-	0,73	31,43	-	5,18	5,18

Pri mjerenju potrebne snage traktor je vozio s relativno malom brzinom kretanja (0,66 do 0,93 km/h). No, u redovnoj eksploataciji vibracijskog podrivača u tom vinogradu je sa tim traktorom gusjeničarom to normalna radna brzina. Također broj okretaja priključnog vratila nije bio nazivnih 540 okretaja na minutu, već je varirao u rasponu 272 - 311 min^{-1} glede na pojedino mjerenje. Iz rezultata mjerenja i izračunanih parametara uočljivo je, da je u prosjeku za vuču podrivača u našim uvjetima bila potrebna velika vučna sila (20 – 28 kN), trenutačni maksimumi vučne sile čak su i dosta viši. Zbog relativno male brzine kretanja agregata i izračunata vučna snaga nije velika. Prikazani rezultati sukladni su s mjerenjima prošle generacije podrivača (Poje i Jejčič, 2003), te i rezultatima drugih istraživača na sličnim podrivačima (Shahgoli et al, 2010) i praktičnim iskustvima eksploatacijskih testiranja podrivača u voćnjaku ili vinogradu. Pri tako velikim vučnim silama javlja se i klizanje pogonskih kotača (ili gusjenica), a to klizanje može biti i veće na mokroj (vlažnoj) travi na ledini ili na tlu sa razasutim stajnjakom. U praksi to klizanje kotača traktoristi izbjegavaju tako, da podignu podrivač čime smanje dubinu rada. Prosječno potrebna snaga za pogon radnih organa je < 2 kW s uključenim osciliranjem radnih organa podrivača, što je sukladno sa rezultatima (Shahgoli et al, 2010). Iz ovih preliminarnih mjerenja vidljivo je da tzv. VVV traktori s kotačima mogu imati problema pri realizaciji dovoljno velikih vučnih sila za rad s ovakvim oruđima. No, to se može djelomično riješiti korištenjem traktora gusjeničara ili smanjenjem dubine rahljenja, ali to je upitno rješenje s razloga kvalitete rada, odnosno cilja ovog posla.

Tablica 3 Potrebna snaga za pogon i vuču podrivača niz brdo vinograda pri dubini rada a= 29 cm

Table 3 Required power for draft and drive of subsoiler on down slope section of the vineyard at a working depth a= 29 cm

Mjerenje Measurement		Moment Torque of PTO	Broj okretaja Speed of PTO	Brzina Velocity	Ukupna vučna sila Total draft force	Snaga za pogon Oscillating power	Vučna snaga Draft power	Ukupna snaga Total power
		Nm	min^{-1}	km/h	kN	kW	kW	kW
1	Prosjek Average	58,96	311,94	0,93	27,27	1,94	7,07	9,01
	Maksimum Maximum	88,49	351,36	1,23	35,99	2,87	10,00	12,24
2	Prosjek Average	-	-	0,72	24,58	-	4,92	4,92
	Maksimum Maximum	-	-	1,06	28,22	-	7,15	7,15

ZAKLJUČAK

Opetovani prolazi traktorskih agregata uvijek istim tragovima - kolotečinama u voćnjaku ili vinogradu u skoro bilo kakvim uvjetima imaju za posljedicu duboke kolotečine ispod kojih tlo ima nepovoljna fizikalna svojstva, a koja utječu na opskrbljenost zrakom, vodom i u konačnoj svrsi i na kemijska i biološka svojstva tla. Poboljšanje fizikalnih svojstava tla u među redu višegodišnjih nasada moguće je s primjenom vibracijskog podrivača. Mjerenja parametara za izračun potrebne snage za vuču i pogon vibracijskog prorahljivača pokazala su, da je potrebna vučna sila limitirajući faktor korištenja podrivača s traktorima "točkašima" za vinogradarstvo i voćarstvo. Unatoč potrebnoj velikoj vučnoj sili, mjerenja su pokazala da se zbijeno tlo može rahliti i s traktorom relativno male snage, ali ako je to traktor gusjeničar s velikom koeficijentom vuče na ledini. Brzina kretanja traktora u ispitivanjima je bila mala, pa je zbog toga i izračunata vučna snaga mala. Potrebna snaga za pogon oscilacijskih radnih organa na podrivaču je relativno mala.

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PRELIMINARY TEST OF OSCILLATING SUBSOILER INO VP 500 IN WINEYARD

ABSTRACT

In the paper there is a description of the engaged power required for the oscillating subsoiler INO VR 500 on a crawler tractor with 44 kW nominal power to work in a vineyard. Measurements of the torque, speed of PTO, draft forces in the connecting links and velocity during the work of subsoiler with oscillating working elements and rigid working elements were carried out. The results were used to calculate the required draft power and oscillating power. We measured high draft force F_v*=20-28 kN. Due to the relatively low velocity v= 0.66 to 0.93 km* h^{-1}*, the calculated draft power is not large. Oscillating power required to drive the working elements by PTO at oscillating subsoiler is lower than 2 kW.*

Key words: *oscillating subsoiler, perennial plantation, draft force, draft power, oscillating power, crawler tractor*

44. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

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Stručni rad
Expert paper

ENERGY CONSUMPTION OF A HAMMER MILL WHEN CHOPPING MISCANTHUS STALKS

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SUMMARY

For pelletizing and briquetting agricultural biomass that remains on the field (straws, cobs, chaff, etc.), respectively biomass from energy crops such as: Miscanthus, energy willow, paulownia, etc.), the material has to be chopped/shredded suitably for the purpose, requiring an energy consumption that most of the times is higher than the one necessary for the main operation: pelletizing / briquetting.

The paper presents experimental researches conducted for determining the energy consumption resulted when chopping miscanthus stalks, using 4 shapes of hammers, mounted on the rotor of a mill (shredders), 4 screens and one rotor speed, in order to identify a correlation between these parameters.

Key words: *Miscanthus, energy consumption, hammer mill, chopping*

INTRODUCTION

Considering the high production of vegetable matter, biomass gradually substitutes wood as an alternative energy source [1, 3, 10, 13]. Biomass is formed such as energetic plants like willow, energetic grass, rape, rice, wheat, miscanthus x Giganteus, etc. Out of these, miscanthus, according to studies [14], has a dry material production of 25 t/ha per season. Miscanthus cannot be used as it is harvested so it is subjected to a preparation process that is the sum of processes like cutting, grinding and briquetting. The high volume of biomass represents an impediment for final use there for it is transforms in pellets or briquettes [5, 10]. One of the first steps in plant preparation happens in the field where Miscanthus harvesting can be done with or without cutting. Out of all technological process of plant preparationan important part regarding energy consumption happens during cutting and grinding process. The energy consumption can be estimated by studying a series of parameters like plant behavior when applying different forces like shear forces, simple cutting and compression, or by using different equipment, each having its own characteristics that need to be considered.

Previous studies highlight the necessity to develop efficient harvesting and grinding equipment's for Miscanthus crops. Taking this into consideration, Johnson et al. (2012), studied the effect of the cutting blades speed and beveling on the cutting energy consumption. Thus tests were done using three blade bevel angles and cutting speeds to determine the energy consumption for cutting one straw of Miscanthus X Giganteus. They concluded that the specific cutting energy was directly proportional with the cutting speed and the cutting energy was proportional with the straw diameter.

The main equipment used for the vegetal materials grinding are hammer mills because the grinding process requires less energy consumption. The grinded material properties depend on the sieve openings dimensions and the machine feed flow.

Experimental tests done by researches shown that the smaller the particle size is the energy consumption is higher [6, 7, 8, 9]. Studying energetic willow researches showed a specific energy consumption of 99Mj/Mg for hammer mill equipment and the sieve orifices of 3.2 mm. [6, 7, 8, 9].

Another study that shown the energy consumption during grinding used as raw material wood and it demonstrated an increase in energy consumption of 1.3 to 2.5 % for sieves with orifices from 2.0 to 0.6 mm. [2].

Other tests done by researchers using corn stalks, concluded that the energy consumption variation was between values 17-46 MJ/Mg for a hammer mill thickness of 6.4 mm and rotor speed between 54-86 m/s [6]. Recent experimental tests regarding specific energy consumption tried to develop a pattern during the process of cutting/grinding by distributing grinded material in classes of dimensions [7].

Müller (2003) and Schubert&Bernotat (2004), in their papers, realized a serious of tests with hammer mills for grinding materials. The materials used for testing were wheat straw, switchgrass, and barley straws. Tests revealed the highest specific energy consumption no matter the sieves orifices dimensions for switchgrass unlike the other two plants. For wheat straws the specific energy consumption was 51.6, 37.0, respectively 11.4 kWh/t for a moisture content of 4–7% and sieves dimensions of 0.8, 1.6, 3.2 mm. For corn stalks the specific energy was 11 kWh/t for a moisture content of about 12% and the sieve dimension of 3.2 mm. Thus, it was concluded that the lower the sieves orifices dimensions are, the higher the specific energy consumption is.

The main objective of this paper was to determine the specific energy consumption of a hammer mill when chopping mischantus stalks and considering different sieves orifices and types of hammers.

MATERIAL AND METHODS

Experimental researches for determining energy consumption for grinding Miscanthus stems were realized on a hammer mill - TCU (fig.1) equipped with an inclined plan (material feeding chamfer), collecting the hash in bags, through a two way evacuation system, hash was directed with the help of a shutter. Miscanthus stem grinding is realized through hitting and shearing between hammers mounted on the hammer disk, and counterknives.

Figure 1 Vegetal waste mill (hammer mill) – TCU

The main characteristics of the milling equipment:

- Electric motor power: 22 kW;
- Electric motor speed: 2.940 rot/min;
- Milling capacity: 900 m^3/h
- Interchangeable grinder sieve with different size.

For experiment sieves with ø7; ø10 and ø25 mm holes sizes were used, on four types of knives (A, B, C and D), and the speed was varied by a frequency converter from 50 Hz (2.940 rpm); 47.5 Hz; 45 Hz; 42.5 Hz and 40 Hz. Taking the fact that dried Miscanthus stems are light and bulky, experiments were realized with each sample weighing 5kg

RESULTS AND DISCUSSION

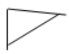
In table 2 are presented the results obtained from the experimental research.

All the results presented in table 2 are adequate for a rotation corresponding at 50 Hz frequency.

The results were processed by Microsoft Excel program in order to realize the graphs of dependence between sieves holes diameter and energy consumption, in different hammer types.

From data analysis from table 2, the experimental points were dragged in fig.2 for the specific energy consumption caused by the sieves orifices dimensions. We can see, though, the value grouping for the four sets of experiments, which proves the influence of the sieve dimensions on the plant grinding energy.

Table 2 Results obtained during experimental testing

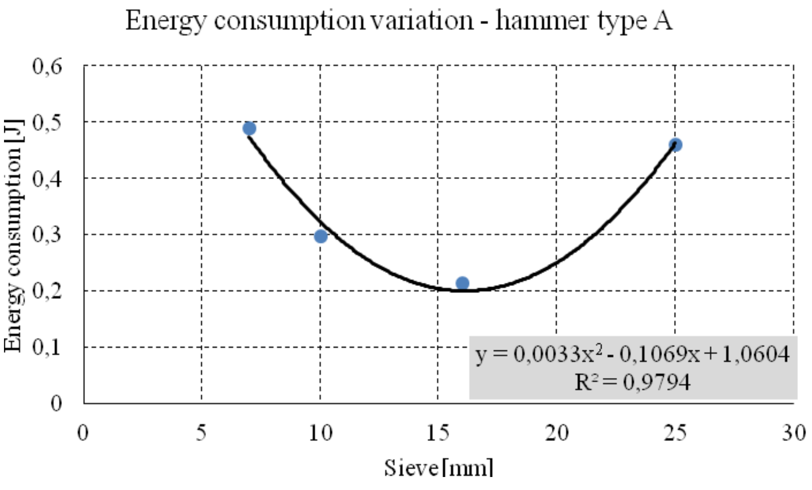
Hammer type	Sieve mm	Time s	Energy consumption MJ
A 	25	34.65	0.461
	16	22.24	0.215
	10	23	0.298
	7	36	0.489
B 	25	17	0.278
	16	20	0.324
	10	31	0.514
	7	41	0.486
C 	25	20	0.261
	16	29	0.554
	10	27	0.475
	7	42	0.572
D 	25	19	0.259
	16	16	0.224
	10	26	0.361
	7	37	0.574

Analyzing the first energy variation curve it can be observed that the energy consumption decreases for the sieves orifices of Φ16 and Φ10 and then increases for the sieve Φ7. Also, the best correlation coefficient for hammer type A used during tests was obtained by regression analysis, for a polynomial function, R^2=0.9794. These values shown good correlation between the two data analyzed. The highest value of the energy consumption, E, was given for sieve Φ7: E = 0.489 MJ.

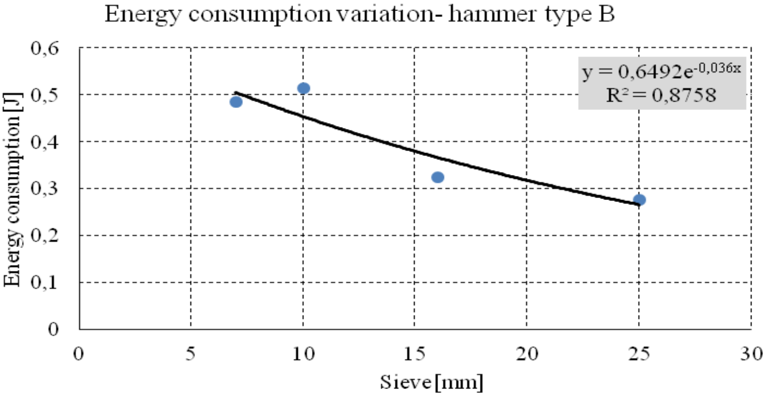
In figure 2.b. the energy consumption variation is analyzed for the hammer type B. As it can be observed the correlation coefficient obtained through regression analysis had a high values for an exponential function, R^2=0.8758, still it doesn't match the first hammer used for testing. It seems that the highest value of the energy consumption was obtained for the sieve with orifices Φ10, E=0.514 MJ.

Also for the third type of hammer, C, used for testing, it can be concluded that for the smallest sieve dimensions the higher energy consumption was, thus for the sieve Φ7, where the energy was E = 0.572 MJ. The regression analysis gave a correlation coefficient R^2=0.8516 for a polynomial function.

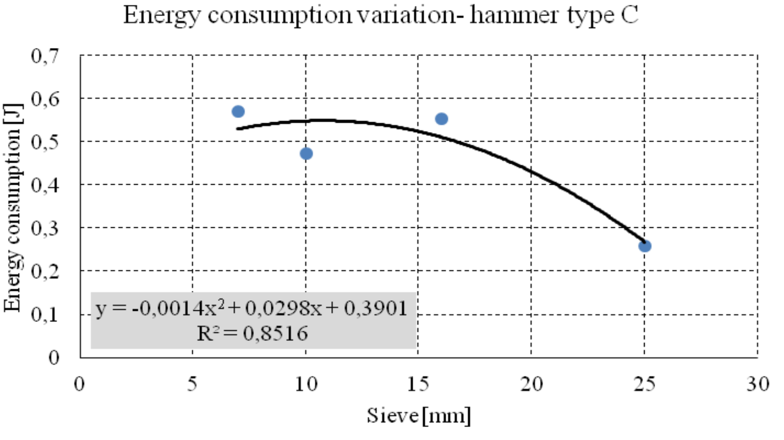
For the last type of hammer analyzed, D, the curve obtained resembles the curve for the hammer type A, with the observation that the energy consumption registered for the sieve with Φ7 was higher, E = 0.574 MJ. The correlation coefficient obtained through regression analysis , R2 = 0.9761.


Energy consumption variation - hammer type A
Energy consumption [J]
Sieve [mm]
0,6
0,5
0,4
0,3
0,2
0,1
0
0
5
10
15
20
25
30
y = 0,0033x2 - 0,1069x + 1,0604
R² = 0,9794

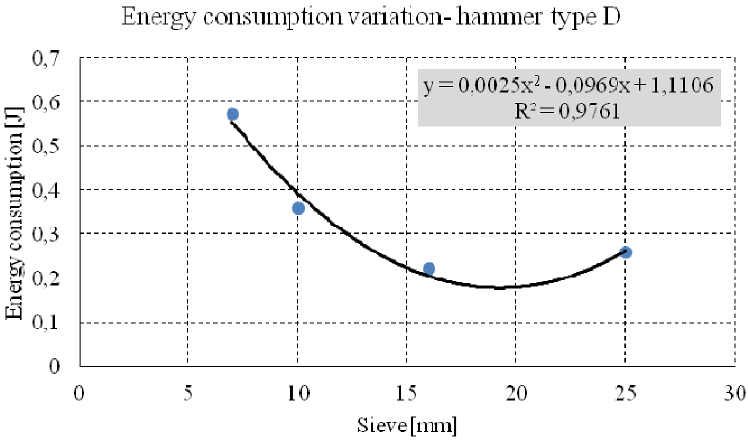
a.


Energy consumption variation- hammer type B
Energy consumption [J]
Sieve [mm]
0,6
0,5
0,4
0,3
0,2
0,1
0
0
5
10
15
20
25
30
y = 0,6492e-0,036x
R² = 0,8758

b.


Energy consumption variation- hammer type C
Energy consumption [J]
Sieve [mm]
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
0
5
10
15
20
25
30
y = -0,0014x2 + 0,0298x + 0,3901
R² = 0,8516

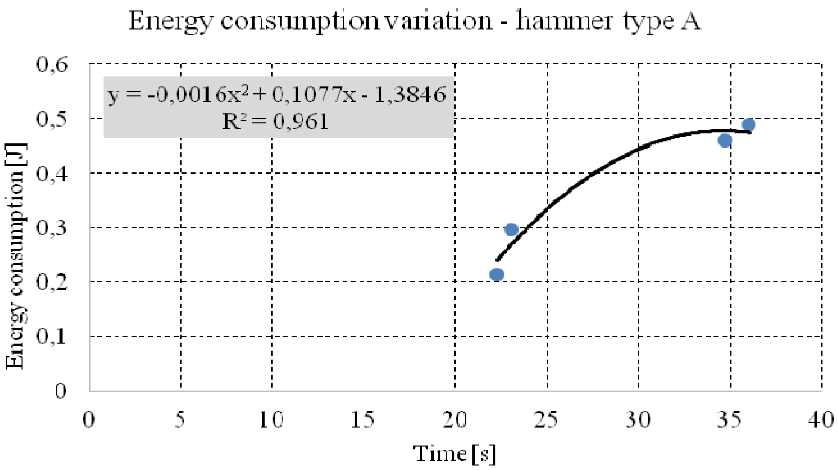
c.



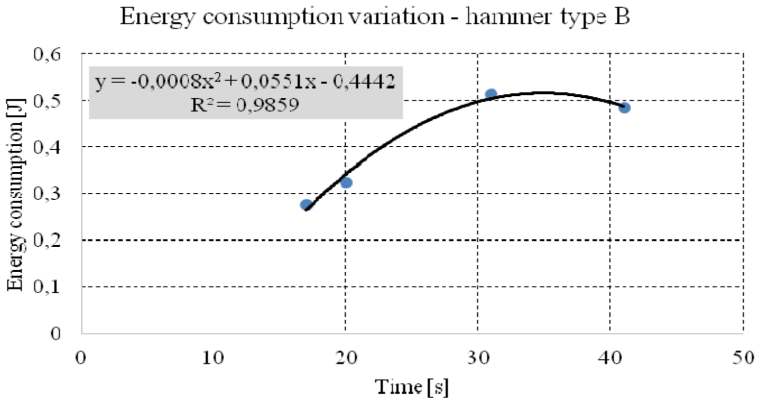
d.

Figure 2 - Energy consumption variation depending on sieves holes diameter; (a. hammer type A; b. hammer type B; c. Hammer type C; d. hammer type D

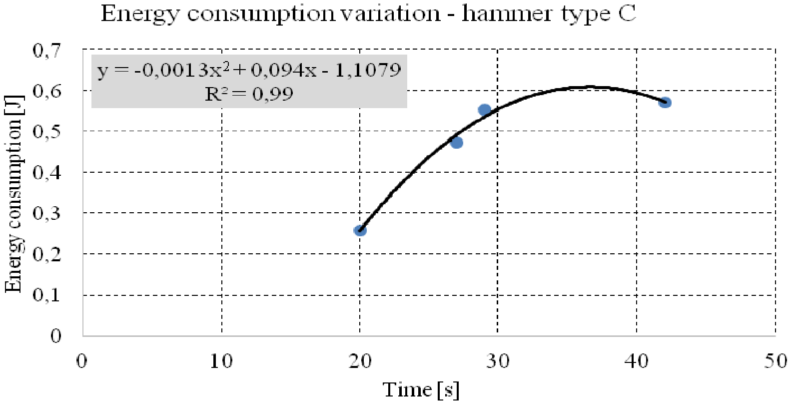
The variation curves drown in figure 3 represent the energy consumption in correlation to the testing time for each sample. A regression analysis was applied for all four types of hammers (A, B, C, D). The correlation coefficient obtained for all four samples was higher than 0.961. As it can be seen the highest values was recorded for hammers type C and D, $R^2 = 0.99$. The values of the correlation coefficient express the accurate estimation of the energy consumption in correlation to the time necessary for testing materials.



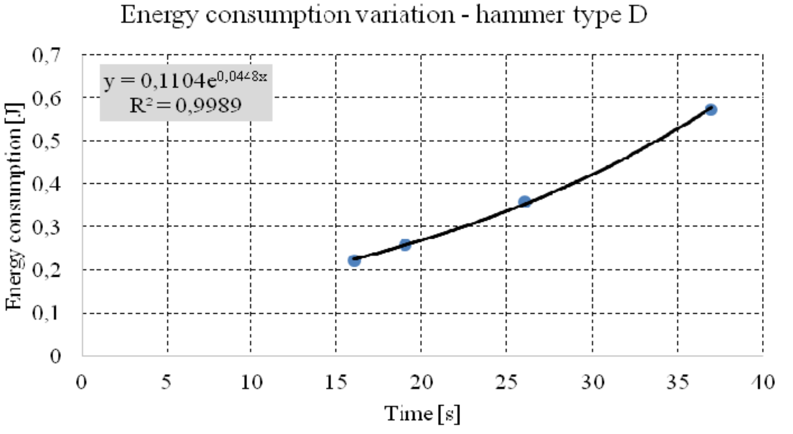
a.



b.



c.



d.

Figure 3 Energy consumption variation depending on testing time; a. hammer type A, b. hammer type B, c. Hammer type C, d. hammer type D

Also, in figure 3 it can be observed that the highest time necessary for grinding the Miscanthus samples happened for the sieve Φ7 which is in accord with the analysis presented in figure 2.

CONCLUSIONS

As mentioned energetic plants are subjected to complex operations during processing, from harvesting to briquetting. In this paper using a TCU hammer mill, the influence of the sieves orifices dimensions on the energy consumption of the equipment could be highlighted. Also, the energy consumption variations curves in correlation to testing time were drawn.

An important conclusion is that the smallest sieve orifices diameter involve the higher testing time, and also, the higher energy consumption during tests. According to hammer mill type, for Φ7, the energy consumption was E= 0.489 MJ (hammer type A), E = 0.485 MJ (hammer type B), E = 0.572 MJ (hammer type C) and E = 0.574 MJ (hammer type D).

Another aspect that can be mentioned is that the correlation coefficient was for both aspects analyzed higher than $R^2 \geq 0.851$ (for energy consumption variation in correlation to sieves orifices dimensions), and higher than $R^2 \geq 0.961$ (for energy consumption variation in correlation to testing time).

All experimental results can be used as a starting point for new experimental research regarding the needed power for biomass homogenization in anaerobic fermenter.

ACKNOWLEDGEMENT

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44. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

UDC 620.95:662.7
Izvorni znanstveni rad
Original scientific paper

FINITE ELEMENT MODEL FOR SIMULATING MECHANICAL BEHAVIOUR OF BIOMASS RESIDUES

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ABSTRACT

Finite element modelling is a useful tool to analyse mechanical behaviour of various materials. In recent times, finite element analysis is more extensively used to determine complex behaviour of biological materials. This study focuses on prediction of mechanical behaviour of biomass residues under compression and expansion using finite element analysis. A rheological model that describes mechanical behaviour of bulk biomass residues has been developed and implemented into ABAQUS finite element software. Model parameters have been determined by a non-deterministic fitting procedure and the potential of the modelling approach to predict mechanical behaviour of the biological material has been analysed. Developed rheological model and proposed 2D finite element modelling approach has potential to predict mechanical behaviour of biomass residues under compression and expansion if the model parameters are defined correctly.

Key words: *finite element modelling, biomass compression and expansion, biomass residues, process simulation*

INTRODUCTION

Biomass residues are extensively used as bedding and fodder material in animal production or as energy (Bartzanas et al., 2010) and building material source (Lawrence et al. 2009). Due to low bulk and energy density of the raw biomass the biomass should be pre-processed through densification (compression) in order to reduce biomass handling, storage and transportation costs (Kaliyan & Morey, 2009). For densification of biomass residues, extrusion process or a compression against a fixed wall is used. The overall performance of the biomass compression processes is influenced by a large numbers of site dependent parameters concerning operating conditions and biomass material, such as biomass composition and moisture content (Galedar et al., 2008), particle size and orientation (Galedar et al., 2008), process temperature (Faborode, 1989), compression chamber design and a clamping force. The increasing energy prices have led to a renewed interest in biomass compression modelling to understand the densification mechanisms. With the current power of computational systems these models can contribute to more efficient machine design and operation which could also result in higher biomass densities and higher process efficiency. Such prediction models could either be utilised to predict the overall process performance in a fast and a cost effective way (Kaliyan & Morey, 2009), as a decision supporting system (Aurbacher et al., 2013) or as a tool for education and trainings (Matthews et al., 2013). Experiments for these purposes can often be very expensive and unpractical.

Different modelling approaches have been proposed for analysis of mechanical behaviour and modelling of biomass residues. Fabrode & O'Callaghan (1989) proposed a one-dimensional rheological model where the compression process is divided into several phases, defined by a certain material behaviour. Mohsenin (1986) suggested that the compression behaviour of biomass can be described in a simple way by means of Maxwell model. Rheological models can predict stress-strain relations during biomass compression in a fast way for specific operating conditions and biomass composition. However, the model parameters need to be defined carefully in order to predict the behaviour in a quality way. The multidimensional discrete element method simulates the compression process as a sequence of mechanical interaction between particles characterised by different rheological models at the particle level. This kind of a modelling approach has been used to analyse the bending behaviour of crop stalks (Leblicq et al., 2015), densification of biomass grinds (Mani et al., 2003) or for a separation process of grain and straw (Lenaerts et al., 2014). However, due to its high computational intensity and high number of input variables simulation of a bulk sample consisting of a large number of biomass particles is still impractical for a large scale analysis. As FEM approaches do not consider biomass as a sum of individual particles but rather as a continuum characterised by a rheological model in multi-element objects the process analysis is very useful in terms of delivered information regarding the process in a more time effective way. Bano et al. (2013) used FEM to analyse the influence of knots and defects on s stress distribution in a wooden beams and to predict bending load capacity (Bano et al, 2011). Petru et al. (2012) analysed mechanical behaviour of an individual seed and later extended the research to bulk seeds (Petru et al, 2014). However, mentioned models are limited only to simulation of compression and not both compression and expansion of the material.

This paper analyses the potential of developed FEM approach to simulate the mechanical behaviour of biomass residues during compression (loading) and expansion (unloading). For this purpose, a rheological model that can be used for simulation of biomass residues under compression and expansion has been developed and the model has been implemented into ABAQUS FEM simulation software. The model parameters have been defined by a non-deterministic fitting procedure.

MATERIAL AND METHODS

Compression setup

In order to define model parameters and to analyse the potential of FEM approach to simulate loading and unloading of biomass residues (namely leaves and branches), dedicated measurements have been performed on a mobile compression box setup (Figure 1). The mobile compression setup consists of a compression box with a fixed bottom with a cross section of 0.20 by 0.50 m and height of 0.3 m. The compression force is measured with a load cell (type U2A, HBM, CITY COUNTRY), with a maximal force of 5 kN and the deformation is measured by a linear vertical transducer. In this study, compression profiles of leaves and branches were measured until 375 kg/m^3 (wed basis) and 150 kg/m^3 (wet basis). The compression tests were performed with random oriented particles. The samples were weighed to be 1.5 ± 0.05 kg (leaves) and 0.6 ± 0.05 kg (branches). Compression (plunger) speed was set to be 0.85 m/s. All the data was recorded on a 1 ms base. The load cell has an accuracy class of 0.02 and the LVDT position measurement system has an accuracy of ± 0.5 %/stroke range.

Figure 1 Compression box setup for material characterization of leaves (left), branches (centre and right)

FEM model

In order to describe mechanical behaviour of biomass residues during compression and expansion, a rheological based two-stage exponential stiffness model has been developed and implemented into ABAQUS software. The model describes bulk properties of biomass material as a visco-elastic material with exponential increase of stresses during compression. Many authors use a mechanical components to model the stress-deformation relation of biological materials. For this particular purpose, a combination of springs and dashpots has been used to describe the behaviour. Based on previous research, the spring stiffness was shown to be non-linear, and a friction element is required to model the fully plastic strain.

To model exponential increase of stress during compression exponential spring has been implemented. The equation that describes exponential stiffness of the spring is presented in Equation 1. The equation consists of 2 parameters (E_1 and E_2), that represent material property and will be defined by model fitting.

$$E_{EQ} = E_1 e^{E_2 \cdot x} \tag{1}$$

In order to limit maximum strain to 1 by using an infinite stress at that particular point the exponent has been defined by a ratio between current strain and the difference between maximum and current strain. Exponent (x) has been defined by Equation 2.

$$x = \frac{\varepsilon}{1-\varepsilon} \tag{2}$$

The overall model has been divided in 2 parts: compression part and expansion part (Figure 2). Compression part of the model consists of an elastic and plastic part which are represented by 2 exponential springs (in elastic and in plastic part) and a damper in the plastic part of the model. Friction coefficient is just a representation of inner stresses that are needed to obtain plastic deformation which will be kept in simulation by switching between compression and expansion model.

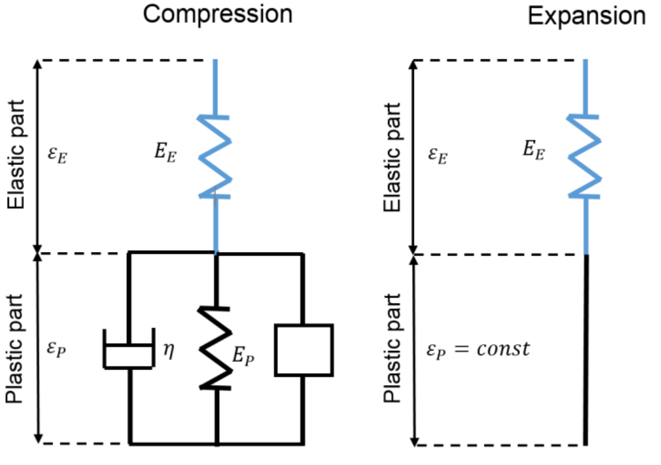

Figure 2 General scheme of material model

Developed compression part of the model is generally described by Eq. 3.

$$\sigma_{COMPRESSION} = E_{EQ}\varepsilon_{COMPRESSION} + \eta\dot{\varepsilon_P} \tag{3}$$

During simulation of compression 2 exponential springs are connected in series. A certain ratio (R) defined by Eq. 4 between spring stiffnesses of elastic and plastic part has been assumed. The ratio has been defined by measurements of material expansion after compression and fitting procedure.

$$R = \frac{\mathrm{E}_P}{\mathrm{E}_E} \tag{4}$$

In the fitting procedure the parameters that define exponential stiffness of the spring in plastic part have been used to determine the overall stiffness coefficient. The overall stiffness coefficient during compression has been defined by Eq. 5.

$$\mathrm{E}_{EQ} = \frac{\mathrm{E}_P}{R+1} \tag{5}$$

The overall deformation (strain) of the material during compression has been defined as a sum of deformation of both elastic and plastic part, and deformation rate as a sum of plastic and elastic deformation rates (Eq 6).

$$\varepsilon_{COMPRESSION} = \varepsilon_E + \varepsilon_P \quad \rightarrow \; \dot{\varepsilon}_{COMPRESSION} = \dot{\varepsilon}_E + \dot{\varepsilon}_P \tag{6}$$

Due to fact that the model is divided in 2 parts and due to model structure (based on Newton’s law the stresses in both parts are equal) equation for compression part of the model can be rewritten as follows (Eq 7 and Eq 8):

$$\sigma_{COMPRESSION} = \mathrm{E}_E\varepsilon_E \;\rightarrow\; \dot{\sigma}_{COMPRESSION} = \mathrm{E}_E\dot{\varepsilon}_E \tag{7}$$

$$\sigma_{COMPRESSION} = \mathrm{E}_P\varepsilon_P + \;\eta\dot{\varepsilon}_P \rightarrow \; \dot{\sigma}_{COMPRESSION} = \mathrm{E}_P\dot{\varepsilon}_P + \eta\ddot{\varepsilon}_P \tag{8}$$

To define stress as a function of overall strain, Eq 7 and Eq 8 can be rearranged to form the final general equation that describes process behaviour during material compression (Eq 9):

$$\begin{aligned}(\mathrm{E}_E + \mathrm{E}_P) \cdot \sigma_{COMPRESSION} + \eta \cdot \dot{\sigma}_{COMPRESSION} &= \\ = \mathrm{E}_E\mathrm{E}_P \cdot \varepsilon_{COMPRESSION} + \;\mathrm{E}_E\eta \cdot \dot{\varepsilon}_{COMPRESSION}&\end{aligned} \tag{9}$$

The expansion part of the model has been defined by one exponential stiffness spring that represents elastic behaviour of the material. The part of the model that describe elastic behaviour of the material during expansion is generally defined by Eq. 10.

$$\sigma_{EXPANSION} = \mathrm{E}_E\varepsilon_E \tag{10}$$

Plastic deformation of the model has been defined as fixed and added to elastic deformation in the analysis in order to define overall deformation (strain) of the material (Eq 11). The change of plastic deformation during expansion is also defined as zero (Eq 12).

$$\varepsilon_{EXPANSION} = \varepsilon_E + \varepsilon_P \tag{11}$$

$$\varepsilon_P = const, \dot{\varepsilon}_P = 0 \tag{12}$$

For implementation of the model into FEM model, the differential equations are expanded to 6 components of stress and strain. Developed model equations for compression and expansion have been rewritten using Poisson coefficient in order to define hydrostatic and deviatory strains. The example for expansion model is described with Eq 13 and Eq 14.

$$\dot{\sigma_{11}} = \lambda\dot{\varepsilon_V} + 2\mu\dot{\varepsilon_{11}}, \dot{\sigma_{12}} = 2\mu\dot{\varepsilon_{12}} \tag{13}$$

$$\dot{\sigma_{11}} = E_E\frac{v}{1-v}\dot{\varepsilon_V} + E_E\frac{1-2v}{1-v}\dot{\varepsilon_{11}},\ \dot{\sigma_{12}} = E_E\frac{1-2v}{1-v}\dot{\varepsilon_{12}} \tag{14}$$

Developed equations have been discretised using centralised differential scheme. The example of final discretised form of equations that define stress increment during compression is given in Eq 15.

$$\Delta\sigma^k{}_{\underset{COMPRESSION}{11}} = \\ = \frac{1}{\frac{\eta_P}{E_E+E_P}+\frac{\Delta t^k}{2}}\left[\begin{array}{c} \left(\frac{E_E\eta_P}{E_E+E_P}+\frac{E_E E_P}{E_E+E_P}\cdot\frac{\Delta t^k}{2}\right)\cdot\frac{v}{1-v}\cdot\Delta\varepsilon^k_{V/COMPRESSION}+\cdots \\ +\left(\frac{E_E\eta_P}{E_E+E_P}\cdot\frac{-\Delta t^k}{\Delta t^{k-1}}+\frac{E_E E_P}{E_E+E_P}\cdot\frac{\Delta t^k}{2}\right)\cdot\frac{v}{1-v}\cdot\Delta\varepsilon^{k-1}_{V/COMPRESSION}+\cdots \\ +\left(\frac{E_E\eta_P}{E_E+E_P}+\frac{E_E E_P}{E_E+E_P}\cdot\frac{\Delta t^k}{2}\right)\cdot\frac{1-2v}{1-v}\cdot\Delta\varepsilon^k_{11/COMPRESSION}+\cdots \\ +\left(\frac{E_E\eta_P}{E_E+E_P}\cdot\frac{-\Delta t^k}{\Delta t^{k-1}}+\frac{E_E E_P}{E_E+E_P}\cdot\frac{\Delta t^k}{2}\right)\cdot\frac{1-2v}{1-v}\cdot\Delta\varepsilon^{k-1}_{11/COMPRESSION}-\cdots \\ -\left(\frac{\eta_P}{E_E+E_P}\cdot\frac{-\Delta t^k}{\Delta t^{k-1}}+\frac{\Delta t^k}{2}\right)\cdot\Delta\sigma^{k-1}_{11/COMPRESSION} \end{array}\right] \tag{15}$$

Final discretised form of equations that define stress increment during expansion is given in Eq 16 and Eq 17, for normal stress components, and Eq 18 for shear stress components

$$\Delta\sigma^k_{11/EXPANSION} = E_E\cdot\frac{v}{1-v}\Delta\varepsilon^k_{V/EXPANSION} + E_E\cdot\frac{1-2v}{1-v}\Delta\varepsilon^k_{11/EXPANSION} \tag{16}$$

$$\Delta\sigma^k_{22/EXPANSION} = E_E\cdot\frac{v}{1-v}\Delta\varepsilon^k_{V/EXPANSION} + E_E\cdot\frac{1-2v}{1-v}\Delta\varepsilon^k_{22/EXPANSION} \tag{17}$$

$$\Delta\sigma^k_{12/EXPANSION} = E_E\cdot\frac{1-2v}{1-v}\Delta\varepsilon^k_{12/EXPANSION} \tag{18}$$

To define new stress values stress increments are added to stresses from previous time point (Eq 19).

$$\sigma^{k+1} = \sigma^k + \Delta\sigma^k \tag{19}$$

It is not possible to define 'a priory' which model should be used during simulation. Eq. 20 has been defined as a rule (threshold) for model decision. Deviatoric plastic strains have been extracted from the simulation. If the parameter d is larger than 0, the process is in expansion. If the parameter d is 0 or lower than 0, the process is in compression.

$$d = \frac{\Delta\varepsilon_{P_V}^{k} + \Delta\varepsilon_{P_V}^{k-1}}{\Delta t^{k} + \Delta t^{k-1}} \begin{cases} d > 0 \ \rightarrow expansion \\ d \leq 0 \ \rightarrow compression \end{cases} \tag{20}$$

Developed model has been implemented into ABAQUS simulation software using dedicated UMAT subroutine. General input for UMAT subroutine are strain, strain derivative and current stress and the output is stress increment. Based on input values and under assumption of compression behaviour new stress, strain and strain increments are calculated. If the plastic strain increments are larger than 0, the process values (new stress, strain and strain increments) are recalculated based on expansion model. ABAQUS solver than finds stress-strain equilibrium for the new time point.

The geometry of ABAQUS simulation model has been defined based on compression setup design. The simulation model consists of compression box (height and width are 0.5 m) that is fixed and a plunger with user defined speed (compression and expansion speed is 0.85 m/s). In the compression box a mesh that represents the material for the analysis has been generated. A dynamic implicit physic has been applied for the simulation.

RESULTS

The proposed rheological model has been implemented in ABAQUS UMAT subroutine and has been used to simulate mechanical behaviour of leaves and branches under compression and expansion. The simulation consists of 3 main parts. The first simulation part lasts for 0.35 s, during which the plunger moves towards bottom of the box and the material is under compression. The second part lasts for 1 second, where the plunger remains fixed and the compressed material is under creep. The third and the last part lasts for 0.85 second where the plunger retracts from the material.

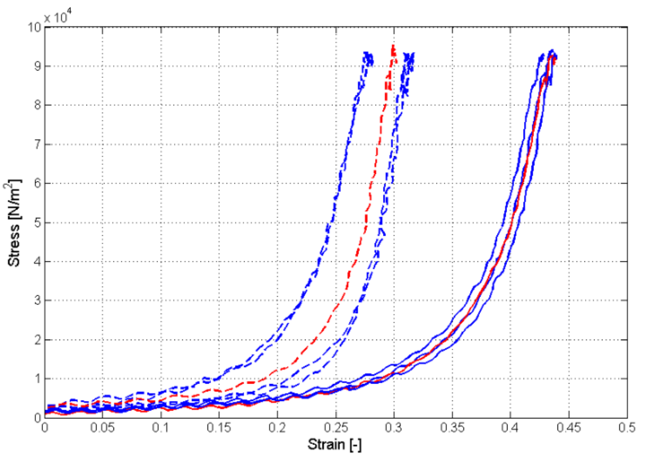

Figure 3 Measured stress-strain relation of leaves (full line) and branches (dotted line)

5 different measurements on leaves (full line) and branches (dotted line) samples were performed, and measured data has been analysed in order to derive a stress-strain relation for particular material. Measured stress-strain relation of leaves is much more uniform than stress-strain relation of branches (Figure 3). This is due to a higher bulk homogeneity of leaves during the tests. Different porosity and wood-leaves ratio in branch samples results in a high difference in stress-strain relationship from sample to sample. Maximum strain of a leaves samples is 0.425-0.445 while maximum strain of branch samples is 0.275-0.32. Measured maximum stress (pressure) is constant due to pressure driven properties of compression setup. Measured cases in red were taken for fitting procedure.

A non-deterministic iterative method has been used to define model parameters that represent material properties and to fit the measured curve (red lines). Simulation results are presented in Figure 4 (leaves) and Figure 5 (branches). With developed 2D ABAQUS simulation model that represents compression setup and with fitted model parameters the simulation model is able to predict mechanical behaviour of biomass residues under compression and expansion. The R^2 of the stress-strain simulation of leaves during compression was found to be 0.9771 while the R^2 of branches was 0.9693. The prediction error of the final strain value (after expansion, represented by a red dot) in the leaves simulation model is -0.5% while in simulation model with branches the prediction error of final strain is 3%. Model parameters that have been implemented into simulation model are presented in Table 1.

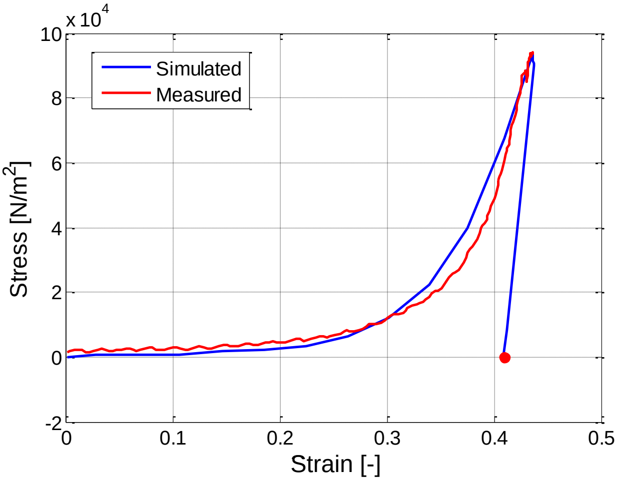

Figure 4 Simulation results of leaves simulation model

Simulation results of 2D ABAQUS model for describing mechanical behaviour of leaves are presented in Figure 6. At the beginning, the stresses in the material are 0. During compression the stresses increase due to forced deformation (by the plunger). After 1s of compression the stresses in the material have been increased. The stress distribution from simulation suggests that the stresses are the highest in the corner areas between compression box and the plunger and the lowest at the corners between side walls of the box and the bottom of the box. This is due to friction forces that occur on the box side walls. Between 0.35 s and 1.35 s a simplified material creep process has been simulated. After 1.35 s the plunger retracts and the stresses in the material decrease. When the stresses in the material are close to 0 (some small residues are left), the material stops to expand. This results in a plastic deformation of the material.

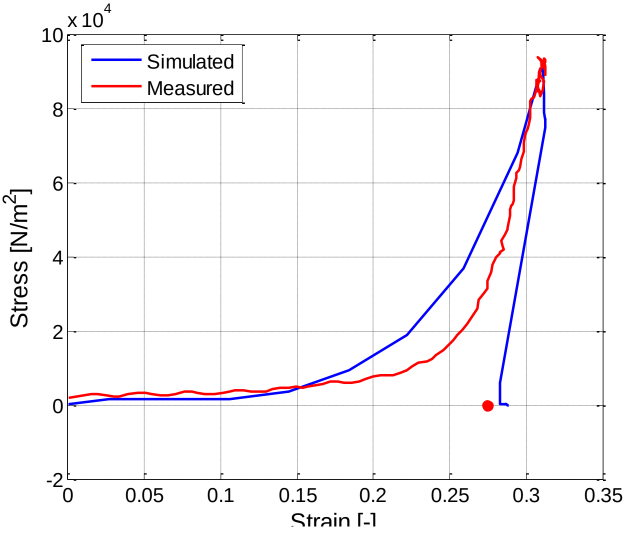

Figure 5 Simulation results for branches simulation model

Table 1 Model parameters

Parameter	Simulation model LEAVES	Simulation model BRANCHES
E1	11000	2400
E2	32	57
R	0.4	0.57
η	1100	50
ν (Poisson coeff.)	0.2	0.2

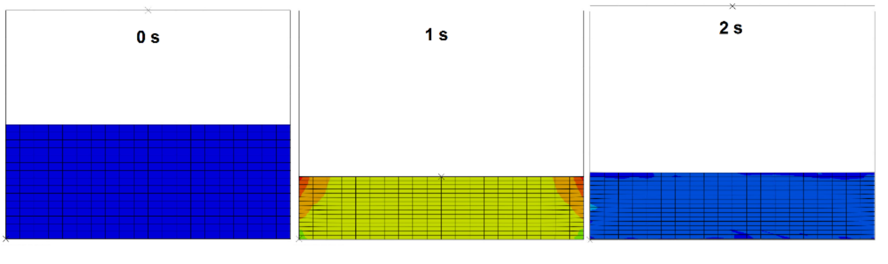

Figure 6 Simulation results after 0, 1 and 2 seconds of simulation

CONCLUSION

In this study, the potential of a 2D finite element modelling approach to predict mechanical behaviour of biomass residues under compression and expansion has been analysed. Finite element models are generally very useful in terms of delivered information for a particular process. Existing finite element models for biomass materials are capable to simulate an individual process but they are still inappropriate for simulation of both compression and expansion. For the purpose of modelling a rheological model that describes mechanical behaviour of biomass residues under compression and expansion has been developed. 2 stage rheological model has been implemented into ABAQUS programming software for finite element modelling analysis. Developed model has been validated for leaves and branches using measurements from developed compression setup. Model parameters were defined by a non-deterministic method. Developed finite element model is capable to predict mechanical behaviour of biomass residues under compression and expansion with reasonable accuracy.

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44. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

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Izvorni znanstveni rad
Original scientific paper

ANALYSIS OF QUALITATIVE INDEXES FOR THE PROCESS OF MECHANIZED HARVESTING OF CHAMOMILLE INFLORESCENCES

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SUMMARY

This paper is a continuation of experimental research conducted at INMA, related to the mechanized harvesting of chamomile inflorescences, using different types and dimensions of tines scrapers (comb with straight tines or comb with curved tines). For two of the dimensional variants of comb (one with straight tines and one with curved tines), for which the highest values of the harvesting degree were registered, it was performed a compared assessment of the quantitative indexes of the harvesting process, by means of processing experimental data, using multivariate regression functions.

Through the means of these functions, the dependency of the variables determined (harvesting degree, the share of damaged inflorescences, etc.) can be expressed analytically by several independent variables. The latter represent the values imposed for several parameters (working speed, working height, peripheral speed of combs), through which we express the conditions on which depend the values determined after conducting experiments.

The conclusions issued after interpreting the results constitute an important premise for optimizing the process of mechanized harvesting of chamomile inflorescences, in order to build efficient equipment.

Key words: *experimental data, multivariable functions, the share of damaged inflorescences*

INTRODUCTION

Chamomile (*Matricaria recutita* L.) is one of the most well known and used natural remedies in traditional therapy, human and veterinarian, its benefactor properties being known since antiquity. It is an aromatic herbaceous plant that can come from the spontaneous flora or from crops. As in the case of other medicinal plants, growing this species is advantageous because it increases productivity and is possible to mechanize the agricultural works Martinov, Konstantinovic 2007). Studied varieties can be grown, with a high content of essential oil in the inflorescences, along with other valuable bioactive compounds (azulene, flavonoids, coumarins etc.) (Salomon 2009). For this reason, the mechanized harvesting of chamomile inflorescences represents a key point in the production chain, because it has a major impact on the quantity and quality of the plant material obtained (Ehlert and Beier 2014).

The paper represents a continuation of experimental researches related to the mechanized harvesting of chamomile inflorescences conducted within INMA. In previous papers were analyzed in comparison the quality of the harvesting process as well as the quality of the harvested product obtained after using multiple dimensions for the active bodies, in the type of scraping tines (6 types with straight tines and 6 types with curved tines). These active organs have equipped in turns the transporter type harvester of a tower machine for harvesting chamomile. This type of machines has a lower productivity compared with the latest models of self-propelled harvesters built in this field **(**Martinov 1992, Colorio 2011, Ehlert 2014)**.**

Because usually the degree of harvesting is the main indicator with the help of which is evaluated the quality of the working process carried out by a specialized machine, on its basis were designated the representative options of active bodies for the case of mechanized harvesting of chamomile inflorescences. Thus, from the types with straight tines and from the ones with curved tines was chosen an option for which the degree of harvesting registered the highest values.

For the representative options of active bodies (one with straight tines and one with curved tines) was conducted an interpretation of experimental results regarding the share of damaged inflorescences (one of the qualitative indices for the harvesting process of chamomile inflorescences) using multivariable functions in order to optimize the process.

MATERIAL AND METHODS

Characteristics of chamomile crop where tests were performed are shown in table 1.

Table 1 Characteristics of chamomile crop

Variety	Pearl
Average number of chamomile plants [pcs m^{-2}]	326
Average number of weeds [pcs m^{-2}]	12
Average number of mature flowers [pcs m^{-2}]	1986
Average number of buds which have not blossomed [pcs m^{-2}]	46
Average production of fresh inflorescences [kg/ha]	3204
Average mass of 100 inflorescences [g]	13.2
Average diameter of inflorescences [mm]	19.4
Minimum and maximum height between which the flowers grow [mm]	298...583

The varieties of the paired scraping combs were noted with M, N, O, P, S, T, having the index 1 for straight tines, respectively 2 for curved tines. The resemblances (ex. the space between the tines has the shape of a rounded "U") (Ehlert 2011) and the differences (ex. the distance between tines) between the options are highlighted by the means of the dimensional characteristics in figure 1.

After analyzing the experimental results, the representative options for the types of active organs were chosen (based on the criteria described above): V1 with straight tines and T2 with curved tines. The dimensional characteristics according to figure 1 are:

- V1: d=4mm; p=14 mm; L=100 mm; b=10 mm;
- T2: d=4mm; p=12 mm; L=80 mm; b=8 mm; R_{T2}=80 mm.

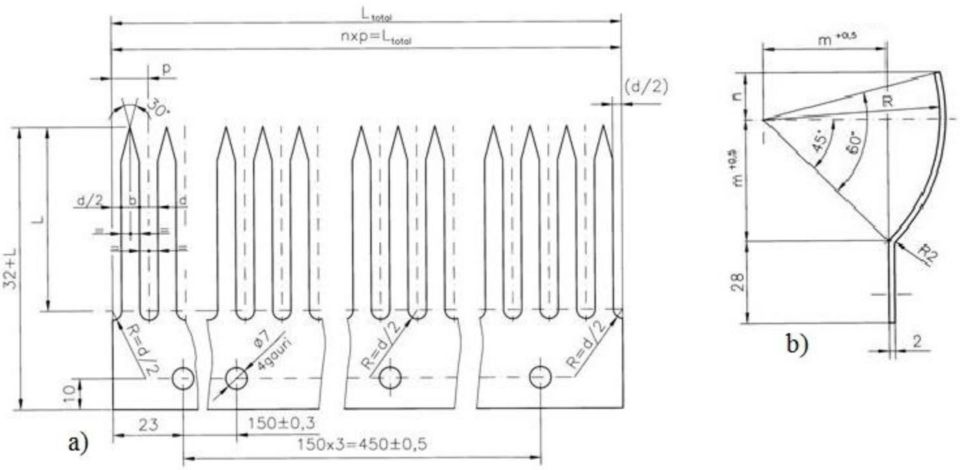

Fig.1 The shape of combs: a) with straight tines; b) with curved tines

The share of damaged inflorescences obtained from the harvesting process represents the participation in percentages of the fraction of damaged (incomplete, crushed) inflorescences from the sample for analysis. For each combination, between the working conditions, from the harvested material obtained various samples were analyzed, both for option V1 and for option T2, in order to determine the share of damaged inflorescences harvested.

After conducting the experiments, it was found that the values determined for the share of damaged chamomile inflorescences harvested are dependent on certain conditions that are expressed using values imposed for the working speed, working height and for the peripheral speed of the combs. Thus, the share of damaged inflorescences harvested is a variable depending on multiple independent variables, simultaneously. This dependence can be expressed using an analytic expression, whose general form must be determined, being a function of the type:

$$y = f(x_i, a_0, a_i, a_{ii}, a_{ij}) \tag{1}$$

Due to the complexity of solving the problem, is necessary to complete several stages: drawing up an adequate program for solving experiments, determining the values of constants, testing the significance of variables, testing the adequacy of the function's shape (Paunescu 1999).

Multivariable functions can be of the polynomial regression function or polytrophic regression function (Draper 1998, Paunescu 1999, Rumsiski 1974).

The polynomial regression function, with three independent variables, in the form (Paunescu 1999):

$$y = a_o + \sum_{i=1}^{3} a_i \cdot x_i + \sum_{i=1}^{3} a_{ii} \cdot x_i^2 + a_{12}x_1x_2 + a_{13}x_1x_3 + a_{23}x_2x_3 \qquad (2)$$

where: x_1 , x_2 , x_3 are the independent variables, y is the dependent variable and a_0, a_i, a_{ii}, a_{12}, a_{13} and a_{23} are the constants whose value will be determined.

The polytrophic regression function, with three independent variables, in the form (Paunescu, 1999):

$$y = a_o \cdot x_1^{a_1} \cdot x_2^{a_2} \cdot x_3^{a_3} \qquad (3)$$

The structure of experimental research programs used for determining the y function is given by: number n* = 14 experiments conducted for different values for the independent variables, necessary for determining the coefficients; number n0 = 4 experiments conducted for identical values of the independent variables, necessary for determining the experimental error. The total number of experiments:

$$n = n_* + n_0 = 14 \qquad (4)$$

The main characteristics of the experimental program, defined in relation to the demands of determining some functions adequate for the research processes are: *compatibility* (defined in relation to achieving a unique solution for the coefficients), *orthogonality* (defined in relation to achieving uncorrelated estimations for the coefficients), verisimilitude (defined in relation to achieving conclusive values of the indicators for testing the significance of coefficients and the adequacy of the function's shape) (Paunescu1999).

For the multivariable regression functions (polynomial and polytrophic) are carried out:

a) *Calculating the coefficients* – the determination of these constants is made using the method of the least squares, expressing the sum of the squares of the deviations for the measured values compared to the ones calculated by the modeling program. Setting the condition that the sum should be minimal, a system of linear equations is obtained, and by solving it, the constants in the expression of the multivariable function are obtained (Draper 1998, Paunescu 1999, Rumsiski 1974).

b) *testing the significance of coefficients* – is carried out using the Fisher test, calculating the sum of the squares of experimental errors and the sums due to coefficients:

$$S_e = \sum_{i=n_*+1}^{n}\left(y_i - \sum_{i=n_*+1}^{n}\frac{y_i}{n_o}\right)^2 , S_0 = nb_0^2 , \; S_j = a_j^2 \sum_{i=1}^{n} X_{ij}^2 \qquad j = 1, 2, 3, ..., m_1 \tag{5}$$

The ratios are calculated:

$$F_o = \frac{S_o(n_o - 1)}{S_e} , \; F_j = \frac{S_j(n_o - 1)}{S_e} , \; j = 1, 2, 3, \ldots m_1 \tag{6}$$

If $F_0 \geq F(1-\alpha, 1, n_o - 1)$, $F_j \geq F(1-\alpha, 1, n_o - 1)$, $F_{jj} \geq F(1-\alpha, 1, n_o -1)$, $F_{1j} \geq F(1-\alpha, 1, n_o - 1)$ and $F_{23} \geq F(1-\alpha, 1, n_o - 1)$, coefficients a_0, a_j, a_{jj}, a_{1i} and respectively a_{23} are significant. If the condition is not fulfilled, for one or more coefficients, they are equal to 0. Critical values F ($P = 1- \alpha$, $k_1 = 1$, $k_2 = n_o - 1$) are given for the level of significance $\alpha = 0.95$ (Draper 1998, Paunescu 1999, Rumsiski 1974).

c) Testing the adequacy of the function's shape – also studying the Fisher test, calculating:

$$F = \frac{(S - S_e)(n_o - 1)}{S_e(n - n_o - m_1)} < F(1-\alpha, n_* - m_1, n_0 - 1) \tag{7}$$

where m_1 represents the number of the function's coefficients (without a_0). If this condition is fulfilled, then the shape of the function is adequate (Draper 1998, Paunescu 1999, Rumsiski 1974).

For the share of damaged inflorescences harvested to be expressed using multivariable regression functions, were chosen the independent variables influencing this dependent variable, as well as the variation interval. These are: *The working speed:* $v_l = 0.5–1.22\ kmh^{-1}$*; The working (harvesting) height:* $H=0.3 – 0.45\ m$*; The peripheral speed of combs:* $v_p = 0.52 – 1.08\ ms^{-1}$. We have defined the working height as being the distance from the ground up to the longitudinal axis of the inferior drum, on which the band of the transporter type harvester is wrapped around. The harvester have an inclined position to the horizontal. Taking into consideration the movement of the band from the bottom to the top, the thickness of the comb supports, the trajectory and the length of the active organs (scrapers combs), the penetration of working device into canopy takes place at a lower height than the working height, previously defined. Due to the position of plants during work and to the trajectory of the active organs, it was proven experimentally that the chosen interval for the working height (*H=0.3 - 0.45m),* is enough so that the combs scrape the area in the chamomile crop on vertical, where the majority of inflorescences are situated.

The calculation algorithm presented previously was used for drafting a program, in the Turbo Pascal 7 programming language.

The experimental testing program for determining the multivariable functions for calculating the share of damaged inflorescences for options V1 and T2 for the combs is given in table 2.

Table 2 Experimental program for determining the share of damaged inflorescences harvested using V1 and T2

Nb. of tests	v_l [km h^{-1}]	H [m]	v_p [m s^{-1}]	The share of damaged inflorescences V1 [%]	The share of damaged inflorescences T2[%]
1	0.5	0.30	0.52	4.1	4.3
2	1.22	0.30	0.52	9.9	7.1
3	0.5	0.45	0.52	4.2	2.9
4	1.22	0.45	0.52	5.8	4.4
5	0.5	0.30	1.08	4.1	4
6	1.22	0.30	1.08	8.4	7
7	0.5	0.45	1.08	3.4	2.6
8	1.22	0.45	1.08	5.5	3.9
9	0.5	0.30	0.76	8.8	3.8
10	1.22	0.30	0.76	10.1	7.6
11	0.76	0.45	0.76	4.7	3
12	0.76	0.30	0.76	5.2	4.7
13	0.76	0.30	1.08	4.6	4.2
14	0.76	0.30	0.52	5.4	5.2
15	0.76	0.30	0.76	5.2	4.7
16	0.76	0.30	0.76	5.7	5.1
17	0.76	0.30	0.76	18	4.3
18	0.76	0.30	0.76	19	4.5

RESULTS

Using the calculus program and the program for experimental tests for option V1, were calculated the coefficients of regression and the coefficients of testing the significance of coefficients both for the polynomial shaped function and for the polytrophic shaped function corresponding to the share of damaged inflorescences harvested. None of the function’s shapes was adequate.

For option T2, following the same stages as in the case of V1, were calculated the coefficients of regression and the coefficients for testing the significance of coefficients for the polynomial function corresponding to the share of damaged inflorescences harvested, but the shape of the function was not adequate.

Were also calculated the coefficients of regression and the coefficients for testing the significance of coefficients for the polytrophic function corresponding to the share of damaged inflorescences harvested for option T2:

a_1 = 1.599940840 F_1 = 6744.0988341 > F=8.25 results: *a_1 is significant;*

a_2 = 0.584574784 F_2 = 128.82226313 > F=8.25 results: *a_2 is significant;*

a_3 = -1.046700654 F_3 = 83.713729364 > F=8.25 results: *a_3 is significant;*

a_4 = 0.147616213 F_4 = 5.515084462 < F=8.25 results: *a_4 is not significant.*

The recalculated coefficients are:

a_1 =1.5999408,

a_2 = 0.5845748,

a_3 = -1.0367007,

a_4 = 0.0

The coefficient of testing the adequacy of the function's shape is F=2.57 < F_{tab} = 9.4, so the shape of the function is adequate (Paunescu 1999, Rumsiski 1974).

The polytrophic function that allows calculating the share of damaged inflorescences for option T2 of the combs is:

$$G_v = 1.5999408 \cdot v_l^{0.5845748} \cdot H^{-1.0367007} \cdot v_p^0 \tag{8}$$

Relation (8) does not depend on the peripheral speed of combs, on the considered interval.

In figure 2 are represented, for option T2 of the combs, the experimental values of the share of damaged inflorescences harvested, compared to the theoretical ones, calculated using the polytrophic function obtained previously, for each experiment.

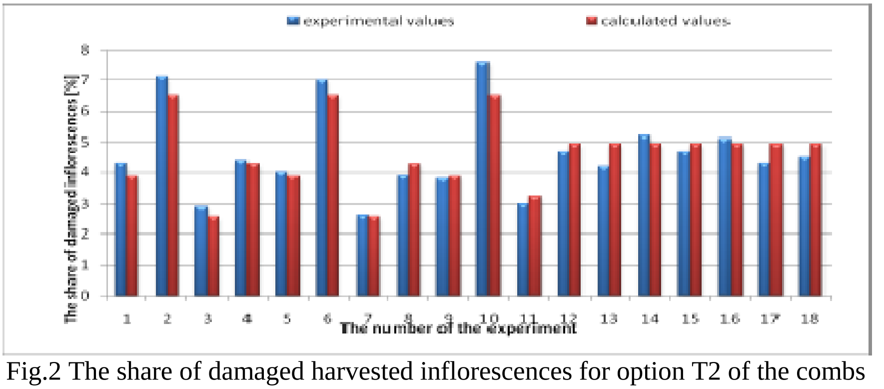

Fig.2 The share of damaged harvested inflorescences for option T2 of the combs

Usually, in a process of harvesting chamomile inflorescences, the harvesting (working) height H is established depending on the height of the placement of inflorescences on the plant. At the first crossing of the equipment through the field, a lower working height is used, increasing it for the following crossings. For a constant working height, the share of damaged inflorescences harvested can be determined using functions with two variables, dependent on the working speed (v_l=x_1) and on the peripheral speed of the combs (v_p=x_2), having the shape:

$$f(x_1, x_2) = a_0 + a_1x_1 + a_2x_2 + a_3x_1^2 + a_4x_1x_2 + a_5x_2^2 \tag{9}$$

Using the values recorded from experiments from table 3 and the MathCad program can be determined the constants of the function with two variables of the shape (9), with which one can study the variation of the share of damaged inflorescences harvested at the working height H=0.3 m for options V1 and T2 of the combs. (Jaboleanu 1995).

For the share of damaged inflorescences harvested corresponding to V1, for the working height H=0.3m, for a coefficient of correlation R= 0.917, function (9) has the shape:

$$G_v(v_l, v_p) = -0.814 - 20.279v_l + 36.097v_p + 16.068v_l^2 - 2.565v_lv_p - 22.042v_p^2 \tag{10}$$

For the share of damaged inflorescences harvested corresponding to T2, for the working height H=0.3m, for a coefficient of correlation R= 0.931, function (9) has the shape:

$$G_v(v_l, v_p) = 8.963 - 9.794v_l - 3.882v_p + 7.864v_l^2 + 0.2v_lv_p + 1.674v_p^2 \tag{11}$$

Table 3 Experimental values of the share of damaged inflorescences harvested for V1 and T2 at the working height H=0.3m

No.	Working speed v_l [km h^{-1}]	Peripheral speed of combs v_p [m s^{-1}]	The share of damaged inflorescences [%] for V1 at H=0.3m	The share of damaged inflorescences [%] for T2 at H=0.3m
1	0.5	0.52	4.1	4.3
2	0.5	0.76	8.8	3.8
3	0.5	1.08	4.1	4.0
4	0.76	0.52	5.4	5.2
5	0.76	0.76	5.2	4.7
6	0.76	1.08	4.6	4.2
7	1.04	0.52	7.1	5,6
8	1.04	0.76	7.8	4,6
9	1.04	1.08	6.2	4,7
10	1.22	0.52	9.9	7.1
11	1.22	0.76	10.1	7.6
12	1.22	1.08	8.4	7.0

In figures 3 and 4 is represented graphically the variation of the share of damaged inflorescences harvested, depending on the working speed ($v_l=x_1$) and on the peripheral speed of combs ($v_p=x_2$), at a working height H=0.3m, for options V1 and T2 of the combs, using the functions given by relations (10) and (11).

From figures 3, 4 the value of the share of damaged inflorescences can be determined, for any value of the working speed and the peripheral speed of tines ($v_l=x_1$, $v_p=x_2$) in the horizontal plane.

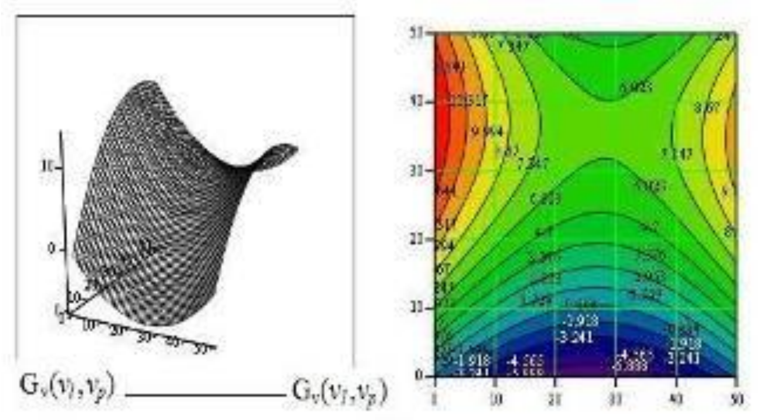

Fig. 3 The variation of the share of damaged inflorescences $G_v(v_l, v_p)$ for V1 at H=0.300 m

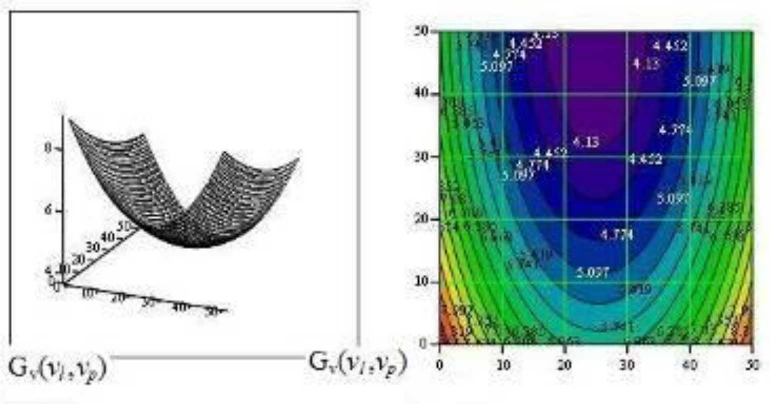

Fig. 4 The variation of the share of damaged inflorescences $G_v(v_l, v_p)$ for T2 at H=0.300 m

In figures 5 and 6 is represented the variation of the share of damaged inflorescences harvested, at a working height H=0.3 m, depending on the working speed, for each peripheral speed ($v_p1=0.52 m\ s^{-1}$, $v_p2=0.76\ m\ s^{-1}$, $v_p3=1.08 m\ s^{-1}$) of combs, corresponding to the constructive options V1 and T2.

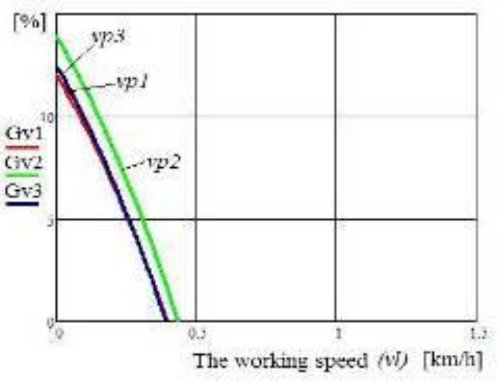

Fig. 5 The variation of the share of damaged inflorescences $G_v(v_l)$ for V1 at H=0.300m

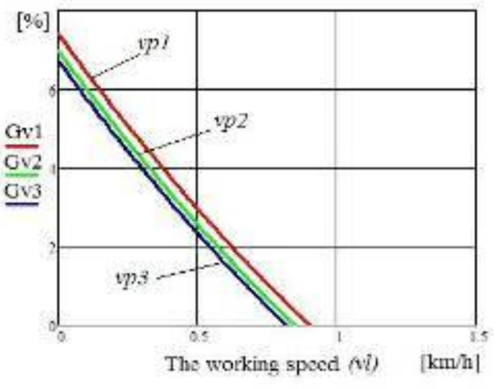

Fig. 6 The variation of the share of damaged inflorescences $G_v(v_l)$ for T2 at H=0.300m

Evidently, following the same steps taken previously, namely using the values registered from experiments and the MaThCad program, the constants of the two variable function of the form (9) can be determined, with which the variation of the degree of harming the harvested inflorescences at the working height H=0.45 m for options V1 and T1 of combs can be studied, depending on the working speed ($v_l=x_1$) and the peripheral speed of combs ($v_p=x_2$).

CONCLUSIONS

The analysis of results from processing the experimental data regarding the degree of harming the chamomile inflorescences obtained from mechanized harvesting highlights the following aspects:

- the degree of harming the inflorescences can be expressed using a polytrophic regression function can only be used for T2;

- whichever the option of scraping combs used, the degree of harming the inflorescences is decreasing depending on the working speed, at a working height H=0.3m;
- the degree of harming has higher values for option V1 that for option T2, at a working height H=0.3m, for the same working speeds;
- the highest peripheral speed for the active bodies *(v_{p3}=1.08m s^{-})* is the most favorable one in order to obtain a low share of damaged inflorescences, at the same working speed and at H=0.3m. This is noticeable especially in the case of T2, when for a working speed between the interval v_l=0.5 kmh^{-1}– 0.75 kmh^{-1}, the share of damaged inflorescences has values lower than 2.5%.

Theoretically, was highlighted the fact that in order to obtain, after the mechanized harvesting of chamomile inflorescences, a plant material with a low share of damaged inflorescences harvested, is advisable to use active bodies in the type of scraping combs with curved tines, having a high peripheral speed, at a working speed as low as possible, for a working height H=0.3 m.

The theoretical results obtained from this analysis constitute an important prerequisite for optimizing the process of mechanized harvesting of chamomile inflorescences, in order to build efficient specialized equipment.

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44. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

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Prethodno priopćenje
Preliminary communication

OIL EXTRACTION USING A VERTICAL PRESS WITH PISTON

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SUMMARY

Oil pressing is a mechanical method for oil extraction from oleaginous materials. For the oil extraction from oilseeds are used generally horizontal screw presses with one or two discharge ends, but another equipment used for this is the vertical press with piston. The paper presents the results of some experimental research on the oil extraction from oilseeds using a vertical press with piston and circular cross section. The holes through which the oil is evacuated from the press are applied to the vertical walls of the press, which is closed at the bottom. The oleaginous materials used for the experiments were whole sunflower seeds, sunflower kernels, rapeseeds and safflower seeds. Experiments have been carried out in two phases. The first phase consisted of pressing samples of the four types of oleaginous material using a piston speed of 2 mm/min, the maximum force applied to the material being 100 kN. When the maximum value of the force was reached the applied force is removed from the oleaginous material. The second phase of the experiments consisted of pressing four samples of safflower seed, at four piston speeds (2, 4, 8 and 12 mm/min), the maximum applied force being also 100 kN, without maintain the force after reaching the maximum value. At the end of the experiments the oil yield and the quantity of meal were determined. Also, using the Microsoft Excel program were made graphs showing the variation of piston displacement with the applied force, for the four types of oleaginous materials, as well as for the four speeds of the piston. Oil yield variation with the piston displacement was also analyzed in this paper for safflower seeds. To highlight the effect of temperature on safflower seeds pressing, was conducted a test with a sample of 100 grams of safflower seeds heated to 40°C, at 4 mm/min piston speed and a maximum force of 100 kN (without maintaining force after the *maximum value). The experimental results obtained in this paper may be used by the operators and the researchers in this field.*

Key words: *oilseeds, mechanical extraction, vertical press, maximum force, piston speed, temperature*

INTRODUCTION

Vegetable oils are one of the oldest classes of chemical compounds known to mankind and even the famous Homer concerned himself with the use of vegetable oils. Numerous references and clues are found that indicate the use of these oils during stone age and bronze age, [6].

Sunflower (*Helianthus annuus* L.) seed is considered to be an important oilseed because it contains large quantity of highly nutritious oil, [5]. The dehulled seeds also have widely been consumed in salads and bakery products, [8].

Rapeseed is closely related member of the mustard family (Brassicaceae) that is grown as oilseed crops. Rapeseed is grown primarily as a source of erucic acid, which is not edible but is valuable in high-performance industrial lubricants. After the removal of the anti-nutitional compounds, rapeseed oil became a product very high in unsaturated fatty acids, thus being considered a high-quality food oil that is healthy in human diets. Recent petroleum price hikes have greatly increased interest in growing rape for production of biodiesel, [4].

Safflower is a plant from the same composital family as sunflower. Each safflower seed contains half its weight in oil, which is richer in linoleic acid (up to 80%) than any other oil, [7]. The oil obtained from safflower seeds, by hydraulic pressing or solvent extraction, is considered by some authorities as the most natural, nutritionally vegetable oil, [3].

There are three main methods used for extraction of oil, with possible variations or even combinations of these processes: batch hydraulic pressing, pressing mechanical continuous (expeller) and solvent extraction, [9]. Taking into account the disadvantages presented by solvent extraction method, many of vegetable oil producers choose to utilize mechanical extraction, using the screw presses or hydraulic presses. Between these equipments, hydraulic press is common in small scale processors because it is less capital-intensive in terms of initial and maintenance costs. Hydraulic presses are now available in different versions, but their efficiency seldom exceeds 70%, [11]. Hydraulic expression involves application of pressure to the oleaginous material found in a cylindrical cage perforated laterally. The results consist of an axial compaction and a radial oil flow. It was shown that as for the efficiency of the process, the result is well below that achieved by the traditional method of solvent extraction, being directly affected by the initial conditions of the grains, such as moisture content and temperature, and constructive aspects of the press, as its design axis and the camera, [12].

In a study realized by Bargale et al., it was presented the influence of temperature, pressing time, applied pressure, height of uniaxial pressed material sample on the extraction efficiency. For the experiments, soybeans were used as oleaginous material subjected to uniaxial pressing. Thus, it was observed that increasing pressing time led to obtaining a greater amount of oil extracted, while increasing pressing temperature from 22°C to 90°C was also beneficial to the amount of oil extracted. A smaller height of the material sample has led to obtain larger quantities of oil extracted and an increasing of applied pressure from 20 to 40 MPa has also led to increasing the amount of oil extracted. Thus, the sample height, applied pressure, temperature, pressing time, and second- and third-order interactions among these variables were found to significantly influence the oil recovery from the soybean samples [2].

Olaniyan also studied the effect of extraction conditions on the yield and quality of oil from castor bean. The experiments was conducted using a piston-cylinder rig in association with California bearing ratio universal testing Machine (CBR-UTM). From this study, it was revealed that the nature of bean, heating temperature and pressing time had influence on oil yield, extraction efficiency and pressure during mechanical expression of oil from castor bean. Therefore, these process conditions must be carefully controlled during the extraction process, [10].

In another paper, the authors evaluated the influence of pressure profile, temperature, cake thickness and moisture content on the oil yields and rate of pressing for a variety of seeds (sesame, linseed, palm kernel, jatropha and rapeseed). The results showed that when the pressure is increased using a temperature of 100^{o}C and using the optimum moisture content (close to 2% dry basis), the oil yield increases for all tested oilseeds. The oil yield obtained for the dehulled seeds were considerably higher than that obtained for the hulled seeds. This can be explained by the absorption of oil by fibers present in the hulls. As a final conclusion, the authors stated that when using a press capable of applying a higher pressure (> 45 MPa), the oil yield is increased by 15% (oil / oil) compared with conventional presses, [13].

Another study conducted with a hydraulic press shows that the yield increase for all seeds, including Jatropha, with increasing mechanical pressure, approaching a limit at higher pressures. Maximum yields were higher for the dehulled seeds compared to hulled seeds since hull does not contain significant amounts of oil and the fibre in the hull absorbs oil during the expression, thereby lowering the overall yield. Experiments were performed for all seeds including Jatropha at temperatures of 40, 80 and 100°C and a constant mechanical pressure of 30 MPa. Significant influence of temperature on the oil yield was found only at 100 °C. Around 100 °C cooking takes place, which coagulates the protein and the oil globules, [*14*].

During the experiments realized, Adeeko and Ajibola focused on highlight the processing factors that affect the yield and quality of mechanically expressed groundnut oil. Thus, it can be observed that the rate of oil expression was increased by an increase in temperature, time of heating, and particle size. An increase in the heating temperature and time increased the free fatty acid, peroxide value, and the colour intensity of the oil expressed, [1].

METHODS

The laboratory stand for oilseeds pressing was realized using one of the pressing chamber from the PU-50 screw oil press with two discharge ends (screw press manufactured by STIMEL Timişoara), which was vertically fixed, and a WDW-100 computer control electromechanical universal testing machine, manufactured by Jinan Testing Equipment IE Corporation, which has a piston built specially for tests achievement. The machine allows to modify the applied force up to a maximum of 100 kN and the piston speed between 0.01-1000mm/min. In Figure 1 it is shown the laboratory stand realized for the experiments with the main components. For conducting the experiments, the pressing chamber of the PU-50 screw press was placed on the machine table in vertical position (with the feeding zone of the chamber on the bottom). From the pressing chamber has been removed the screw and the cake discharge end (the nozzle).

After the introduction of the seeds sample into the pressing chamber, the piston was positioned on the seed mass and connected at the testing machine through its clamping system. On the outside of the pressing chamber, below the area with oil evacuation orifices, was fixed a metal ring to collect the oil drained from the pressing chamber. The oil collected in the ring is guided in a collecting vessel by means of a welded metal channel. After the introduction of the sample of seeds into the pressing chamber, the piston placement in the working position and the corresponding adjustments of the testing machine, the experimental determinations were started.

For these experiments, they were used rapeseeds, safflower seeds, sunflower seeds and sunflower kernels obtained by total decortications of the seeds. Seed samples were weighed using a KERN electronic balance and their temperature was fixed at 30 °C using an electric oven, the temperature being determined with a digital thermometer.

Fig. 1 The laboratory stand realized for oilseeds pressing

The experiments presented in this paper were conducted in two phases. The first phase consisted of pressing the four types samples of oleaginous material using a 2 mm/min piston speed, the maximum force applied to the material being 100 kN, and when this value was reached, the applied force is removed. The second phase of the experiments consisted of pressing four safflower seeds samples (100 g seed/sample), at four piston speeds (2, 4, 8 and 12 mm/min), with the maximum force applied of 100 kN, without maintenance after reaching the maximum force. At the end of the experiments it was determined the oil yields, respectively the cake quantities obtained after pressing.

In order to highlight the effect of temperature on safflower seeds pressing, were made experiments using 100 grams of safflower seeds samples with different temperatures (30°C and 40°C), at 4 mm/min piston speed and 100 kN maximum force applicable (without maintenance after reaching the maximum force).

RESULTS AND DISCUSSION

Table 1 shows the results obtained by pressing the four types of oleaginous material samples, having the same temperature (30°C), the 2 mm/min piston speed for all samples and the maximum force of 100 kN. The amount of material that represents a sample was different because the space occupied in the pressing chamber varied according to size and the void volume between the seeds. Analyzing the table with data obtained from the experiments and the figure 2, it can be observed the variation of the oil yield extracted from the oleaginous material depending on its type, at the set parameters. Thus, the highest oil yields were recorded at the sunflower kernels (37.7%) and at sunflower seeds (26.72%), while the oil yields from rapeseeds and safflower seeds were lower (11.25% and, respectively, 10.90%). Of course, this leads to a quantity of cake higher for safflower seeds and rapeseeds and lower for sunflower seeds and kernels.

Table 1 The quantities of material obtained by pressing the seeds samples

Piston speed=2 mm/min, Seeds temperature = 30 °C, Maximum force=100 kN					
Seeds type	Seeds mass, (g)	Extracted oil mass, (g)	Oil yield, (%)	Cake mass, (g)	Cake percentage, (%)
Rapeseed	120	13.5	11.25	106.50	88.75
Sunflower seed	97.3	26.0	26.72	71.30	73.28
Sunflower kernel	100	37.7	37.70	62.30	62.30
Safflower seed	100	10.9	10.90	89.10	89.10

Selecting from the data saved by the testing machine software, it was traced a graph showing the stroke variation depending on the applied force, in the case of four oleaginous materials. By analyzing the graph shown in fig. 3, it can be said that there is a general upward trend of the stroke depending on the loading force, irrespective of oleaginous material type (sunflower, rapeseed, safflower, sunflower kernel). It can be seen that on the first area of the graph, the curves show a steep increase of the stroke, after which the growth is smoother for all seeds types. The piston has the highest stroke for sunflower seeds pressing (about 70 mm), while the lowest stroke was observed for rapeseeds (about 45 mm).

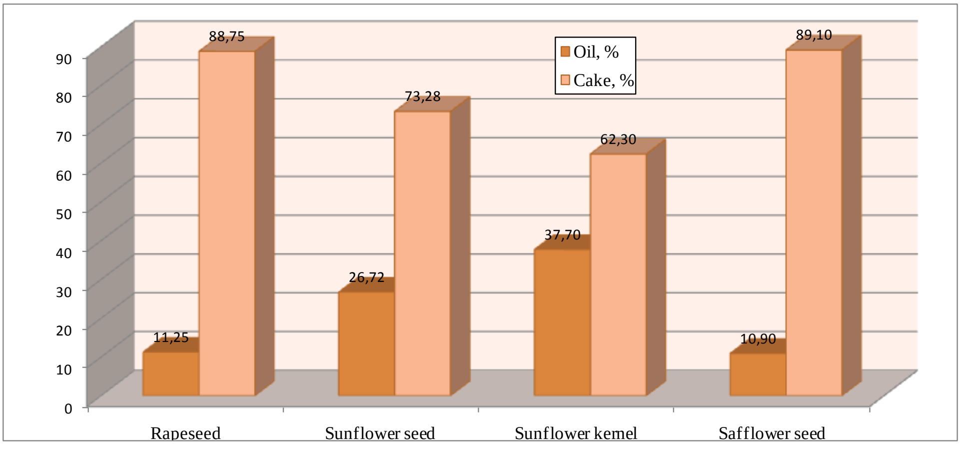

Fig. 2 Oil yield variation depending on the oleaginous seeds type, at 2 mm/min piston speed and 100 kN applied force

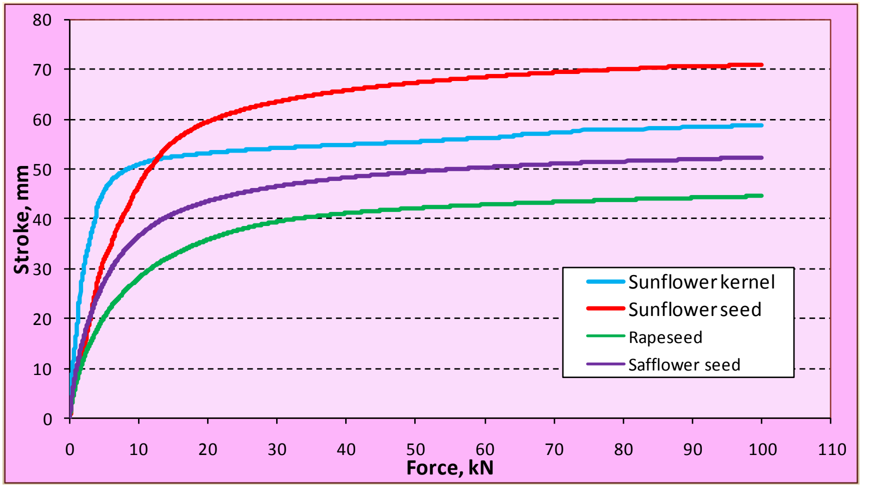

Fig. 3 Stroke variation with the applied force, for four oleaginous materials types, at 2 mm/min piston speed

Thus, at the 10 kN applied force, the stroke was 50 mm for the sunflower kernels, about 45 mm for sunflower seeds, about 37 mm for safflower seeds, and only about 28 mm for rapeseeds. Beyond this value of applied force, for the sunflower kernels, the stroke presents a trend approximately linear constant to about 58 mm at 100 kN force, while at the unpeeled seeds the stroke trend is approximately parabolic up to the 20 kN force, when it reaches the stroke value of about 60 mm; after this point the stroke variation is relatively constantly increasing up to about 70 mm at 100 kN force.

The results obtained from the second type of experiments (samples safflower pressing at different piston speeds) are shown in Table 2.

Table 2 The quantities of oil and cake obtained at pressing 100 g safflower seeds, with a temperature of 30 °C, with a maximum force of 100 kN, for four different piston speeds

Piston speed, (mm/min)	Extracted oil mass, (g)	Oil yield, (%)	Cake mass, (g)	Cake percentage, (%)
2	12,6	12,6	87,4	87,4
4	10,9	10,9	89,1	89,1
8	10,1	10,1	89,9	89,9
12	7,3	7,3	92,7	92,7

An analysis of the obtained data and on the chart of Fig. 4 shows that the oil yield extracted from the oleaginous material decreases (from 12.6 to 7.3%) with the increase of the piston speed from 2 to 12 mm/min. This variation has been subjected to a regression analysis in Microsoft Excel using linear and exponential variation laws. The best correlation was obtained in the case of linear variation law (R^2=0.949), but the correlation obtained with exponential law had also a satisfactory correlation coefficient value (R^2=0.936).

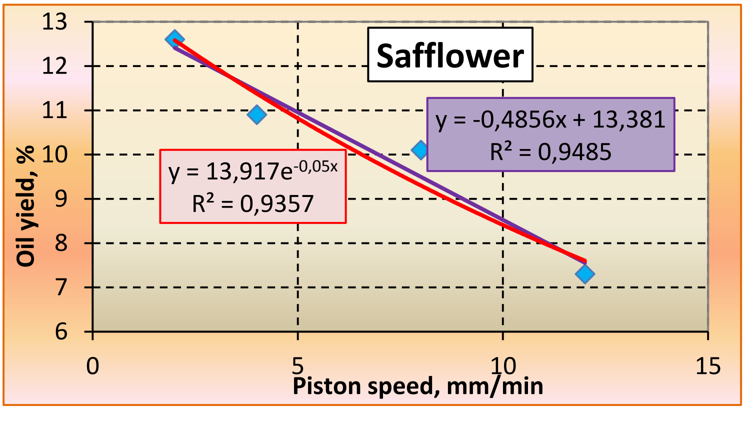

Fig. 4 Oil yield variation with the piston speed, at 100 kN force and 30 °C temperature

The stroke variation with the applied force, at the safflower seeds pressing, at different piston speed, is shown in fig. 5, being observed that at lower piston speeds (2 and 4 mm/min), the stroke has higher values. Thus, for the speeds of 2 and 4 mm/min, the stroke was approximately 53 mm, while at 12 and 8 mm/min the piston stroke was up to 50 mm.

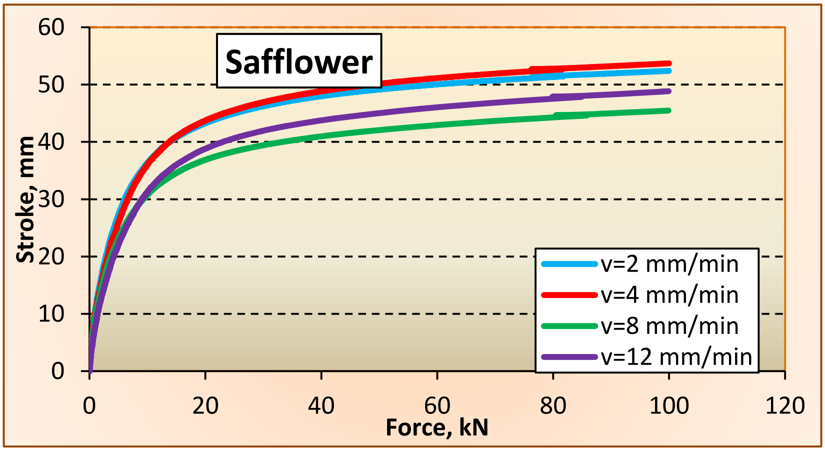

Fig. 5 Stroke variation with the applied force, at four piston speeds, with the maximum force of 100 kN and 30°C temperature

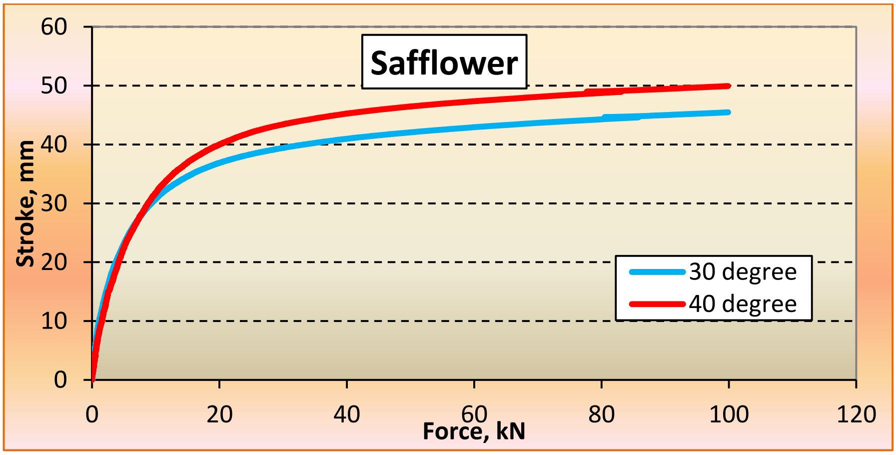

Fig. 6 Stroke variation with the applied force, at two different seed temperature, with the maximum force of 100 kN and 4 mm/min piston speed

To highlight the effect of temperature on safflower seeds pressing, it was conducted a test with a 100 grams safflower seeds sample heated to 40°C, at the piston speed of 4 mm/min and a maximum force of 100 kN (without force maintaining after the maximum value). Analyzing the oil yield obtained, it was found that the pressing of the seeds at 40°C will lead to a higher oil yield obtained (10.1 % oil yield for seeds at 30°C temperature and 10.82 % oil yield for seeds at 40°C temperature).

Also, the stroke variation with the applied force (fig. 6) has the same trend as other previous curve, the piston stroke having higher values in the case of pressing the seeds with temperature of 40°C (about 50 mm, while in the case of 30°C temperature the stroke was 45 mm).

CONCLUSIONS

Hydraulic extraction is influenced from various parameters, as it results from the researches, the most important being the oleaginous material, the pressing time and the temperature. At the pressing of rapeseeds, sunflower seeds, safflower seeds and sunflower kernels at 30°C temperature with 2 mm/min piston speed and maximum force of 100 kN, it was found that the highest oil yield is obtained from sunflower kernels (37.7%), while the lowest oil yield was obtained from safflower seeds (10.90%). Analyzing the piston stroke variation with the applied force, for the four types of oleaginous material, at the piston speed of 2 mm/min, it was observed that the piston has the highest stroke for pressing the sunflower seeds (about 70 mm) and the lower stroke was observed in the case of rapeseeds (about 45 mm).

This work also shows the influence of piston speed on the efficiency of hydraulic extraction method, in the case of rapeseeds and sunflower seeds. Thus, an increasing of speed piston, meaning a decreasing of pressing time, involves a decreasing of oil extracted, which is equivalent with the increasing of residual oil in the cake. It is necessary that the pressing time to be not small, so that the oil has enough time to cross the oleaginous material and be evacuated. By the experiments carried out on safflower seeds was observed that piston speed influences the oil yield extracted from the seeds. Thus, by analyzing the oil yield variation with the piston speed, at the force of 100 kN and a temperature of 30 ° C was noted that the oil yield extracted from the safflower seeds decreases (from 12.6 to 7.3 %) by increasing the piston speed from 2 to 12 mm/min. Analyzing the graph that presents the stroke variation with the applied force, when pressing safflower seeds with different piston speeds, it was observed that at lower piston speeds (2 and 4 mm/min), the stroke has higher values.

Another parameter that influences the oil yield extracted is seeds temperature. Analyzing the oil yield extracted from safflower samples pressing with different temperatures, it was found that the pressing of the seeds at 40 ° C leads to a higher oil yield extracted from the oleaginous material (10.1% oil obtained at 30°C and 10.82% oil in the case of 40°C temperature). In this case, the piston stroke had higher values for pressing the seeds at 40°C (about 50 mm, while in the case of 30°C temperature the stroke was 45 mm).

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44. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

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MOŽNOST ANALIZE SLIKE ZA OCENO CVETENJA IN ŠTEVILA PLODOV PRI SORTAH JABOLK 'MAIRAC' IN 'DALINBEL'

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POVZETEK

V nasadu jablan sadjarskega centra Maribor v Gačniku smo želeli napovedati pridelek dveh sort jablan 'Mairac' in 'Dalinbel', s pomočjo analize slike. Poskušali smo prešteti število cvetov z metodo avtomatskega štetja cvetov in jo primerjati z ročnim štetjem. Namen poskusa je bil oceniti natančnost avtomatskega štetja cvetov in plodov v zgodnjih razvojnih fazah in možnost zamenjave ročne metode, s hitrejšo metodo analize slike. Metoda je bila preizkušena v štirih razvojnih fazah pri obeh sortah (rdeči balon, polno cvetenje, T-stadij plodičev in po junijskem redčenju plodičev). Rezultati so predstavljeni s Pearsonovim koeficientom linerarne korelacije. Pri sorti 'Mairac' je znašal Pearsonov koeficient v času rdečega balona r = 0,33, v fazi polnega cvetenja r = 0,37, pri plodičih pred redčenjem r = 0,27 in v fazi plodičev po redčenju r = 0,14. Nizka vrednost koeficienta v vseh opazovanih fazah kaže na šibko linearno povezavo, zato metoda ni dovolj natančna. Pri sorti 'Dalinbel' je znašal Pearsonov koeficient v fazi rdečega balona r = 0,38, v fazi polnega cvetenja r = 0,67, v fazi pred redčenjem plodičev r = 0,30 in v fazi po redčenju plodičev r = 0,55. Dokaj uporabne ocene pri tej sorti smo dobili v fazi polnega cvetenja, v ostalih razvojnih fazah jabolk pa metoda analize slike ni ponudila uporabnih ocen. Ob dodatnem izboljšanju metode analize slike in programa za štetje cvetov plodičev in plodov lahko predstavlja opisana metoda alternativo dosedanjim metodam ročnega štetja.

Ključne besede: *jabolko, sorta, 'Dalinbel', 'Mairac', analiza slike, sadje, donos, napoved, štetje*

UVOD

Ugodno podnebje in tla so razlogi za dolgoletno tradicijo gojenja sadja v Sloveniji. S količino in kakovostjo pridelka morajo domači pridelovalci nenehno konkurirati ponudnikom kakovostnega sadja iz tujine. Na kakovosten in obilen pridelek vplivajo vremenski pogoji in tehnološki ukrepi. Spomladi se sadjarji pogosto srečujejo s preobilnim cvetnim nastavkom, kar povzroča droben in boleznim ter škodljivcem izpostavljen pridelek. Poruši se tudi razmerje med rastjo in rodnostjo, to pa velikokrat privede do alternativne rodnosti. Pri jablani se pojavlja trebljenje, ko del cvetnega nastavka in plodičev odpade že med rastjo, kar traja do konca junija. V intenzivni sadjarski pridelavi to ne zadošča za količinsko in kvalitetno ustrezen pridelek, zato je pomembno dodatno redčenje cvetov in plodičev.

Za redčenje cvetnega nastavka se uporablja mehansko in kemijsko redčenje cvetov ter ročno redčenje plodov. Postopek mehanskega odstranjevanja poteka s posebnim ometalcem cvetov. Z njim ob skrbni pripravi in izvedbi postopka dosežemo okoli 25 – 30% odstranitev cvetov.

Figure 1 Mechanical fruit thinning (Darvin, FruitTec).

Jablane praviloma kemijsko redčijo v treh terminih. Izredno pomembna je temperatura in zračna vlaga. Optimalna temperatura v času redčenja naj bi bila med 15 ºC in 18 ºC, visoka zračna vlaga, da je izhlapevanje raztopine manjše. Uporaba kemijskih sredstev za redčenje zahteva veliko izkušenj in ni vedno dovolj učinkovita.

Velik problem pri natančnem doziranju kemičnih sredstev predstavlja pravilna ocena števila cvetov oziroma velikosti cvetnega nastavka. Štetje cvetov in plodičev je zamudno ročno opravilo. Sodobna digitalna tehnika se je v preteklosti že uspešno vpeljala za zgodnje napovedovanje pridelka jabolk in hrušk in omogoča hitro in enostavno zajemanje vseh vzorcev z digitalnim fotoaparatom ter hitro obdelavo le-teh v laboratoriju.

Zaradi nenatančnega določevanja predvidene letne količine jabolk so Stajnko in sodelavci (2004) začeli razvijati in uvajati nov način napovedovanja pridelka jabolk s pomočjo avtomatizacije štetja cvetnega nastavka in plodičev. Ta deluje na principu pridobivanja vzorcev s pomočjo digitalne tehnologije in računalniške analize. Umetni vid, ki je novejše računalniško orodje za ugotavljanje gostote, velikosti in zdravja rastlin v kmetijstvu omogoča v kratkem času zajeti veliko število vzorcev in daje natančne rezultate (Stajnko in sod., 2004). Gre za računalniško orodje, ki se dandanes pogosto uporablja v preciznem kmetijstvu z namenom ugotavljanja gostote, velikosti, zdravstvenega stanja ter ostalih parametrov rastlinske proizvodnje. Z nadaljnjim razvijanjem umetnega vida bo mogoče informacije za potrebe rastlinske proizvodnje pridobivati še hitreje (Jimenez in sod., 1999).

Velik pomen ima zgodnja prognoza pridelka, saj je treba zagotoviti dovolj delovne sile za spravilo, primerne skladiščne kapacitete ter tržne kanale za prodajo pričakovanih količin. Pridelovalci bodo lahko konkurenčnejši na globalnih trgih sadja tudi s pomočjo sodobnejših mehanizmov prognoze pridelkov v zgodnjih fazah razvoja (Stajnko in Vindiš, 2011).

Združenje pridelovalcev jabolk in hrušk Wapa (World Apple and Pear Association) pripravlja vsakoletne napovedi pridelka jabolk in hrušk za večino svetovnih pridelovalk sadja. Cilj napovedi je čim natančnejša ocena prihajajoče letine v obdobju po junijskem trebljenju. Doseči želijo oceno pridelka, katere odstopanje ne bi presegalo ± 5%. Metode za ocenjevanje pridelka jabolk se razlikujejo od države do države. Najpogosteje se uporablja metoda ročnega štetja in bavendorfska metoda (Stajnko in Vindiš, 2011).

MATERIAL IN METODE DELA

V poskus smo vključili 20 jablan sorte ´Mairac´ in ´Dalinbel´. Jablana sorte ´Dalinbel´ se trži pod blagovno znamko Antares in spada v skupino jablan, odpornih na škrlup, ter izvira iz Francije. Nastala je s križanjem sorte ´Elstar´ in nosilcem odpornosti na škrlup s selekcijsko oznako x3191. Sorta je bila žlahtnjena pod okriljem INRA (Institut National le la Recherche Agromonique – francoski nacionalni inštitut za raziskave v agronomiji) in ELARIS iz Francije. Jablane sorte ´Mairac´ izhajajo iz Švice in spadajo med novejše sorte, ki je nastala s križanjem sorte ´Gala´ in ´Maigold´ (1986). Uvrščajo jo med bolj priljubljene sorte jabolk predvsem zaradi njenega trdnega mesa (Godec in sod. 2011).

Fotografiranje in ročno štetje cvetov, plodičev in plodov smo vedno izvajali v vidnem polju 1 m^2. Zaradi lažje določitve opazovanega področja drevesa smo pred drevo namestili lesen okvir 1 x 1 m, ki smo postavili na višino 90 cm od tal. Na okvir je bila pritrjena tenis žogica, ki je služila kot objekt standardne velikosti, velik 65 mm. Objekt standardne velikosti smo potrebovali za kasnejši preračun dejanske površine zajete fotografije. Fotografije smo poskušali zajeti z oddaljenosti dveh metrov in poravnane s središčem opazovanega okvirja. Pri ročnem štetju smo si pomagali z mehanskim števcem.

Fotografiranje in štetje smo izvedli v štirih terminih, da bi ugotovili, kakšna so odstopanja metode avtomatskega štetja v posameznih fazah razvoja jabolk, saj se od cvetenja do obiranja spreminja velikost, barva in oblika cvetov, plodičev in plodov.

Table 1 The dates of performing the experiment

Dates	Date
1. A red balloon	24. 4. 2013
2. Full flowering	29. 4. 2013
3. Before fruit thinning	16. 5. 2013
4. After fruit thinning	26. 6. 2013

Algoritem programa za avtomatsko šteje cvetov, plodičev in plodov je napisan v programskem okolju Labview 7.0 Imaq Vision 6.1. in je primeren za operacijski sistem Windows. Program Labview 7.0. je namenjen analizi grafičnih podatkov. Grafično okolje programa je sestavljeno iz knjižnice za uvoz in shranjevanje fotografije. Vse fotografije v RGB obliki že vsebujejo tri ravnine (rdeča, modra in zelena). Nato se pretvorijo v binarno sliko (Stajnko in sod., 2004).

Figure 2 Example of capturing photos with the frame and the object of standard size

Program za štetje cvetov in plodičev vsebuje sedem sklopov (slika 3). Sklop 1 predstavlja značilnosti nasada. Točka 2 prikazuje izračune števila dreves in rodne površine dreves na hektar. Sklop 3 so trenutni rezultati, ki jih poda program. Sklop 5 je knjižnica za uvoz in shranjevanje fotografij, ki jih mora obdelati računalnik. Sklop 6 so nastavitve upragovanja. Sklop 7 predstavlja velikost posameznih delcev, ki jih kot cvetove zazna in prešteje računalnik in pod točko 7 je podana velikost žogice, izražene v pikslih (slikovnih elementih).

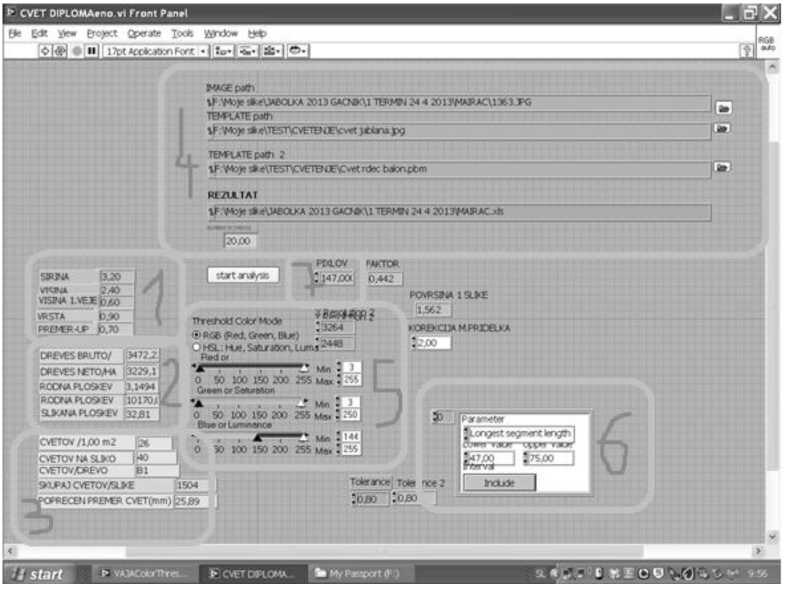

Figure 3 Working window of automatic counting flowers

Figure 4 Counting inflorescence.

Obdelava fotografij poteka v stopnjah. Najprej s pomočjo računalniške miške izmerimo premer tenis žogice v pikslih, zato da računalnik preračuna velikost cvetov in plodičev v realne enote mm. RGB slika vsebuje tri osnovne barve (rdečo, zeleno, modro). Na ta način postanejo deli slike z iskanimi objekti bolj razločni. Zelena in rdeča slika se pretvorita v binarno sliko, na kateri rdeča barva interpretira objekte (cvetove), črna barva pa podlago, s tem se izloči veliko motenj oziroma objektov, ki bi ovirali štetje cvetov. V drugem koraku iz določene osnovne slike (rdeče ali zelene) s pomočjo ročnega upragovanja ustvarimo binarno sliko. V zadnjem koraku odstranimo še vse vidne elemente, ki niso podobni obliki cvetov. Rezultat dela so prešteta socvetja, prikazana na sliki 4.

Dobljene rezultate računalniških meritev je program izvozil v Excel obliko, kamor smo dodatno vnesli še rezultate ročnih meritev in jih statistično obdelali z računalniškim programom IBM SPSS 21. Statistične razlike med obravnavanji smo ugotavljali s pomočjo korelacijskega koeficienta pri obeh sortah. Linearno povezanost dveh spremenljivk smo izrazili s pomočjo Pearsonovega koeficienta (r). Kadar je vrednost Pearsonovega koeficienta pod 0.6 gre za šibko linearno povezavo, kadar je vrednost med 0.6 in 0.8, govorimo o srednje močni povezavi, kadar pa je vrednost nad 0.8, govorimo o močno koreliranih spremenljivkah.

REZULTATI Z RAPRAVO

Table 2 Person's coefficient in different development phases for the cultivar 'Mairac'.

Observation	Date	Development phase	Person's coefficient, r_{xiyi}
1.	24. 4. 2013	A red balloon	$r_{x1y1} = 0{,}33$
2.	29. 4. 2013	Full flowering	$r_{x2y2} = 0{,}37$
3.	16. 5. 2013	Before fruit thinning	$r_{x3y3} = 0{,}27$
4.	26. 6. 2013	After fruit thinning	$r_{x4y4} = 0{,}14$

V fazi rdečega balona je model težko ocenil natančno število socvetij pri sorti 'Mairac'. Vrednost Pearsonovega koeficienta (0,33) je zelo majhna, in pove, da je komaj 33% variance rezultatov pojasnjenih.

Pri polnem cvetenju je povezanost med računalniško dobljenimi rezultati in ročnim štetjem šibko korelirana. Koeficient korelacije je majhna (0,37) in kaže na šibko linearno povezavo.

Pri plodičih pred redčenjem je znašal Pearsonov koeficient $r_{x3y3} = 0{,}27$. Metoda pa zaradi koeficienta korelacije ni točna in ni primerna za napovedovanje količine pridelka.

V fazi plodičev po redčenju je vrednost Pearsonovega koeficienta zelo majhna, $r_{x4y4} = 0{,}14$. Vrednost Pearsonovega koeficienta korelacije pri sorti 'Mairac' je v vseh fazah zelo majhna, zato rezultati niso dovolj natančni, da bi lahko metodo analize slike uporabili za oceno števila cvetov in plodičev pri sorti ´Mairac´ v praksi. Odstopanja med ročnim štetjem in računalniško analizo so rezultat prekrivanja socvetij in plodičev jablan. Vzrok je tudi v zeleni barvi plodičev in listov jablan, zato pride do slabega kontrasta pri ločevanju med plodiči in socvetji. Tudi gosto listje je povzročalo probleme, saj je zakrilo socvetja in plodiče (Kokošinek, 2014).

Rezultati statistične obdelave podatkov v fazi rdečega balona pri sorti 'Dalinbel' so pokazali, da je bil Pearsonov koeficient enostavne linearne korelacije r_{x1y1} = 0,38. Povezava je šibka, zato metoda računalniške napovedi ni natančna. Vzroki so v majhnosti cvetov, slabi opaznosti cvetov in dvobarvnosti cvetov, ki so bili v balonske stadiju v belo–rdeči barvi. Slaba računalniška ocena bi lahko bila posledica neizenačenosti v odprtosti cvetov, saj je del cvetov bil še vedno zaprt. Pri fotografiranju je bil velik del cvetov v balonskem stadiju prekrit z listjem ali pa močno osenčen.

Vrednost Pearsonovega koeficienta v fazi polnega cvetenja znaša r_{x2y2} = 0,67. Dobljen rezultat izkazuje srednje močno povezanost preštetih in računalniško določenih cvetov. Z dodatnimi izboljšavami programa in izpopolnjevanjem tehnike fotografiranja bi lahko dosegli, da bi bila jakost korelacije še boljša in bi računalniška analiza lahko v fazi polnega cvetenja postala alternativa ročnemu štetju. Rezultati bi bili boljši če med fotografiranjem ne bi bilo prekrivanja cvetov. Prednost faze polnega cvetenja za analizo slike pred fazo v balonskem stadiju je kontrastnost med iskanim elementom bele barve in zeleno okolico.

Table 3 Person's coefficient in different development phases for the cultivar 'Dalinbel'.

Observation	Date	Development phase	Person's coefficient, r_{xiyi}
1.	24. 4. 2013	A red balloon	r_{x1y1} = 0,38
2.	29. 4. 2013	Full flowering	r_{x2y2} = 0,67
3.	16. 5. 2013	Before fruit thinning	r_{x3y3} = 0,30
4.	26. 6. 2013	After fruit thinning	r_{x4y4} = 0,55

Vrednost Pearsonovega koeficienta pred redčenjem plodičev je r_{x3y3} = 0,30. Vzrokov za šibko povezanost je več. Plodiči so zelene barve in malega premera, do 8 mm, in so težko opazni. Težavo pri fotografiranju je povzročalo tudi prekrivanje plodičev z listi in suhi cvetovi.

Pearsonov koeficient za obdobje po redčenju plodičev je pokazal vrednost r_{x4y4} = 0,55, kar govori o dokaj šibkem razmerju obeh spremenljivk. Plodiči so bili precej bolje razviti in zaradi tega tudi lažje opazni kot na termin predhodnega fotografiranja. Težave so povzročali plodiči, ki so bili prizadeti zaradi kemičnega redčenja in zaradi tega neizenačeni. Težko je prepoznati plodiče zaradi zelene barve in bujne olistanosti drevja (Kokol, 2014).

ZAKLJUČEK

V letu 2013 smo na posestvu Sadjarskega centra Maribor preverjali natančnost računalniškega štetja cvetov, plodičev in plodov dveh sort jablan ´Dalinbel´ in 'Mairac'. V poizkus smo vključili dvajset dreves za vsako sorto ter jim s pomočjo metode analize slike napovedovali pridelek v posameznih fazah zorenja ter ga primerjali s ročno dobljenimi podatki. Izračunali smo povezanost obeh spremenljivk, ki je podana s Pearsonovim koeficientom. Rezultati, ki smo jih dobili, še niso dovolj natančni, da bi lahko metodo analize slike uporabili za oceno števila cvetov in plodičev pri jablanah sorte ´Mairac´ in

'Dalinbel'. Za učinkovito in kvalitetno napovedovanje pridelka s pomočjo analize slike je potrebno izpopolnit in nadgradit program. Odstopanja med ročnim štetjem in računalniško analizo so posledica prekrivanja socvetij in plodičev jablan, predvsem v fazi polnega cvetenja, saj se posamezna socvetja težko ločijo med seboj. Pri plodičih predstavlja problem barva, saj so zelene barve enako kakor listi, zato pride do slabega kontrasta.

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THE POSSIBILITY OF THE IMAGE ANALYSIS FOR EVALUATION OF FLOWERING AND NUMBER OF FRUITS IN ´MAIRAC´ AND 'DALINBEL' APPLE CULTIVARS

ABSTRACT

In the apple orchard in a Fruit growing center Gačnik, Maribor we wanted to predict the yield of two apple cultivars ‘Mairac’ and 'Dalinbel' by using the image analysis. We tried to count the number of flowers with the method of automatic flower counting and compared it to manual counting. The aim of the experiment was to estimate the precision of automatic counting of flowers and fruits in the early developing stages and the possibility of replacing the current manual method with the faster method of image analysis. The method was tested in four development phases for both cultivars (a red balloon, full flowering, T-stage of fruits (before fruit thinning) and after fruit thinning in June). The results *were introduced by the Pearson linear correlation coefficient. The low value of the coefficient in all observation phases at the cultivar ‘Mairac’ indicates a weak linear relationship, so that the method is not precise enough. For the cultivar 'Dalinbel' the method of image analysis offers very useful forecast in the phase of full blossom, however in following stages the method did not bring useful details. With additional improvements the tool of image analysis might be a perfect substitution for manual flower and fruit counting.*

Key words: *apple, cultivar, 'Dalinbel', ´Mairac´, image analysis, fruits, yield, prediction, counting*

44. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

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ENGINEERING PROPERTIES OF TWO CHERRY TOMATO VARIETIES CULTIVATE IN PLASTIC GREENHOUSE

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SUMMARY

Our study presents several important physical and mechanical parameters of two varieties of cherry tomatoes (Solanum Lycopersicon), named Sweet and Orange, which should be taken into account in the design of equipment used in the processes of harvesting, transport, processing or storage. The fruit mass of Sweet and Orange were measured as ***8.86*** *g and* ***16.67*** *g, respectively. The mean of height for Sweet and Orange were found to be* ***22.18*** *mm and* ***28.99*** *mm, respectively. The dimensions, geometric mean diameter, sphericity and surface projected area were closely related to mass of the tomato fruit. Moisture content and pH of the Sweet variety samples were* ***89.53*** *% (wb) and* ***6.50*** *respectively, and* ***88.19 %*** *(wb) and* ***6.18****, respectively, for the Orange. The calculated sphericity it was* ***0.92*** *for Sweet and* ***0.95*** *for Orange in sample fruits. The rolling resistance coefficients of tomato fruits on the plastic and textolit material surfaces were determined using a custom designed test device. The mean of rolling resistance coefficient for plastic and textolit surface was* ***0.0121*** *and* ***0.0118,*** *respectively. The theoretical elements are detailed, together with experimental evaluation.*

Key words: *cherry tomato, engineering properties, rolling resistance*

INTRODUCTION

Cherry tomato fruit, a tomato variety cultivated in extreme climatic conditions in a wide range of environments, is a small fruit garden very productive and resistant to diseases. If properly planted, crop maintenance is minimal and does not require further attention, bringing major benefits to farmers. Also, it is an important segment of fresh vegetables market in the world or in the food industry for its outstanding features: sweet, tasty, a rich source of vitamins and minerals. Fresh fruits and vegetables are strongly recommended in the human diet since they are rich in antioxidant, vitamins, dietary fibers and minerals. Several studies and research applications involving the physico-mechanical of agricultural products have been performed by many researchers. Mohsenin (1986) and Sharobeem (2007) investigated the reasons of variation in the coefficient of friction values of biological materials. Arazuri et al. (2007) in their study shows that physical properties vary due to ripening process and diseases and mechanical actions can change. Polat et al. (2007) in their research concluded that the coefficient of static friction between cherry tomatoes and the transporting system surface affects the maximum angle between the transporting surface and the horizontal axis. Li et al. (2011) found that the variety, locule number and material had a significant effect on the static and sliding friction coefficients of tomato fruits but had no significant effect on rolling resistance coefficients. Altuntas et al. (2013) reports that the static friction coefficients increase linearly in medlar fruit ripening for all materials studied. In recent years, a number of studies such as: Beckles (2012), Gezer et al. (2012) or Tabatabaekoloor (2013), have been made by researches regarding qualitative evaluation of agricultural products. However, although the level of knowledge between physical and mechanical parameters of cherry tomato determines the above-mentioned research and design parameters and control of agricultural equipment for tomato processing is high, it may be improved by carrying out further studies. This study was conducted to obtain data about some of the physical and mechanical properties of cherry tomatoes grown in greenhouses useful in the design of equipment used in harvesting, transportation, storage and processing. The increasing demand for high quality vegetables, impose in this way, more advanced research on products but also investments in new production techniques.

METHODS

The cherry tomato (Solanum lycopersicum) analyzed in this study was, Super Sweet 100 variety, small tomatoes that have been bred and grown in Greece since the early 1800s, and Orange variety. The experiments were conducted for 17 fruits from each cultivar and structure. at the Laboratory of Physical Properties of Foods, Department of Biotechnical Systems, Polytechnic University of Bucharest. The fruit's surface was cleaned manually and tested within 48 h at room temperature (24±1 °C: 60–65% RH). Each sample was tested five times, and the results were averaged. The physical properties such as size, weight, volume, density or moisture were determined by conventional methods encountered in specialized literature for biological material (Aktas et al.(2006), Naderiboldaji et al. (2008), Li et al. (2011), Altuntaş et al. (2013)). The geometric mean diameter and sphericity values were calculated using the following relationships (Moshenin, 2006):

$$Geometric\ mean\ diamter = (D_1 D_2 H)^{1/3} \tag{1}$$

$$Sphericity = \frac{(D_1 D_2 H)^{1/3}}{D_1} \tag{2}$$

where, D_1, D_2 and H are the main dimensions (mm) of fruit (figure 1). The projected area of tomato fruits was determined from pictures taken by a digital camera (Samsung Ativ S, 3264 x 2448 pixels), and then the reference area was compared to a simple area using an image processing algorithm of MATLAB package, as can be seen in figure 2. Packing coefficient (λ) was defined by ratio of fruit (V) packed to the total volume (V_t) calculated by the following equation (Naderiboldaji, 2008):

$$\lambda = \frac{V}{V_t} \tag{3}$$

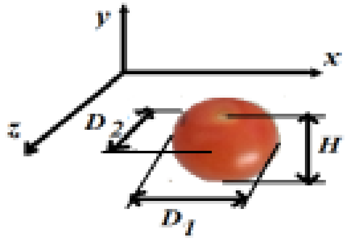

Figure 1 Representation of tomato dimensions

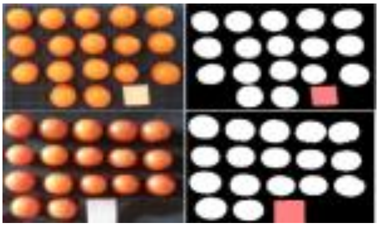

Figure 2 Projected area

Two materials, namely, plastic PVC and textolit were tested in this study to determine the rolling resistance coefficients of tomato fruits on these surfaces. Surface roughness parameters R_a were determined using a 25 mm pass across the surface, with a Digital Comparator. Preliminary tests were made using some variation in normal force. These tests confirmed the reports of other research, in that within a broad range, the value of the rolling coefficient is not dependent on normal force.

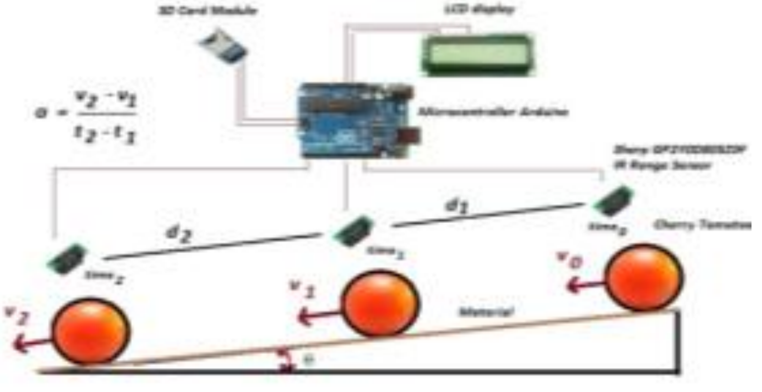

Figure 3 Test device used to determine the rolling resistance coefficients of tomato fruits

Rolling resistance coefficient determination was done by measuring the acceleration fruit in motion on a plane, inclined to the angler θ, as can be seen from figure 3. We will only consider rolling without slipping. The tomato sample was placed as shown in the figure; the slope was tangent to the fruit shoulder and the longitudinal axis of fruit was perpendicular to the slope. When tomato, of mass **m** and moment of inertia **J**, rolls without slipping and its center mass has velocity ***v***, the tangential velocity of the tomato at its radius, R, normal to the axis of rotation, must also be ***v***, and therefore

$$\omega = \frac{v}{R}\,, \tag{4}$$

where *ω* is the angular velocity of fruit rotating about its center of mass. The angular momentum of the tomato is ***J·ω***, and substituting ω:

$$J \cdot \omega = J \cdot \left(\frac{v}{R}\right) = \left(\frac{J}{R}\right) \cdot v. \tag{5}$$

The total torque on the fruit when it rolls without slipping is the rate of change of its angular momentum, which equals:

$$\frac{d(J\omega)}{dt} = J/R\,\frac{dv}{dt} = \left({}^{J}\!/_{R}\right) a \tag{6}$$

The component of the fruit's weight normal to the inclined plane is:

$$F_n = \mathrm{mg}\cos\theta\,. \tag{7}$$

Thus, the kinetic friction force acts on the fruit is:

$$F_f = \mu_r \mathrm{mg}\cos\theta. \tag{8}$$

The frictional force is normal to the radius of the fruit's axis of rotation (when it rolls) and it is applied at the surface of the fruit at a distance R from the axis, so friction makes a torque, τ, on the ball equal to:

$$\tau = \mathrm{R}\mu_r \mathrm{mg}\cos\theta \tag{9}$$

In order for the tomato not to slip, the torque on the tomato from friction can not be less than the total torque on the tomato when it rolls, and therefore we can calculate the rolling resistance coefficient, μ_r, as:

$$\mu_r = k\,\frac{a}{\cos\theta}\,, \tag{10}$$

where **a** is acceleration of tomato fruit's, **θ** is the angle of inclination from the horizontal plan and **k** is a constant that depends on the shape of the fruit and gravitational acceleration, **g**, who can be determined by the relation:

$$k = {}^{J}\!/_{mR^2}\,. \tag{11}$$

Rolling friction behavior was done using a custom designed test device. The system utilizes an Arduino UNO board, three analog distance sensor IR Sharp GP2Y0D805Z0F (emitting wavelength range of LED λ = 870 ± 70nm, sampling rate 390 Hz) and associated modules for data acquisition, display (Liquid Crystal Display with 16 characters per line and 2 lines) and data storage (microSD Card Logger). An Arduino software source code is used to colect data sampling during a test and calculate velocity, acceleration and rolling resistance coefficients of tomato fruit's. Basic source code structure is presented in the flowchart of figure 4. By using this very sensitive device it is possible to provide a greater understanding of this aspect of product's quality. This method for determining rolling resistance coefficient has not been used in numerous studies to date.

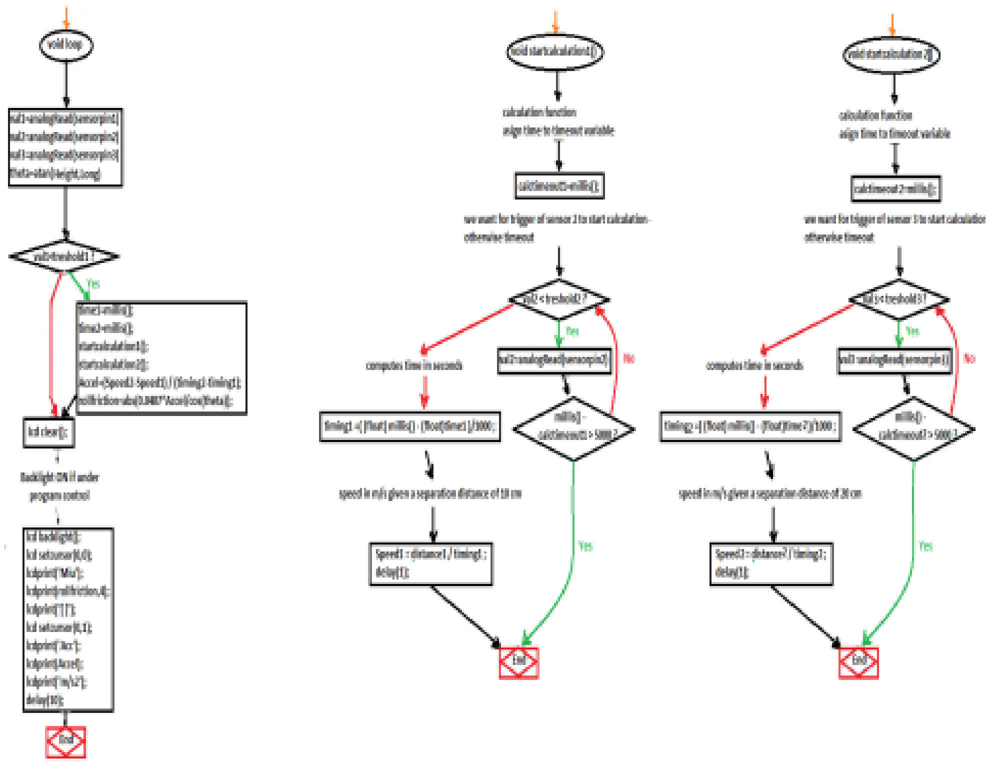

Figure 4 Flowchart of programe

The statistical evaluations in this study were done using MATLAB package program (R2014b - MathWorks Inc.). The one-way analysis of variance (ANOVA) was performed to evaluate the influence of the different tomato varieties on the physico-mechanical properties of cherry tomato fruits and the significance degree selected was p = 0.05.

RESULTS AND DISCUSSION

Some physical properties of cherry tomato are shown in Table 1. Fruit height of **81.25** % of the Sweet cherry tomatoes ranged from **21.3–23.5** mm, equatorial diameter of **87.50** % of the samples ranged from **23.9–26.9** mm and the mass of **75** % of the samples ranged from **7.10–9.75** g. Also, for the Orange varieties, fruit height of **62.5** % of samples ranged from **27.3–30.5** mm, equatorial diameter of **87.50** % of the samples ranged from **29.5–32.3** mm and the mass of **68.75** % of the samples ranged from **13.20–17.72** g. The average geometric mean diameter, meridional diameter and fruit sphericity values for Sweet varieties fruit were **23.81**, **23.67** mm and **0.92** at **89.53** % moisture content (wb) while **29.96**, **29.71** mm and **0.95**, respectively, were reported for Orange varieties fruit at **88.19** % moisture content, wet basis (wb). There was a significant difference between dimensions and the sphericity of two cultivars. The sphericity values indicate that fruit shape is approximately close to a sphere.

Table 1 Distribution of size, shape and density of cherry tomato varieties

	Sweet		Orange	
Characteristic	Mean value (St. err.)	Range	Mean value (St. err.)	Range
Diameter1 (mm)	25.72 (0.23)	23.90-27.90	31.24 (0.24)	28.50-32.30
Diameter2 (mm)	23.67 (0.17)	22.50-24.80	29.71 (0.24)	27.20-31.00
Heigth (mm)	22.18 (0.18)	20.60-23.50	28.99 (0.28)	26.20-30.50
Mass (g)	8.86 (0.23)	7.12-10.61	16.67 (0.35)	13.17-1923
Geom. mean dia. (mm)	23.81 (0.18)	22.32-25.33	29.96 (0.23)	27.28-30.96
Volume (cm^3)	7.99 (0.21)	6.5-9.6	15.26 (0.21)	12.96-16.5
Projected area (mm^2)	615.1 (16.19)	496.6-726.5	840.5 (13.40)	704.1-954.1
Sphericity (%)	0.92 (0.003)	0.90-0.96	0.95 (0.003)	0.93-0.99
Density (kg/m^3)	1100 (0.01)	1.04-1.18	1090 (0.02)	0.99-1.21
Packing coefficient	0.478 (0.004)	0.437-0.505	0.417 (0.004)	0.394-0.445

The volume and fruit density for Sweet varieties was found to be **7.99** cm^3 and **1100** kg m^{-3}, respectively, and **15.26** cm^3 and **1090** kg m^{-3}, respectively, for Orange. The values of the packing coefficient ranged from **0.394–0.505**, with mean values of **0.447**. The results were probably due to the volume and shape of the cherry tomatoes. The packing coefficient increased with a decrease in fruit volume. Similar results were found by Polat et al. (2007) for cherry tomato varieties and by Altuntas (2013) for medlar fruits.

The mean values of projected area in perpendicular directions of the height fruit for Sweet cultivar was found to be **615.1** mm^2, in the range **496.6-726.5** mm^2. For Orange fruits projected area was found to be **840.5** mm^2, in the range **704.1-954.1** mm^2, and was slowly greater than that of the Sweet fruit. Analysis of variance results indicated that cultivar had a significant effect ($F=1066>F_{crit}=3.98$, $p<0.01$) on the projected area. In general, results indicated that some physical parameters such as dimensions, mass, volume, projected area, sphericity are depended on cultivar. The effect of cultivar on the fruit density and pH was not significant. The results are similar to those reported by Naderiboldaji et al. (2008) for sweet cherry varieties, and Taheri-Garavand et al. (2011) for tomato.

Table 2 Rolling resistance coefficient of cherry tomato varieties

	Sweet			Orange		
Material	Mean	Range	St. dev.	Mean	Range	St. dev.
plastic	0.014	0.006-0.019	0.004	0.011	0.008-0.015	0.002
textolit	0.013	0.010-0.017	0.002	0.011	0.008-0.016	0.002

Summaries of the measured rolling resistance values are provided in Table 2. The calculated rolling resistance coefficients of two cherry tomato varieties, determined on the plastic (R_a=4.3μm) and textolit (R_a=4.2μm) surface material, showed a wide variety of responses. On the plastic surface values of rolling friction was found to be 0.014 for the Sweet and 0.011, respectively for Orange. The mean values of rolling resistance coefficient for Sweet cultivar on textolit surface, 0.013, were easy higher than those for Orange cultivar, 0.011, and this might be due to the effect of sphericity.

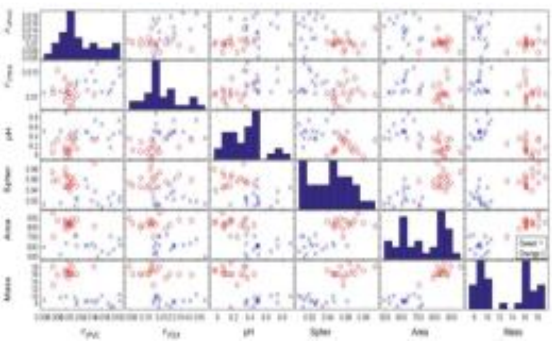

Figure 5 Group plot matrix

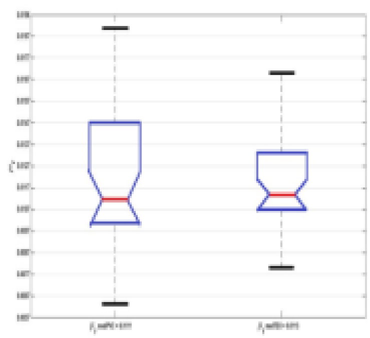

Figure 6 Box plot

For exploratory data analysis, we used statistical plots shown in Figures 5 and 6. In figure 5 the function graphs present the columns of the x argument against each other, and places histograms along the diagonals. The upper right plot, for example, is a graph of rolling resistance coefficients on a plastic surface versus mass fruits. The Sweet variety appears to have a higher rolling resistance coefficient than the Orange variety, and they appear to weigh less on average. Figure 6 shows the box plot. The graph compares values of rolling resistance coefficient samples tested from every material surface (plastic-left, textolit-right). The distances between the tops and bottoms of each box are the interquartile ranges: ***0.004*** - plastic and ***0.002*** - textolit. The line in the middle is the sample median

(***0.0111***-plastic, respectively ***0.0113***-textolit). The long lower tail also show the lack of symmetry in the sample values. The mean (***0.0121; 0.0119***) and median (***0.0111; 0.0113***) values seem very close to each other. A positive skewness value ***0.58*** (plastic) and ***0.54*** (textolit) means the data are right skewed. The data do not have a higher peakedness than the normal distribution, because the kurtosis value (***2.463; 2.987***) is less than 3. Since the notches in the box plot do not overlap, you can conclude, with 95% confidence, that the true medians no differ. To investigate different levels of grouping data, we created a hierarchical tree of clusters. The cophenetic correlation (c = 0.8338) verify that the cluster tree is consistent with the original distances. Large values indicate that the tree fits the distances well, in the sense that pairwise linkages between observations correlate with their actual pairwise distances.

To test that the surface material had a significant effect on the rolling resistance coefficients, we perform a single factor analysis of variance (one-way ANOVA). Results ($F=292.24 > F_{crit}=3.08$, $p<0.01$) showed that the means is not equal, and we need a t-Test (two-tail) to test each pair of means. Given the significance level of the test $\alpha=0.05$, the main effects were examined. In this case, $-t_{crit} = -2.003 < t_{Stat} = 0.433 < t_{crit} = 2.003$, $P(T<=t) = 0.666$. Therefore, we do not reject the null hypothesis. The observed difference between the sample means (***0.0002***) is not convincing enough to say that the average number of rolling resistance coefficient between plastic and textolit surface differ significantly. The overall mean of the rolling resistance coefficient was 0.0122, but the values were significantly lower than those reported by Li et al. (2011) for tomato on stainless steel and rubber.

CONCLUSIONS

Results obtained prove that among the physical properties of two varieties, significant difference was observed between dimensions, mass, volume, projected area, sphericity and tomato varieties. No significant differences resulted in rolling resistance coefficient and tomato variety or material. New method proposed and developed for determining rolling resistance coefficient tomatoes provides promising results. It has a broad applicability, not only in the educational process, but also practical in agricultural equipment design necessary processes of harvesting, transport, storage or processing of cherry tomatoes.

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44. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

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USE OF DIGESTATE IN THE POTATO GROWING TECHNOLOGY

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SUMMARY

A field trial performed in the locality Valečov between 2014 and 2015 was focused on comparison of digestate with a typical mineral fertilizer. In total, three variants were established with four replications: 1) 100 % nitrogen in urea (120 kg N ha^{-1}); 2) 100 % nitrogen in digestate (120 kg N ha^{-1}); 3) 150 % nitrogen (180 kg N ha^{-1}). The effect of fertilization variants was studied on yield and quality parameters of ware potatoes. The obtained results show that year of growing had a significant effect on potato yield and quality, especially in 2015, when yields were to a certain extent affected by extreme drought. Potato yield, particularly in 2014, was positively affected by variants with digestate compared to urea and simultaneously, no significant effect was found on internal tuber quality. On the average of years, the highest yields were tendentiously recorded for the variant with digestate rate of approx. 120 kg N ha^{-1} compared to the other variants.

***Key words**: digestate; fertilization; yields; internal tuber quality*

INTRODUCTION

Digestate is material remaining after fermentation process, which is produced by anaerobic fermentation during biogas production.

Digestate production and composition depends on amount and composition of individual co-ferments, which enter the process of digestion in biogas plants and especially on output of biogas plants, in which co-ferments are processed into digestate. Based on data from Czech Biogas Association (http://www.czba.cz/en.html, 2014) 507 biogas plants (BGPs) with installed output of electrical energy of 358 MW were in operation in the Czech Republic before January 1, 2015. On the beginning of the year, from this number, 378 were agricultural plants with installed output of 318.78 MW, which process farmyard manure and fodder, incl. maize silage and which are predestined for application of digestate to agricultural land. Based on measuring production and installed output of plants we expect annual production of digestate from agricultural biogas plants of 7.9 mil. tons.

Fertilization with digestate is similar as slurry application, but it is always suitable to take into account current nitrogen content. With mean content of 0.5 % of total nitrogen and with rate of one tone of digestate 5 kg of N ha^{-1} are supplied into the soil. Compared to farmyard manure digestates usually have high total nitrogen content ranged between 0.2 and 1 % in original mass, pH between 7 and 8 and dry matter in the range between 2 and 13 % (Smatanová, 2012). Applying on agricultural land based on principles of good agricultural practice digestate reaches required effect from the view of harmonic nutrition and level and quality of field crop yield. Digestate is a source of nutrients, which with successful elimination of above mentioned potential risks using continuously developed technological discipline could help to production efficiency of soils under conditions of sustainable agriculture (Dostál et al., 2015). Wellinger et al. (2013) indicate that the effect of digestate on crop yield is diverse, from null to a significant effect. Digestate application in firm or liquid form could result in substantial improvement of amount and quality of food due to nutrient supply and microelement content in available form for plants (Makádi et al., 2012). Based on plant response to digestate application, plants could be classified as sensitive (alfalafa, sunflower, soybean) and insensitive (winter wheat, triticale, maize). In sensitive plants, digestate could be only applied in certain developmental stages (Makádi et al., 2008). Almost all literature sources are directed to acting of wet digestate as a fertilizer for wheat, maize, rape, rye or sorghum (Dominguez, 2012). However, in the Czech Republic digestates are especially applied in growing of potatoes, grain corn and silage maize under conditions of absence of animal production accompanied with lack of farmyard manure. Use and dosage of digestate as a fertilizer is to a certain extent similar to use and dosage of slurry, always with taking into account current content of nutrients, especially nitrogen (Kasal et al., 2010). The objective of the contribution is comparison of fertilization variants with digestate and typical mineral fertilizer on yield and quality parameters of ware potatoes.

METHODS

Results of a field trial with ware potatoes, digestate and urea applications were evaluated. The trial was performed on Valečov Research Station between 2014 and 2015. In an exact field trial with early potato variety Dali in total three variants of fertilization with four replications for each variant were established (1. 100 % N in urea; 2. 100 % N in digestate; 3. 150 % N in digestate). Nitrogen rates in individual years were determined within trial variants based on sampling and analysis of digestate prior to application onto the soil (Table 1). Differences of nitrogen content in digestate were insignificant in individual years. Digestate was applied with technique involving direct incorporation into soil approx. 14 days prior to planting. On the plot de-stoning technology was used, which lead to fertilizer distribution in the whole soil profile. During the field trial common cultural practices were used with herbicide and fungicide application. After harvest tubers were analysed based on tuber size distribution and starch and dry matter content was measured. The results were statistically assessed using software (Statistica.cz) with one-factor analysis of variance and Tukey HSD test.

Table 1 Agrochemical composition of digestate from BGP Vadín

Year	Dry matter	Organic subst.	N - tot.	P_2O_5	K_2O	MgO	pH
2014	7.06	5.48	0.38	0.23	0.32	0.046	8.3
2015	5.30	3.70	0.43	0.13	0.53	0.074	8.6

RESULTS

Obtained potato yields (Figs 1 and 2) were partly affected by weather in individual years. Lower yields in 2015 were especially recorded on the variant 3 with higher rate of digestate. This fact was probably caused by extreme drought during summer months. Based on findings of Jůzl (1994) yield of early potatoes is especially affected by rainfalls during July. The beginning of growing season 2015 was optimal for growth and it could be expected that plants in the variant with higher nitrogen rate formed vegetative organs at first, what could be evidenced from results within vegetation monitoring. Vaněk (1998) confirms that under good growing conditions high N rates particularly act on growth of vegetative organs and later generative stage is coming and it results in extension of ripening period.

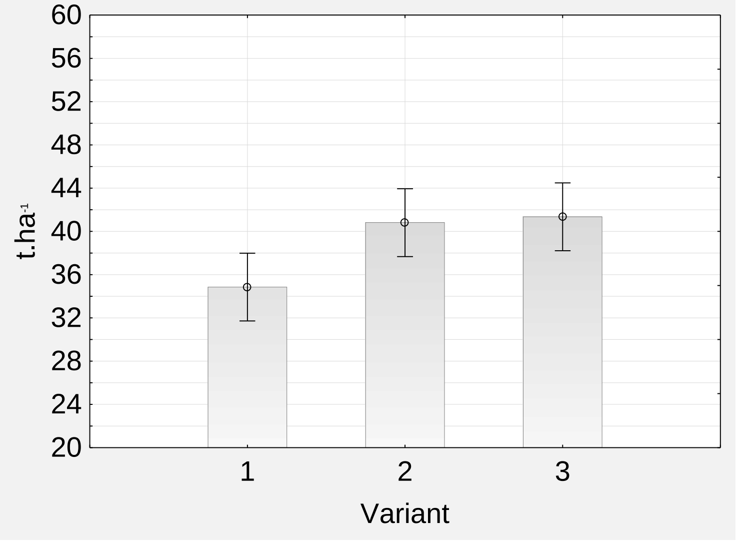

Fig. 1 Effect of variants on potato yield in 2014

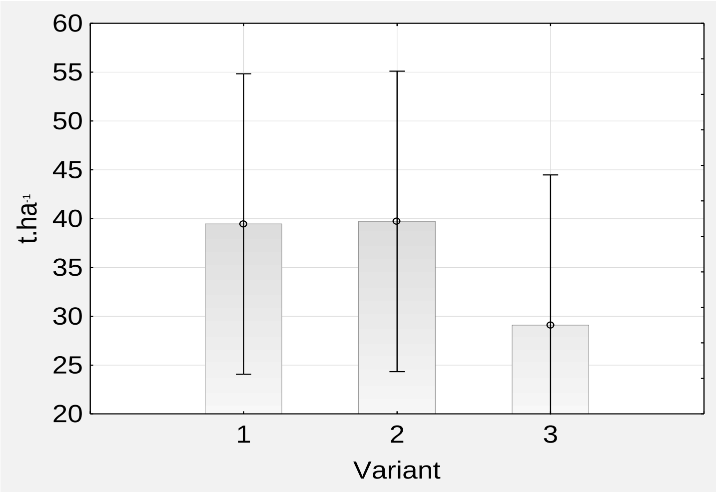

Fig. 2 Effect of variants on potato yield in 2015

During tuber bulking dry and very warm weather was recorded, which probably resulted in approx. 25 % yield decrease in the variant 3 compared to the other variants. On contrary, in 2014 the variant 3 (150 % N in digestate) gave statistically the highest yields compared to the variant 1 (100 % N in urea). Variant 2 with 100 % N in digestate seemed to be optimal within the years. Potato yields from this variant were about 40 t.ha^{-1} on the average of the years. Based on findings of Smatanová (2012) mineral fertilization has the highest yield effect. Digestates and compost are only slightly below the yielding level of fertilization using common mineral fertilizer. Garfi et al. (2011) confirm that potato yield was 27.5 % increased after digestate application compared to unfertilized control (compared to compost with 15.1 % yield increase).

Tuber size distribution was measured on sieves with square holes, for three basic sizes – less than 35 mm, 35-55 mm and more than 55 mm (Table 2). The results show that distribution of tubers in individual size categories was not statistically significantly affected by fertilization variant. Particularly, year of growing was unambiguous, when differences in tuber distribution in individual size categories were found in both studied years. Based on findings of Smatanová (2012) portion of tubers sized more than 35 mm was increased after digestate application compared to mineral fertilizer application, namely by 14.1 %. It corresponds with obtained results within the trial, with the exception of the variant 3 in 2015.

Rate or kind of fertilizer had no effect on potato quality.

Starch content in potato tubers (Figs 3 and 4) was not statistically significantly affected by fertilization variant. A difference between studied variants was 0.5 % within the variants. Year of growing had a statistical significant affect on starch content, when differences between studied years were almost 2 %. Conclusions of Roháček (2013) were confirmed; the author mentions that slurry application substantially decreased starch content, however, for digestate this effect was not almost found (from initial 16.1 % of starch decrease to 15.8 %). Dry matter content in potato tubers was 10.9 % increased after digestate application compared to mineral fertilizer; in our field trial this effect was not confirmed. The effect of year on dry matter content was not statistically significant.

Table 2 The effect of variant and year on tuber size distribution (%)

Tuber size distribution (%)	Variant	Year			F – test for variants
		2014	2015	Mean	
< 35 mm	1	4.67	5.57	5.12a	*1.581*
	2	3.52	10.48	7.00a	
	3	3.50	22.63	13.07a	
	Mean	3.90a	12.89b		
	F - test for year	*0.004*			
35 - 55 mm	1	48.12	94.43	71.28a	*0.412*
	2	54.34	89.52	71.93a	
	3	36.75	77.37	57.06a	
	Mean	46.40a	87.11b		
	F - test for year	*0.000*			
> 55 mm	1	47.22	0.00	23.61a	*0.784*
	2	42.14	0.00	21.07a	
	3	59.75	0.00	29.88a	
	Mean	49.70a	0.00b		

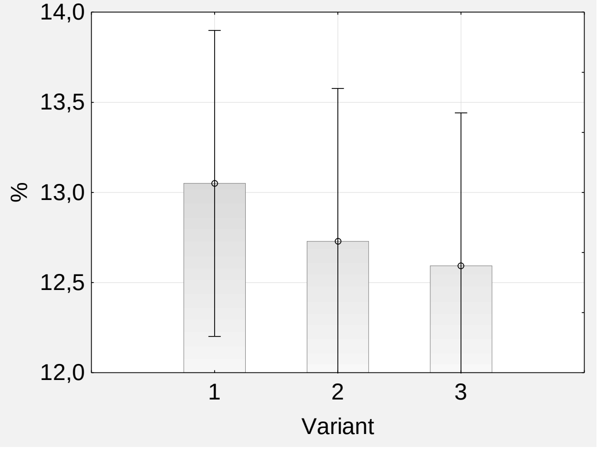

Fig. 3 Effect of variant on tuber starch content (%) in 2014

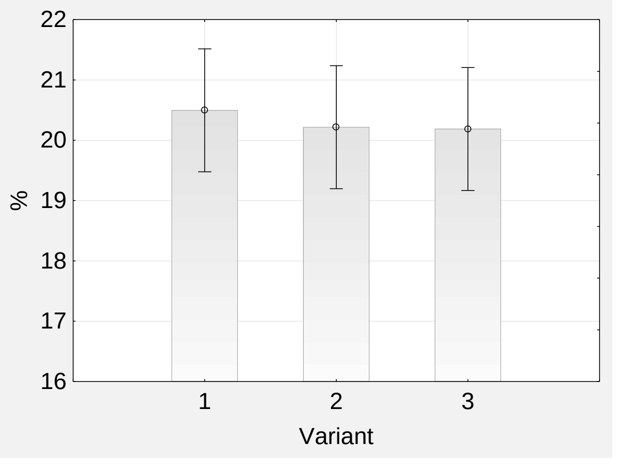

Fig. 4 Effect of variant on tuber starch content (%) in 2015

Based on obtained results digestate could be recommended as a suitable alternative to basic fertilization.

Use of digestate as a fertilizer provides economic and environmental benefits, since it decreases amount of mineral fertilizers required for agricultural production. As results show, digestate application could lead to substantial increase of amount and quality of agricultural crops due to supply of nutrients harmonized with plant demands. Due to year effect (2015) in the field trials with potato fertilization using digestate statistically significant results were only obtained in 2014.

ACKNOWLEDGEMENT

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44. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

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Original scientific paper

OFF-GRID SLAUGHTERHOUSES: SERVICES AND USE OF RENEWABLE ENERGY IN INNER AREAS

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SUMMARY

At European level, there is a growing attention to inner rural areas carried out by the European Cohesion Policy. These areas have problems in terms of scarcity and economic inefficiency of productive activities, for the aging and loss of population and for the absence of basic services. At the same time, these areas could be a catalyst for the recovery and strengthening of regional identities. At national level, the Italian Department for Development and Economic Cohesion has developed indexes for mapping inner areas (European Commission, 2014). In this framework, it is strategic to strengthen the work of local authorities and processes to make optimal use of the structural funds from EU for the development and re-establishment of these areas. The goal of the study is to experiment the adoption of technology solutions in agriculture able to satisfy the energy needs of small scale food producers in areas with high environmental and landscape value. The specific objective is to find a winning solution for self-sufficiency and reducing emissions of mobile production and processing units. This study is focused on the potential of a PV system to guarantee the energy needs of a family farm and a mobile small slaughterhouse for sheep in a rural area of Umbria Region. To guarantee energy autonomy of the small farm chosen as case study, this paper shows that it is necessary a PV system of 7,88 kWp power and 22 Lithium-ion batteries (120 Ah). In this case the total energy overflow is 3172 kWh, but it is possible to use the 43,24 % of this energy for the operation of a slaughterhouse during March, April, August and October. This solution meets about the 18% of demand of lambs slaughtering in the study area.

The mobile slaughterhouse is able to guarantee a real support to production process for several small farms that continue to oversee territories, local products, and communities located in the inner areas. Small-scale smart grids *are interesting for small family farms that adopt sustainable models and methods of production with low environmental impact and low energy demand to define the indications for their optimal energy planning. This paper concerns a proposal to ensure energy independence of small farms in inner areas, in a logic of energy sovereignty (United Nations Non-Governmental Liaison Service, 2015).*

Key words *sheep farm, micro grid; PV system, renewable energy, family farming*

INTRODUCTION

Inner areas

Inner areas are the subject of specific integrated projects in the 2014-2020 European strategy. These projects are aimed at the development and the enhancement of local communities (European Commission, 2014).

Inner areas are territories characterized by an inadequate offer of/access to essential services to assure a certain level of citizenship among population and that are substantially far from large and medium-sized urban centres, able to supply adequate services. At the same time inner areas are considered strategically relevant to foster a more sustainable and inclusive national growth. From the energy point of view, these areas are characterized by low consumption, which, however, is difficult to satisfy. In fact, even when the consumption demand is reached through the existing networks, it involves high costs and multiple operating issues. In these settings, the concept of energy sovereignty is especially significant, linked to the establishment of development models, accepted and embraced by the local communities, based on the sustainable and long-lasting use of natural resources (United Nations Non-Governmental Liaison Service, 2015). The inner area chosen as case study is the valley of Nera (Valnerina), located in Region of Umbria (figure 1).

Energy sovereignty

The concept of energy sovereignty recognises energy as a human right (World Development Movement, 2015). Seeks to return the control of energy to users, rather than remote corporations that seek to profit from regardless of its impact on consumers or how it is generated (Menges, 2003; Martinez-Alier J., 2011.).

The establishment of energy sovereignty is strongly connected to the development of renewable energies, which, by their own nature, are spread throughout the region. Renewable energies have had a strong development at European level since 2000. This development is connected to a widespread increase in energy consumption that has also involved growing energy production from coal and gas (+ 25 and + 23 % respectively, International Energy Agency, 2014). Despite the positive performance of renewable energy recorded globally in the last few years, the average energy produced is still definable as "dirty". The cause of all this lies in the fact that coal continues to be the dominant energy source, within a picture of continuously and significantly increasing energy consumption.

In the case of Italy, the increase in the use of renewable energies reflects the European trend. This increase has entailed local overloads to the existing energy distribution grids, which should be redesigned and upgraded in view of the energy storage possibilities supplied by net metering (Delfanti and Olivieri, 2015).

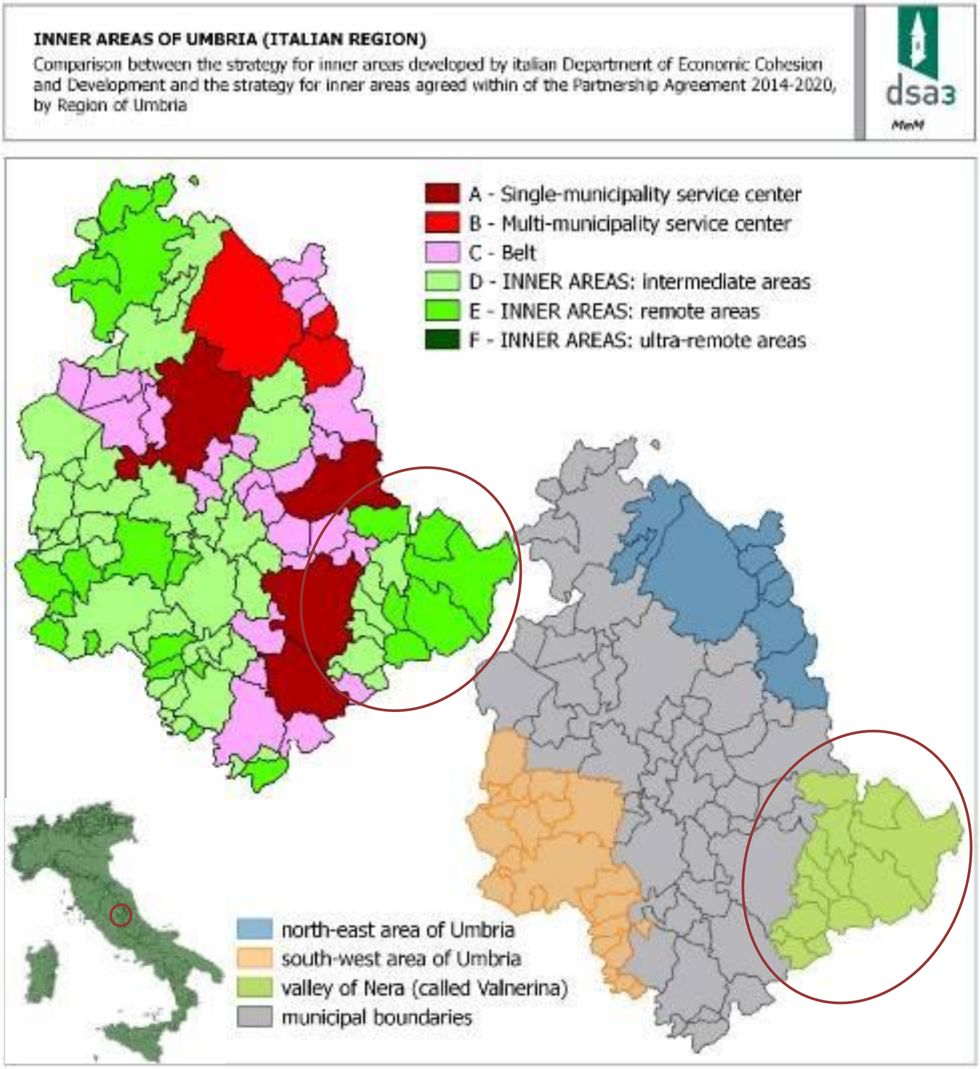

Figure 1 Representation of the inner areas identified in the regional context (Umbria). The study area is highlighted with an orange ellipse that surrounds it

That observation reinforces the importance of reasoning in terms of energy sovereignty, imagining a widespread energy system, unfettered by the presence of traditional distribution grids.

Small scale food producers

The study area examined by the present study is the Valnerina (Umbria), a valuable rural area in terms of landscape and environment, characterized by a marked resilience of small family farms that practice sheep farming.

Nationally, sheep farming is a strategic sector, as Italy is among the top 5 producers of sheep's cheese in the world (Faostat, 2011). In Umbria region, specifically there are 1,475 farms for a total of 107,13 heads of sheep (Istat, 2010). In this framework, the small family farms are the activities most affected by the crisis and that need services in support of production.

In this direction, it is strategic to consider establishing mobile slaughterhouses to serve the small and very small sheep farms (Umbria Region, 2014).

Case study: a sheep farm located in Valnerina

The sheep farm chosen as case study is a multifunctional family farm, located in the Municipality of Spoleto (Valnerina). The farm is at 298 meters above the sea and is located in central Italy (geographical coordinates: latitude 42°48'16,01" north, longitude 12°43'52,80" east). The farm produces different goods: sheep, fodder (wheat and barley) and cereals (maize). The farm's buildings consist of a sheepfold, some silos for storage of grain and a mechanical workshop.

Energy consumption is attributable mainly to the house of the farmer, to the operation of the mechanical workshop and to the handling of grain in silos. Annual consumption amounts to 5615 kWh.

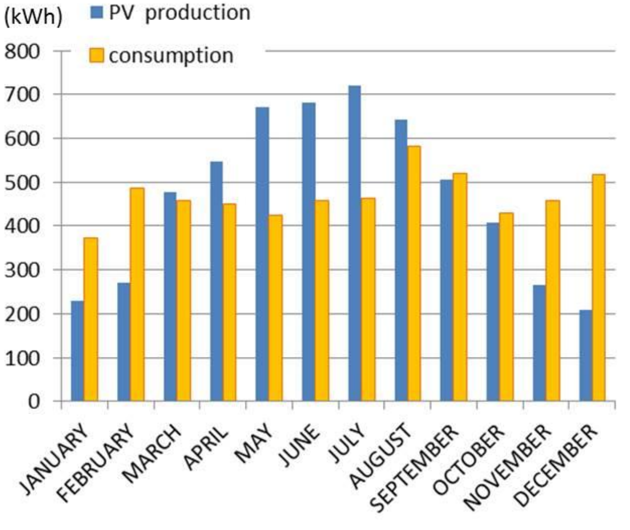

Figure 2 Energy consumption and PV production of the case study -year 2014

The farm has installed a PV system with nominal power equal to 4,5 kW. It consists of polycrystalline panels arranged in series, featuring 230 Wp power, with dimensions 992x1640 mm. The PV panels were sited on and integrated in the sheepfold's roof with an orientation featuring -3° azimuth and 13° tilt. Annual production amounts to 5627,88 kWh. This case study has made it possible to monitor, throughout 2014, the actual energy consumption of the building and the energy produced by the PV system (figure 2).

The comparison between energy production and consumption highlights 6 months of deficit and 6 months of energy over-production.

Objectives

The objective of this work is to develop a methodology to achieve a small smart grid capable of meeting the energy demand of small family farms in inner areas. In particular, starting from the energy demand monitored for the year 2014, the method has the aim to optimize the energy production of a PV system in order to meet demand and to use the surplus for services related to agricultural activity. This paper evaluated the effectiveness of the use of surplus energy for a mobile slaughterhouse, usable by farms located in the study area (Valnerina).

METHOD AND RESULTS

The scheme of the small scale smart grid, object of this paper is represented in figure 3.

The developed methodology has these different steps:

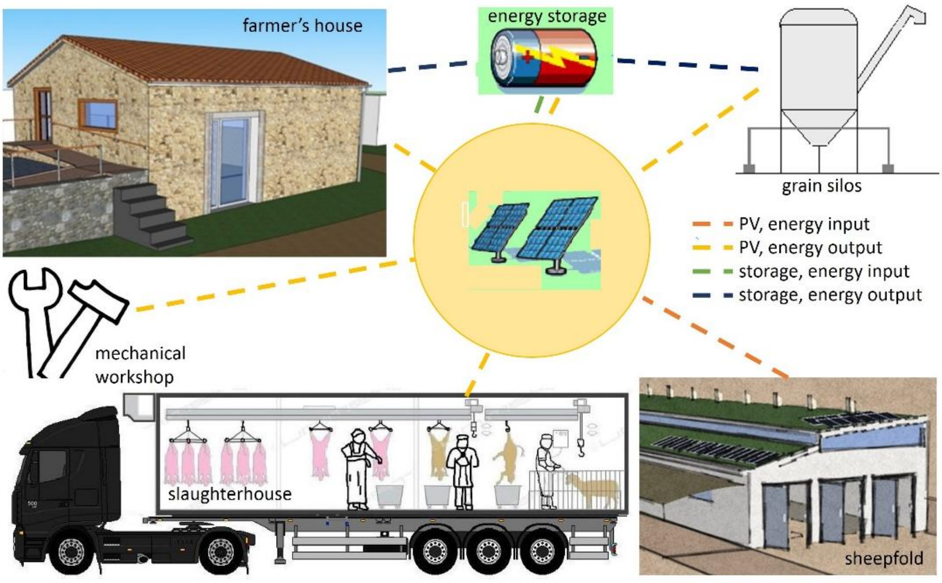

Figure 3 Small scale smart grid design

PV project: design of a PV system that meets the following two requirements:

- Fulfil energy demand linked to the farm
- Optimize the balance between production and energy demand

Storage system project: design a low cost storage system that solves the time shift between energy supply and demand.

Energy autonomy of a slaughterhouse: evaluate the potential use of the energy surplus of the PV system integrated with the storage system for the operation of a mobile slaughter unit.

PV project

To simulate the energy produced by the PV system was used the open source tool "Simulare_11", available at http://www.intellienergia.com/. Simulare is a technical-economic simulator to design PV solar systems developed by the Italian Spin-off firm Intellienergia. This tool was chosen for its versatility and its widespread and frequent use by consultants and researchers. To obtain energy independence is important to identify the optimal storage systems that can guarantee useful energy supplies in time and space, finding solutions that meet the high variability of production profiles at hourly, daily and monthly times and adapting to the energy demand profile. This presentation focalize its attention to resolve the monthly time shift from production and consumption, because the energy carriers designed for long term energy storage are too expensive for a small family enterprise. To achieve the optimal configuration of the PV system were prepared various project proposals, called with letters: A, B and C. These proposals are not alternatives, but are the results of the different steps of the work to achieve the optimal solution (final proposal).

Proposal A. In order to reduce the deviation between production and consumption, the first step in the construction of the project proposal A concerned optimizing the positioning parameters of the PV system's panels. To define the proposal A, we coupled an energy simulation program with an optimization algorithm (Attia, 2012) to find the optimal position of the PV system. The objective function find the minimum monthly deviation between production and consumption trends, varying the position of the PV system (tilt and azimuth). The logic with which the proposal A was simulated is no longer that of maximizing the energy produced by the PV system but to reduce the time shift, i.e. to balance energy production and use over time to assure the building's energy independence. The optimization algorithm identified an orientation featuring 0° azimuth and 66° tilt as the optimal panel positioning. This proposal shows an annual energy deficit that was not present on the case study, but it reduces by 68% the maximum deficit on a monthly basis (December).

Proposal B. Since the currently most commercially significant chemical storage systems consider the energy independence assured by the batteries at around 4 days on average (Linden and Reddy, 2002), the power of the installed system must be increased in order to assure that the monthly system production is always greater than consumption. The power of the hypothesized system was therefore increased in steps until the overall power of the system was able to meet the above condition. The required nominal power of the resulting proposal B turned out to be equal to 7,61 kW, with estimated total production of 8787 kWh.

The table 1 shows the monthly consumption and the different monthly productions obtained (case study, project proposal A, project proposal B).

From figure 4, one may observe how the trends of the curves related to the energy produced on proposal B and A are closer to the consumption's curve respect the energy produced in the actual case study.

Table 1 Comparison between case study (PV system, -3° azimuth, 13° tilt, 4,5 kWp) and project proposals (A: PV system, 0° azimuth, 66° tilt, 4,5 kWp; B: PV system, 0° azimuth, 66° tilt, 7,61 kWp). The cells with red values show the months of energetic deficit

Energy parameters (kWh)	consumption	case study: production	case study: overflow	A production	A overflow	B production	B overflow
1	372,0	229,5	-142,5	329,2	-42,8	556,8	184,8
2	486,0	271,8	-214,2	332,3	-153,7	562,0	76,0
3	458,0	476,1	18,1	488,4	30,4	825,9	367,9
4	451,0	547,2	96,2	456,7	5,7	772,3	321,3
5	424,0	671,7	247,7	480,5	56,5	812,6	388,6
6	457,0	682,3	225,3	453,0	-4,1	766,0	309,0
7	462,0	721,1	259,1	488,6	26,6	826,3	364,3
8	581,0	642,9	61,9	503,5	-77,5	851,5	270,5
9	519,0	504,6	-14,4	487,0	-32,0	823,5	304,5
10	430,0	406,7	-23,3	497,7	67,7	841,7	411,7
11	457,0	266,0	-191,0	372,6	-84,4	630,1	173,1
12	518,0	208,0	-310,1	306,4	-211,6	518,1	0,1
total	5615	5628	13	5196	-419	8787	3172
annual deficit	-	-	-895	-	-606	-	0

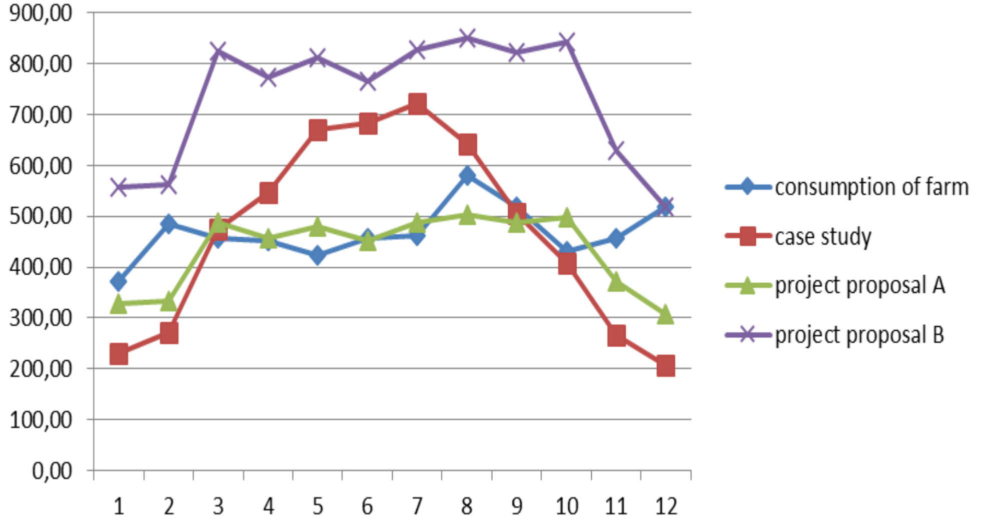

Figure 4 Comparison between annual trends of case study and project proposals, year 2014

Storage system project

Proposal C. Concerning energy storage for proposal C, the use of Lithium-ion batteries was assumed. Lithium-ion batteries are potentially suitable for applications in small residential and production units because they represent a chemical storage system widely present on the market and they constitute a mature and accessible technology at relatively low cost compared to potentially more efficient energy carriers, such as fuel cells (Linden and Reddy, 2002).

These storage systems were designed for short-term energy storage able to assure energy self-sufficiency on a monthly basis. To dimension the batteries required to meet the needs of proposal C, the calculation was based on the average daily consumption from the grid for the day with the worst sunlight in December and only the percentage of consumption currently fulfilled by the grid was considered.

Starting from the peak power of the hypothesized system and taking into account the storage performance of the Li-ion batteries, one arrives at the sizing of the PV system in terms of peak power and surface taken by the panels based on the following equation (equ.1):

$$A = (((Pd \times r)+Pp)/Ppp) \times Sp \tag{1}$$

where A is the surface occupied by the PV system, Pd is the energy to be stored (equal to 70,18 % , the number represents the percentage of consumption currently fulfilled by the grid), r is the performance of the battery used (equal to 95%), Pp is the identified nominal power (7,61 kW), Ppp is the peak power of the individual panels used (230 Wp), Sp is the surface occupied by one module (92x1640 mm).Using equ.1 for project proposal C results in the need for a PV system of 56,94 m^2 with peak power equal to 7,88 kWp. This solution is possible only using other roofs of the farm's buildings. To achieve the amperage related the following equation was adopted (equ. 2):

$$Ah4d = E_d / V \times NdaysA \tag{2}$$

where E_d (energy demand) is the average daily consumption from the grid related to December, V is the characteristic voltage of the batteries used (12) and NdaysA is the expected number of days of maximum independence (4).

Equation 3 was used to calculate the required batteries (Nb):

$$Nb = (Ah4d/DOD)x(EE/Ah) \tag{3}$$

where DOD is the maximum characteristic discharge capacity of the batteries (75%), EE is the batteries' energy efficiency (2,5%) and Ah is the common amperage of the batteries (120). The results of the equation 3 in project proposal C require 22 batteries.

The key to keeping this system advantageous is programming an efficient management of the energy overflow. Figure 5 shows the logic of the proposed energy management.

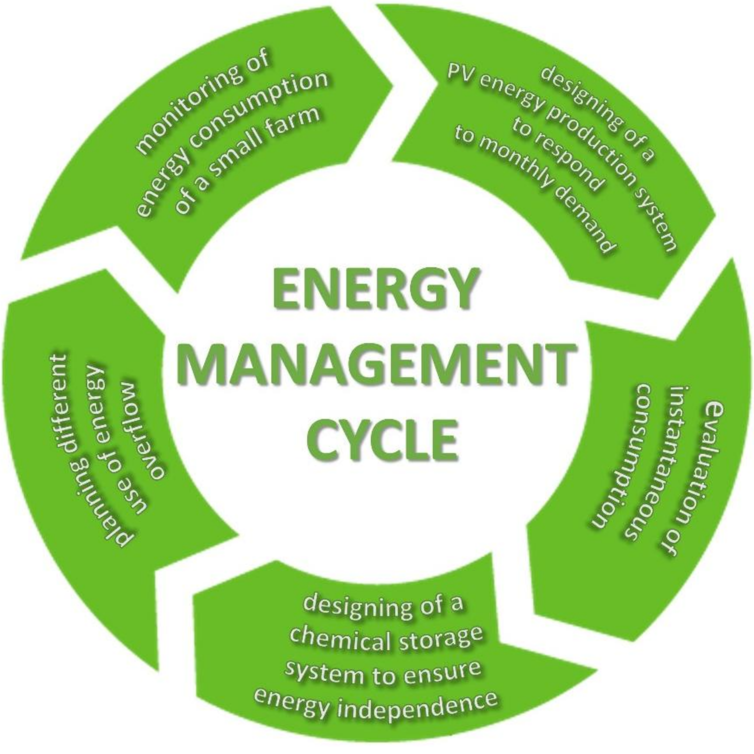

Figure 5 Energy management cycle proposed

Energy autonomy of a slaughterhouse

A mobile sheep slaughterhouse is a standalone unit with such operations: knocking and slaughtering; carcass hanging on overhead rail by the hoist; dehiding; evisceration; weigthing and storage. The module object of the study has a capacity up to 15 sheep per shift, its dimensions are 9x2,45x4 meters (length x width x height).

Below are calculated the animals that could be slaughtered using the overflow of energy of the final project proposal (C). It is calculated only the energetic surplus of the months during which the lambs normally are slaughtered in Umbria (March, April, August, October). The daily surplus (average) was calculated for the reference months and it was compared with the levels of absorption of the mobile slaughterhouse, for a standard cycle machining (8 hours in total, 1 hour of processing, 7 hours of refrigeration, 15 carcasses, 9,5 kWh energy consumed) and for a second cycle designed to use all the capacity of the refrigerating cell (8 total hours, 2 hours of processing, 7 hours of refrigeration, 30 carcasses, 11,5 kWh energy consumed).

The total of animals that could be slaughtered with double cycle is 3333 (table 2); considering the totals sheep present on Valnerina, the number of births, the mortality and the percentage of sheep that aren't slaughtered, it is possible to assert that the solution with double cycle meets about the 18% of slaughtering demand.

Table 2 Evaluation of the animals that could be slaughtered using the monthly energy overflow

	March	April	August	October
Monthly energy overflow	367,89	321,27	270,54	411,69
Daily energy overflow (average)	11,87	10,71	8,73	13,28
percentage of satisfaction of consumption (standard cycle)	124,92	112,73	91,86	139,79
percentage of satisfaction of consumption (double cycle)	103,19	93,12	75,89	115,48
lambs that could be slaughtered (standard cycle)	465	450	427	465
lambs that could be slaughtered (double cycle)	930	838	635	930

CONCLUSION

The results of this study show that to guarantee energy autonomy of the farm (case study) it is necessary a PV system of 7,88 kWp power and 22 Lithium-ion batteries (120 Ah). The total energy overflow is 3172 kWh. It is possible to use the 43,24 % of this energy for the operation of a slaughterhouse, and this solution meets about the 18% of demand of lambs slaughtering in the study area. The annual energy overflow not used with this simulation is 1371,7 kWh and the 77 % of this energy refers to May, June and July. It could be significant to find other systems which require energy during these months.

The results could be modulated in different geographical contexts and demonstrate the feasibility and the strategic use of small scale smart grid systems for individual units ensuring energy sovereignty of local communities using PV systems.

These results are interesting for small family farms that adopt sustainable models and methods of production with low environmental impact and low energy demand to define the indications for their optimal energy planning

Concerning the study area (Valnerina in Umbria region), it can be assumed the technical feasibility for the designed grid to cover the energy needs of a small slaughterhouse for the slaughter of sheep.

The results prove that focusing exclusively on the independence of a single production unit in the present state of things is not effective in view of the low availability of efficient storage systems (see fuel cells) and/or absence of alternative circuits to employ the energy overflow.

In this perspective, small farming businesses become especially interesting players in marginal rural areas. In fact, due to their small size as well as to the extensive and low energy requirement production methods they often employ, unlikely larger farms whose consumption is unlikely to be fulfilled by renewable sources.

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44. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

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QUALITY OF THYMUS (*THYMUS VULGARIS*) SCREENING PROCESS IN ORDER TO OBTAIN BIOACTIVE EXTRACTS

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SUMMARY

Medicinal plants contain biologically active substances with therapeutic value. Medicinal plants cultivation and capitalization by different processing operations are important for assuring an enhanced quantity of raw material and preserving or increasing their valuable constituents. Furthermore, obtaining available high quality phyto-therapeutic products is possible only by using state-of-the art technical equipment adapted to each plant requirements.

The paper presents experimental researches on thymus herb, related to sorting the fragments of dry and chopped plant for the four size group, which obtained bioactive extracts.

The screening evaluation taking into account the screening degree by means of some numerical results obtained by experimental data processing, is presented. The results represent an important asset for medicinal plant processors, as well as for manufacturing specialized equipment of high performance in the view of a correct and adequate processing of the thyme (Thymus vulgaris) plant in order to obtain high quality phyto-therapeutic products.

Key words: *herb, thymus, screening, bioactive extracts*

INTRODUCTION

Medicinal plants represent the oldest category of therapeutic remedies that have been helping human beings during their history evolution. Researches on importance of active biological substances contained by medicinal plants have led to much more demands of products coming from these vegetal products. Therefore, it is important that the valorisation of these raw materials by different processing operations adapted to each plant specific requirements should be performed so that the plant valuable constituents be preserved and be traded at accessible prices.

As a result, the mechanizing technologies and technical solutions for medicinal plants processing after harvesting will enhance products quality, increase operations output, determine the conservation of plant bioactive substances, create optimum working conditions, reduce physical effort.

Plants from the variety *Thymus* are important medicinal herbs, which are known to contain antimicrobial (especially antibacterial) agents, and are rich in different active substances such as thymol, carvacrol, p-cymene and terpinene (Nabavi et al., 2015; Stojkovic et al., 2013). In Romania, *Thymus* variety contains one cultivated species and 18 wild species. The constituents of these species are: volatile oil with a variable content (thymol, methylchavicol, cineol, borneol), flavonoids, phenyl-propane derivatives, tannins (Marculescu et al., 2007; Necula et al., 2011).

Medicinal plants processing comprises several operations aiming to transform the raw vegetal matter obtained after harvesting into vegetal product and/or raw material (Paun et al., 2012). Within the processing, the operations of extracting bioactive substances and sorting in size fractions (groups) of medicinal plants chopped, capitalized as whole, fragments or powder, take an important place (Muscalu et al., 2012).

Operation of extraction depends on vegetal product type (humidity, mincing degree), solvent type (temperature and imbibing time between vegetal product and solvent), extraction method used (ultrasounds, microwaves, pressure, steam), (Stoian et al., 1977).

In order to sort medicinal plants, complex specialized equipment are used, comprising plane sieves with oscillating movement (Casandroiu et al., 2009; Muscalu et al., 2012). Sieve oscillating movement is characterized by its main parameters (oscillation frequency and amplitude), parameters related both to the process and characteristics of material to be processed: sieves slope angle, friction coefficients of vegetal matter, optimum sieving speed and limit speed imposed by passing through sieves, interactions between particles, interactions with sieving surfaces, energetic consumption of processing, dimensions and form of separation holes (Ene et al., 2013; Oztekin et al., 2007).

The paper presents, on one hand the dimensional characteristics of thymus herb and extraction of bioactive substances from four fractions (groups) obtained, and, on the other hand, the experimental researches made on a dimensional sorter with plane oscillating sieves, for finding an optimum working regime aiming to obtain the desired sort (maximum content of bioactive substances).

MATERIALS AND METHODS

Thymus *(Thymus vulgaris)*, used in experiments was identified and harvested from spontaneous flora according to morphological and biological characteristics (Ardelean, 2008; Bojor,2003) of the species. Herb was naturally dried, in the shadow up to storing humidity (13 %, at most), cleaned of foreign bodies (inorganic materials or other plants, damaged parts) according to provisions from Romanian Pharmacopoeia, 1993; European Pharmacopoeia, 2005, then it was chopped in bulk by medicinal plants chopper of TIMATIC type, equipped with a knife of gate shear type set at 2 mm size.

For determining the dimensional characteristics of vegetal matter chopped, five samples for each plant have been analyzed. For each sample, 120g of vegetal matter was weighed, that was sieved by sieves classifier of Rietsch AS 200 type, at 50 mm amplitude for 5 minutes. On each sieve, was found a vegetal matter quantity representing the totality of fragments with smaller size than holes of sieve superior to the considered one and bigger than considered sieve through which they passed.

After weighing the vegetal matter on each sieve, the average of five samples has been made and size groups have been established; after that, 20g of vegetal matter out of each fraction sieved, were weighed, in which were added one after another, 250 ml ethanol of 96%, respectively water and ether for extraction of bioactive substances. Samples were manually agitated during 10 minutes up to their homogenization and to the moment when the vegetal product is imbibed in solvent, then, they were put on water bath at temperature of de 50^0 C and 100 rpm bottle's rotation speed for performing a continuous agitation and a rapid maceration, for 120 minute. Macerates obtained were filtrated with filter paper and the vegetal matter was dried in the oven at 105^0C temperature, for 3 hours.

Then, the vegetal extracts were concentrated for all the appropriate groups, samples were weighed and the quantity of bioactive substances extracted from each sort (fraction) was determined, identifying the sort (fraction) with maximum yield.

Based on distribution of size groups (figure 1) and setting the maximum percentage fraction in bioactive substances extracted, the sieves holes dimensions were chosen and equipment working parameters were adjusted. Experimental researches were performed on a dimensional sorter of plants cut, operating within INMA Bucharest.

Figure 1 Distribution of size groups of thymus

Sorter of cut plants (figure 2) is a mechanical equipment used to separate fresh or dry vegetal products (seeds, dried leaves, flowers, herbs etc.). It is endowed with 9 frames with sieves, used in sets of three with different size meshes, made of wire braid with square shape holes, that will be used according to necessities. Dimensions of sorter sieves holes are framed between 1.15 – 13.2 mm and they directly influence the vegetal material granulation (***Technical Manual).

For sorting the thyme fragments, sieves with holes of 2.15 mm, 3.15 mm and 5.0 mm were used, according to dimensional analysis of chopped vegetal fragments (Allen, 2003).

Construction of chassis allows an easy side access to sieves for cleaning, in case of blocking. Sieves frame leans upon a support made of laminated profiles welded by rubber damper. Vibrating engines are mounted on plates welded symmetrically outside the chassis, whose structure allows their rotation and modification of their inclination to horizontal, in order to adjust oscillations amplitude and frequency. The sieve slope may vary between 12-15^0 depending on type of plant and plant parts removing.

The sorter feeding with material is performed by a tilted conveyor with band, which discharges the vegetal matter into the sorter hopper and from here on the upper sieve, where the separation process by impurity removing method, takes place.

Working parameters chosen in order to evaluate the sorting level of the equipment used during the tests were the sieve tilting angle (α = 12.08^0; 13.33^0; 14.07^0), oscillation frequency set by the frequency converter (f = 50Hz; 47.5 Hz; 45 Hz) and supply rate (Q = 30 kg/h; 45 kg/h; 60 kg/h).

Figure 2 Sorter of cut plants

Mass (M) of sorter flow (Q_{alim}) was uniformly distributed on conveyor surface and was adjusted, by relation 1, knowing that the band length (L) is of 6 meters and conveyor speed (v) is of 0.04 m/s, table 1.

$$Q_{a\lim} = \frac{M}{L} \cdot v, \text{ [kg/s]} \quad (1)$$

Table 1 Adjustment of sorter flow

Material mass, M [kg]	Band length, L [m]	Band speed, v [m/s]	Flow rate set, Q_{alim} [kg/s]
1.25	6	0.04	0.0083
1.875			0.0125
2.5			0.0166

An experimental determination was performed as it follows:

- one box for collecting the vegetal fragments was mounted at each of the four exhaust openings of sieves;
- a mixture of chopped vegetal fragments was fed on conveyor's band;

- first, the sorter was put into operation, then the conveyor band and sieves were supplied with vegetal matter, letting it to go along the sieves length up to the discharge areas; then, the material flew uniformly through the four exhausting openings;
- chronometer was put into operation and covers of vegetal fragments collecting boxes were drawn;
- chronometer was stopped after 30 seconds and the vegetal matter suitable to a certain variety, from each box was weighed;
- total mass of material passed through the sieve and that discharged from the sieve, and the sieve supplying rate (Q_{exp}) were determined by relation 2:

$$Q_{\exp} = \frac{M_t}{t}, \quad [\text{kg/s}] \tag{2}$$

M_t is total mass of material sorted by sieves during time t= 30 s

Interpretation of outcome was made for the desired Sort 1, by representing functions with multiple variables, situation when the dependent variable (percentage of Sort I), depends, at the same time, on several independent variables, x_1 respectively x_2, replaced one after another, so that: $x_1=Q_{exp}$, $x_2=f$; then, $x_1=f$, $x_2=\alpha$, resulting in one polynomial function of II degree with two variables, having the general form shown in relation (3), (Paunescu et al., 1999):

$$f_{(x_1,x_2)} = a_0 + a_1 \cdot x_1 + a_2 \cdot x_2 + a_3 \cdot x_1^2 + a_4 \cdot x_1 \cdot x_2 + a_5 \cdot x_2^2 \tag{3}$$

For processing the experimental data, an experimental fragmented testing program was chosen, for 15 tests out of the total of 27 experiments, within Mathcad program, given by values of independent and dependent variables for each experiment**.**

RESULTS AND DISCUSSION

Mass and percentage values obtained after sieving are shown in table 2.

Results obtained following the fragments dimensional analysis were presented in graphic of figure 3 by representing the variation curves of screening, impurities removing and vegetal matter distribution as percentages according to sieve mesh size.

These curves establish in percentage the distribution of vegetal matter separated from the first till the last sieve of vibrating classifier and can be used for choosing the suitable sieves allowing to separate the fragments appropriate to vegetal matter desired, for obtaining high quality extracts and determining the flow rates of screening product and impurities removal.

Percentage of substances extracted in three solvents was calculated for each group (fraction) and is shown in figure 4.

Table 2 Thymus fragments broken down in size fractions

Sample No.	Limits of Thymus dimensional fractions [mm]							
	0- 2.2		***2.21-3.15***		***3.16-4.5***		***4.6-6.3***	
	[g]	[%]	[g]	[%]	[g]	[%]	[g]	[%]
1	83.64	69.72	29.86	24.88	4.37	3.64	1.68	1.4
2	83.89	69.9	30.07	25.06	4.81	4.0	1.25	1.04
3	84.10	70.08	29.21	24.34	5.02	4.18	1.9	1.58
4	84.32	70.26	29.42	24.52	4.59	3.82	2.11	1.76
5	84.52	70.44	29.64	24.7	4.16	3.46	1.46	1.22
Samples average	***84.1***	***70.08***	***29.64***	***24.7***	***4.59***	***3.82***	***1.68***	***1.4***

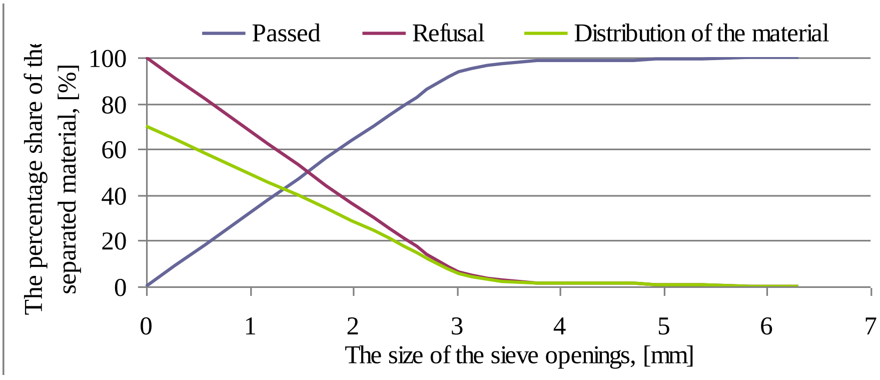


Figure 3 Curves of variation of percentages of screening and vegetal matter distribution as percentages according to sieve mesh size

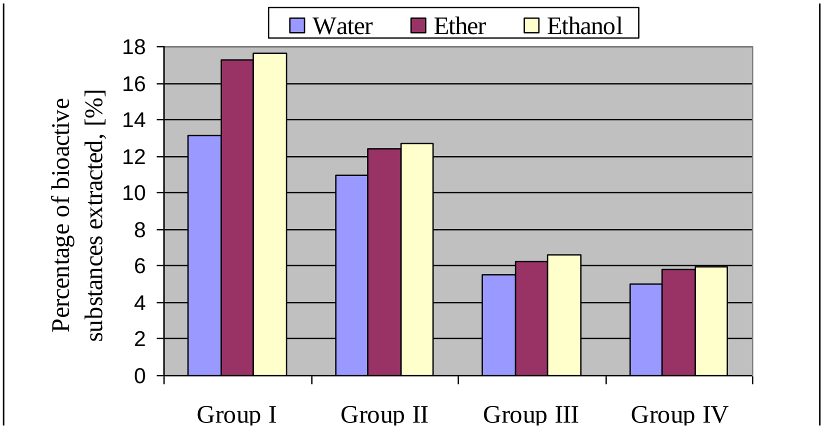


Figure 4 Percentage of substances extracted in three solvents for four *Thymus* size groups.

Values of experimental data characterizing the sorting process by sorter on 4 size groups, are presented in table 3.

Table 3 Experimental results regarding the screening of *Thymus* fragments

Flow rate adjusted Q_{alim} [kg/s]	f [Hz]	Sieve angle, α [^{0}]	Sorting time, t [s]	Mass Group 1 [kg]	Mass Group 2 [kg]	Mass Group 3 [kg]	Mass Group 4 [kg]	Total mass [kg]	Experimental flow, Q_{exp} [kg/s]
0.0166	50	12.08	30	0.346	0.102	0.041	0.008	0.497	0.0166
		13.33	30	0.337	0.099	0.053	0.010	0.499	0.0166
		14.70	30	0.327	0.098	0.056	0.009	0.490	0.0163
	47,5	12.08	30	0.295	0.112	0.037	0.008	0.410	0.0150
		13.33	30	0.339	0.098	0.047	0.007	0.491	0.0164
		14.70	30	0.291	0.100	0.050	0.008	0.449	0.0150
	45	12.08	30	0.228	0.119	0.049	0.009	0.405	0.0135
		13.33	30	0.308	0.102	0.045	0.005	0.460	0.0153
		14.70	30	0.259	0.103	0.054	0.007	0.423	0.0141
0.0125	50	12.08	30	0.232	0.102	0.034	0.006	0.374	0.0125
		13.33	30	0.255	0.085	0.028	0.004	0.372	0.0124
		14.70	30	0.236	0.104	0.029	0.005	0.374	0.0125
	47,5	12.08	30	0.237	0.086	0.024	0.004	0.351	0.0117
		13.33	30	0.230	0.085	0.026	0.004	0.345	0.0115
		14.70	30	0.222	0.088	0.027	0.003	0.340	0.0113
	45	12.08	30	0.188	0.098	0.037	0.003	0.326	0.0109
		13.33	30	0.206	0.087	0.026	0.003	0.322	0.0107
		14.70	30	0.197	0.091	0.024	0.003	0.315	0.0105
0.0083	50	12.08	30	0.172	0.051	0.022	0.004	0.249	0.0083
		13.33	30	0.165	0.060	0.020	0.004	0.249	0.0083
		14.70	30	0.161	0.063	0.017	0.003	0.244	0.0081
	47.5	12.08	30	0.147	0.050	0.028	0.004	0.229	0.0076
		13.33	30	0.167	0.057	0.019	0.004	0.247	0.0082
		14.70	30	0.146	0.057	0.021	0.003	0.227	0.0076
	45	12.08	30	0.114	0.066	0.030	0.003	0.213	0.0071
		13.33	30	0.149	0.064	0.017	0.003	0.233	0.0078
		14.70	30	0.107	0.070	0.024	0.003	0.204	0.0068

Signification and sizes of mass size groups from table 1 are the following:

- mass of group 1 represents the screening of the lower sieve of the sorter with sizes framed between 0.1...2.15 mm;
- mass of group 2 is made of sieved matter from middle sieve and refuse matter from lower sieve and comprises vegetal fragments framed between 2.16...3.15 mm;

- mass of group 3 is made of big sieve screened product and middle sieve refuse product, with vegetal fragments framed between 3.16...5 mm;
- mass of group 4 represents the big sieve refuse product with size of vegetal fragments bigger than 5 mm.

Sorting level of vegetal fragments (S_f) is expressed in percentages (%) and is defined as the ratio between the quantity of fragments from each collecting box (group I, group II, group III, group IV) and quantity of fragments from the four collecting boxes.

Using the experimental data from *Thymus* fragments sorting, for constant value of group I the variation of sorting degree (S_f) was evaluated in percentages depending on experimental flow rate ($x_1=Q_{exp}$) and oscillation frequency ($x_2=f$), represented in figure 5, using the polynomial function and function coefficients replaced, in relation 4, correlation coefficient. **R=0.926**:

$$f_{(Q\exp,f)} = -1{,}676\times10^{3} + 9{,}207\cdot Q_{\exp} + 3{,}431\cdot f - 0{,}081\cdot Q_{\exp}{}^{2} - 7{,}111\times10^{-3}\cdot Q_{\exp}\cdot f - 1{,}699\times10^{-3}\cdot f^{2} \tag{4}$$

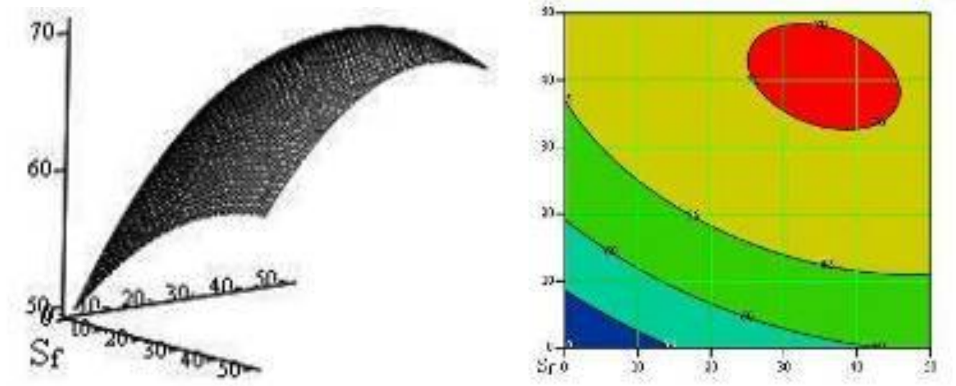


Figure 5 Variation of sorting degree (S_f) depending on experimental flow and oscillations frequency at group I for Thymus

Using the experimental data coming from *Thymus* fragments sorting, for a constant value of group I, the screening degree (S_f) variation was calculated in percentages, according to oscillation frequency ($x_1=f$) and sieve slope angle ($x_2=\alpha$), represented in figure 6, always based on polynomial function and its coefficients replaced- in relation 5, correlation coefficient **R=0.915.**

$$f_{(f,\alpha)} = -1{,}758\times10^{3} + 2{,}833\cdot f + 64{,}696\cdot\alpha - 1{,}307\times10^{-3}\cdot f^{2} - 0{,}018\cdot f\cdot\alpha - 1{,}78\cdot\alpha^{2} \tag{5}$$

In figure 7 are comparatively represented the experimental values and sorting degree (S_f) values calculated, for each experiment depending on two parameters.

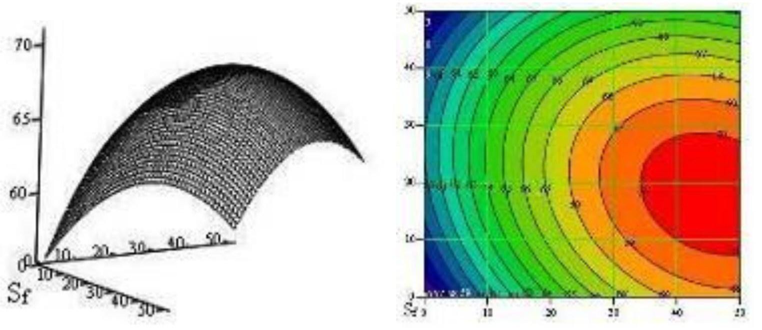
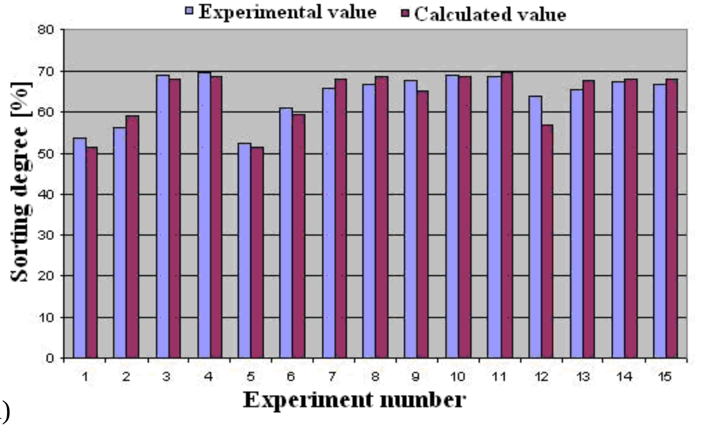
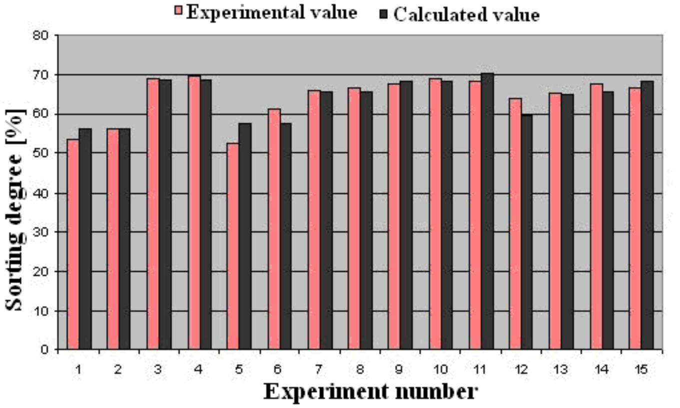


Figure 6 Variation of sorting degree (S_f) depending to oscillation frequency and sieve slope angle for group I of *Thymus*



a)



b)

Figure 7 Content in percentages of group I of Thymus, for experimental and theoretical values depending on a) experimental flow rate and oscillations frequency and b) oscillation frequency and sieve slope angle

Differences between the experimentally obtained values and those calculated for group I at *Thymus,* depending on experimental flow rate and oscillation frequency are rather small, namely 0.38 %, respectively 0.64 % for the same average frequency of 47.5 Hz and high flow rate 0.0164 kg/s, respectively average flow rate 0.0117 kg/s. Major difference between values- 11.31 % has been recorded at small frequency of 45 Hz and experimental average flow of 0.0107 kg/s.

Comparing the differences between the experimentally obtained values and those calculated for group I of *Thymus*, depending on oscillation frequency and sieve slope angle, one may conclude that there are small differences of 0.14-0.34 % for a small slope angle of sieve- 12.08^0 and small frequency of 45 Hz and high frequency of 50 Hz. Important differences have been recorded between 5.08 – 9.81 % for a bigger sieve angle of 14.7^0 and small frequency of about 45 Hz.

Taking into account that *Thymus* valuable bioactive substances are comprised in *Thymus* herb (stalk with leaves and flowers), for evaluating the sorting and product quality (vegetal extract) resulted after the extraction, it was aimed to perform a comprehensive screening for the desired sort (group I) and obtain a big quantity of bioactive compounds.

CONCLUSIONS

In the context of Romania’s market concern about medicinal and aromatic plants and enhancement of the natural remedies interest, dimensional fractions sorting represent an important step in obtaining high quality phyto-therapeutic products.

After analyzing the repartition on size fractions, it can be noticed:

- size groups and quantities in percentages have been the following: material size of group I was framed between 0.1-2.2 mm; for group II- between 2.21-3.15 mm; for group III-between 3.16-4.5 mm and for group IV-between 4.51-6.3 mm;
- taking into account the sieve holes of medicinal plant sorter, the *Thymus* fragments should be sorted on sieves with the following holes: 5 mm, 3.15 mm, 2.15 mm.

After analyzing the bioactive substances content for fractions obtained after vegetal material screening, it has noticed that from group I with dimensions smaller than 2.2 mm a maximum of 17.67 % was extracted in ethanol, 17.24 % in ether, 13.17 % in water, followed by groups II, III and IV always with maximum extraction in ethanol.

Knowing the vegetal matter dimensions, it is very important if one wants to optimize the separation and extraction processes, for achieving specialized state of the art equipment for medicinal plant processing.

From the analysis of own experimental values obtained and values calculated as II degree polynomial function with two variables aiming an optimum working process of size groups sorter, the following aspects have been emphasized:

- depending on experimental flow rate (Q_{exp}) and oscillation frequency (f) the optimum is obtained at the big experimental flow rate (Q_{exp} = 0.0164 kg/s) at average oscillation frequency of vibrating engines (f = 47.5 Hz);

- depending on oscillation frequency (f) and sieve slope angle (α) the optimum is obtained at small angle ($\alpha = 12.08^0$) and high frequency (f = 50 Hz);
- parameters (frequency and flow rate) reduced values do not achieve separation and determine vegetal fragments stratification, including the diminishing of productivity and screening precision, and big parameter values enhance the quantity of separated fragments and reduce screening precision;

Obtaining group I in optimum conditions can be achieved by choosing a sieve small angle (α=12.08^0) and a high frequency of Hz, but also a big experimental flow rate 0.0166 kg/s.

In conclusion, it has noticed that size groups sorter with plane oscillating sieves can be successfully used for sorting medicinal plants chopped if the working parameters are appropriately chosen for the purpose aimed when capitalizing the vegetal material.

Data shown can be important for all the specialists and workers in medicinal plant field, mainly referring to sorting operation from technological process.

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44. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

UDC 631.563.2:635
Stručni rad
Expert paper

LABVIEW TOOL FOR INFRARED MONITORING THE QUALITY OF VEGETABLES DRYING PROCESS

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SUMMARY

The quality parameters of the fruits and vegetables products such: size and shape, colour or different biochemical compounds can be preserved during the convective drying process by monitoring the products surface temperature. In the paper's described experiments this was done by taking infrared images using a FLIR i50 camera. Pixels acquired were transformed into a temperature data matrix by using a special developed LabView software application.

This method make possible to find out the lowest, highest, medium surface temperature values which can become references for setting up the drying process.

A new indicator, temperature uniformity coefficient was defined in order to manage better the drying process, taking in consideration the connection with defects like cracks, deformation, colour changes, etc.

Key words: *vegetal products drying, infrared images, monitoring temperature*

INTRODUCTION

Monitoring of drying process through non-contact methods is a technique that is more often used by more and more researchers. The final purpose of the researches is the achievement of a robust and reliable system for quality control in industrial drying processes, taking into account the color, shape, texture, content of different thermolabil biochemical compounds.

Infrared cameras convert infrared radiation into colors of the visible spectrum. They are used in many fields where temperatures are observed and knowledge about temperatures of an area is more significant than of only one spot.

Because it can provide a map of values with usual measurements 240 x 320 of the surface temperatures from the products surface, infrared cameras can be used with success in management of the convective drying industrial process, especially for sliced vegetables and fruits. From the current temperature map it can be calculated an indicator named index of temperature non-uniformity, which provides important data about:

- temperature distribution on the products surface;
- difference between the product medium temperature and temperature of drying agent.

Temperature distribution on the product surface during the drying process is an important value linked to the deformation indicator of slices because high temperature gradients induce mechanical tensions with deformation effect. In some cases, the mechanical tensions can produce cracks and even ruptures of the material.

The difference between the medium temperature of product and the temperature of drying agent provide informations about the stage of the drying process and shows the end of the process.

Empirically adjusted drying air temperature of 50°C is known to prevent great loss of nutrients, but it does not pre-vent the product from overheating at the end of the drying process. Investigating the product temperature by infrared cameras helps to stop the deteriorative impact of heat, which happens in the end of the drying process when the product heats up. Liviu GACEU, Badea Lepadatescu, (2009)

MATERIALS AND METHOD

In order to emphasize already mentioned aspects, were used carrot radial and axial slices with the same evaporation area. The slices were convective dried at a medium temperature of 55 degrees C, the whole process being monitored by an infrared camera FLIR I 50, and a data acquisition system NOVA Fourier 5000. Carrot slice thickness was 2,4 mm (Fig. 1.).

For the experiment a cabinet dryer of the size 2.20m x 1.12m x 2.30m [l x b x h] was used. The dryer consists of the parts shown as schematic chart in Figure 2. The drying oven allows the control of temperature in the range of 30…60 degrees. The drying process was focused for obtaining o high quality products, so the drying temperature was fixed to the 55 C value. The process takes 350 minutes in order to decrease the material humidity for long term storage. The weight of the carrot slice varies between: 46.7 g at the beginning process to 5,7 g at the and of the drying process. For having an overview of the entire drying process and for making some correlations regarding the drying process were measured 4 other thermal parameters such: the air temperature inside and outside of the drying oven; the air humidity inside and outside of the drying oven.

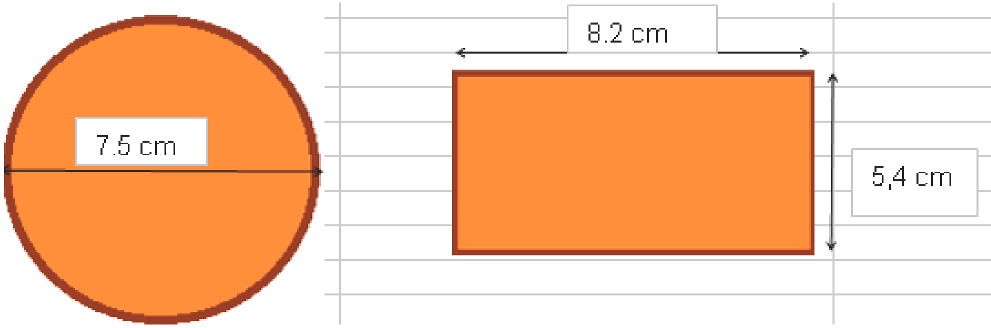

Figure 1 Carrot slices, axial and radial cutted, with the same evaporation area

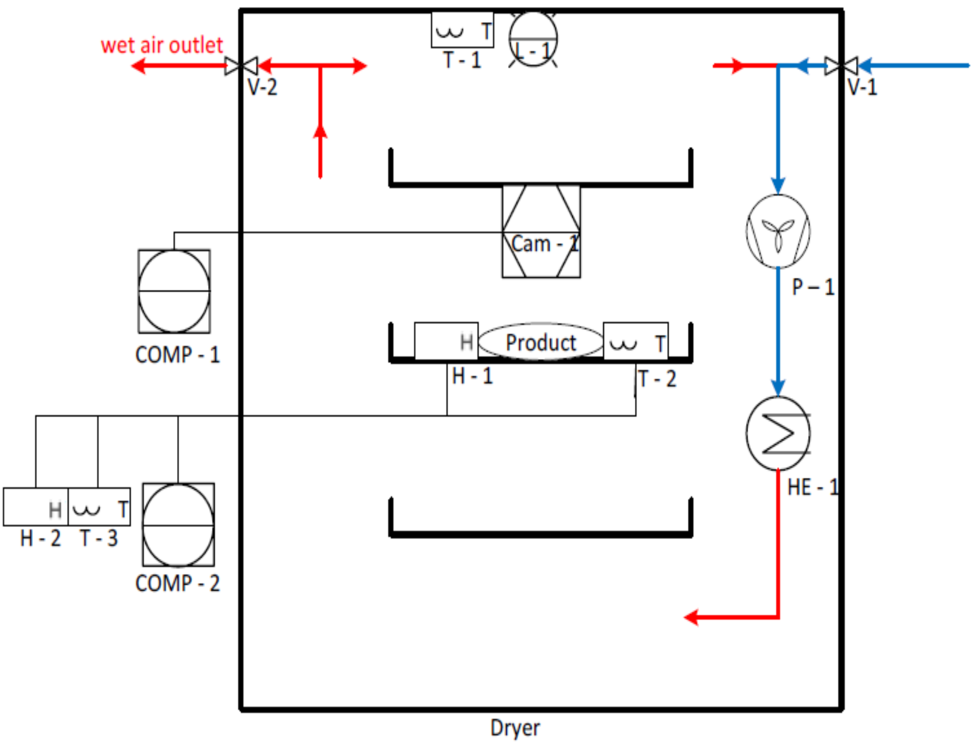

Figure 2 Schematic chart of the dryer used for experiments

This was done by using a Nova Fourier system, which allow to connect a series of dedicated sensors. After the experiment, the products were weighted again. The removal of the remaining moisture in the dried products was done following these steps (Table 1) - 105 °C for 3 hours in the first oven. 600 °C for 8 hours in the second oven.

Tabel 1 Weight of carrot slices before/after drying

Cut:	radial direction of carrot	axial direction of carrot
Weight before drying in g:	11.54	14.06
Weight after drying in g:	1.75	2.75
Weight after 1st oven in g:	1.53	1.71
Weight after 2nd oven in g:	0.44	1.03

The dryer has an air inlet (V – 1) and outlet (V – 2). Fresh, cold, dry air from the outside is mixed with hot drying air inside the dryer. P – 1 is a ventilator and sucks the air into the heat exchanger (HE – 1), where the air is heated up. After that, the hot, dry air is dispersed in the whole dryer. The pre-set drying temperature of 50°C was regulated with a PID regulation by comparing temperature T-1 with the reference temperature. Next to T – 1 is a light arranged (L – 1) that can be turned on upon need. There are 2 additional temperature and humidity sensors used for the experiment. The temperature sensor T – 2 and humidity sensor H – 1 are placed next to the product inside the dryer. The humidity sensor H – 2 and temperature sensor T – 3 are placed outside for measuring the room temperature and humidity. These four sensors are linked to a computer (COMP – 2). The infrared camera (Cam – 1) is arranged on the upper tray of the wagon and focused towards the product. The infrared camera is linked to a computer placed outside (COMP – 1), on which the infrared images are processed.

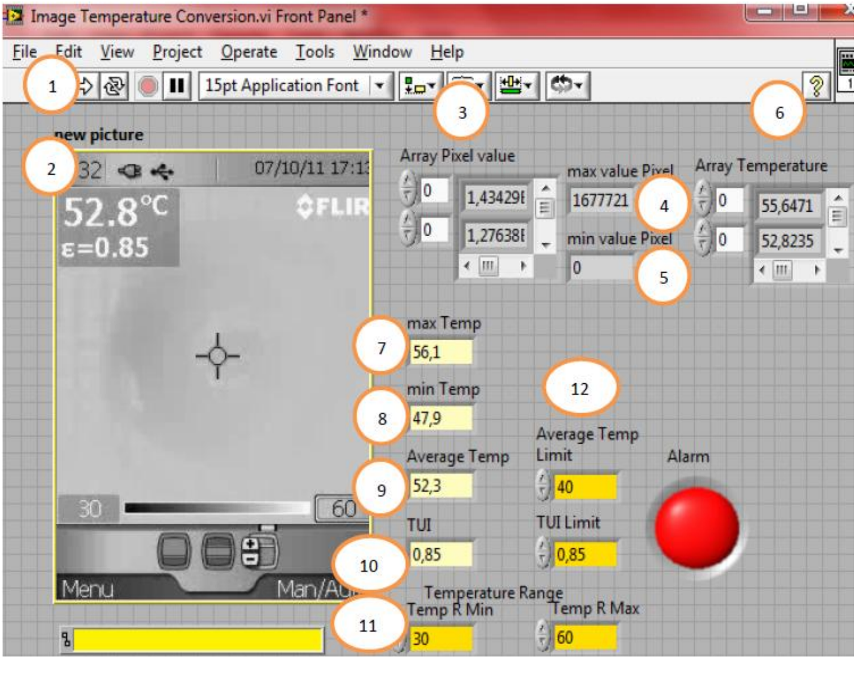

Figure 3 Front Panel of LabVIEW VI "Image Temperature conversion"

The acquisition of the surface products temperature (figure 4) was done using an infrared thermal scan camera type FLIR i50 with the following technical characteristics: thermal sensitivity/NETD <0.10 ºC (<0.18 ºF) @ +25 ºC (+77 ºF) / 100 mK; image frequency 9 Hz; iR resolution 240 × 240 pixels; display Built-in 3.5 in. LCD, 256k colors, 240 × 320 pixels; object temperature range –20 to +120 ºC (–4 to +248 °F); 0 to +350 ºC (+32 to +662 °F); accuracy ±2 °C (±3.6 °F) or ±2% of reading.

Infrared camera was connected with a laptop and the images were converted into numerical matrix using LabView software (fig. 3). The images have 240 x 240 pixels, each of them showing the temperature of one point of the surface o material. In table 2, a list with all front panel elements is presented. Gaceu, L., (2008) .

Table 2 List of elements of the front panel

No.	Name	Description
1	Run program	When clicking this button the program starts and asks for the .jpg image to load.
2	new picture	Display of the actual, loaded .jpg image with the compati-ble path to file.
3	Array Pixel value	The values of each pixel for the whole image shown in a 2D-array.
4	max value Pixel	The maximum value from the 2D-array “Array Pixel value”.
5	min value Pixel	The minimum value from the 2D-array “Array Pixel value”.
6	Array Temperature	A 2D-array with temperature values.
7	max Temp	The maximum temperature from the 2D-array “Array Temperature
8	min Temp	The minimum temperature from the 2D-array “Array Tem-perature”.
9	Average Temp	The average of all temperatures from the 2D-array “Array temperature”.
10	TUI	The temperature uniformity index is min Temp / max Temp
11	Temperature Range	The temperature range indicates the minimum and maximum temperatures from the measurement during drying.
12	Average Temp Limit; TUI Limit	Two controls that indicate the drying characteristics. The input defines when an alarm is triggered.

RESULTS AND DISCUSSION

- The infrared pictures were converted into a matrix of values by applying different tools available in LabView (Ellen Schur, Gaceu Liviu (2012). The component values are stored as integer numbers in the range 0 to 255, the range that a single 8-bit byte can offer (by encoding 256 distinct values).

These may be represented as either decimal or hexadecimal numbers. Furthermore, the numerical matrix can be analysed and it is possible to show in real time some important values, like:

- the mean temperature of the product surface;
- the coefficient of non uniformity temperature;
- the minimum/maximum temperature value on the surface of material;
- an overheating blinker that can be use for controlling of the dryer heater.

For monitoring the drying process and visualizing in real time the temperature pattern, it was use the VLC player. This allows the viewing of the current infrared images, and captured automatically one picture/10 min. The pictures were saved into a dedicated local folder. In this way, VLC player consist also into a interface between FLIR camera and Labview software.

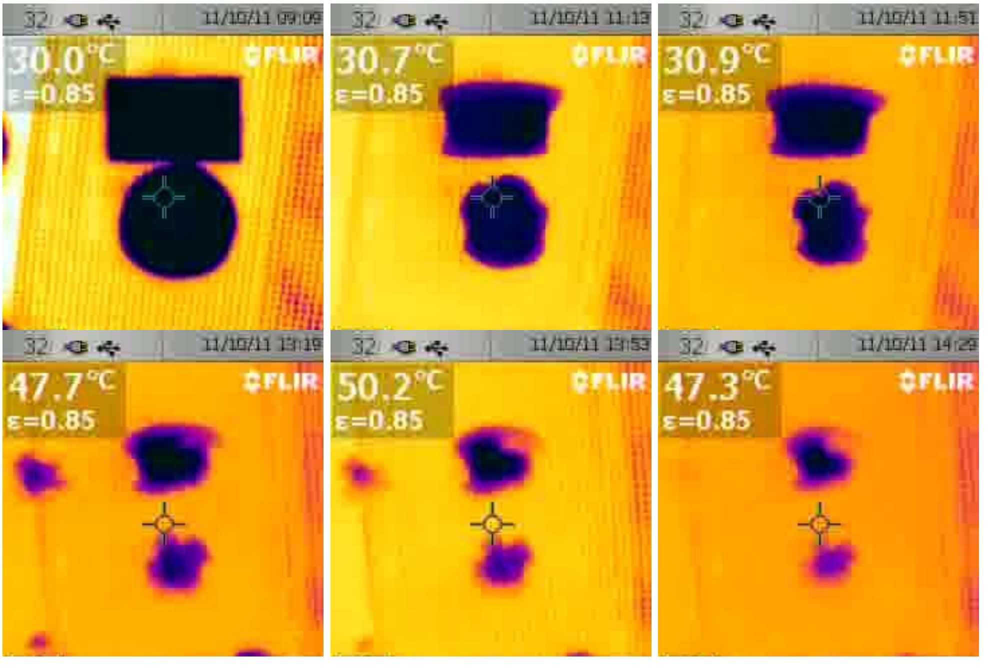

Figure 4 Different thermal images from different stages of drying process of carrot slices

In figure 4 are presented 6 pictures from different stages of the drying process. Initially, at the beginning of the process, there is a big temperature differences between the product temperature and drying agent temperature. In the next steps, parts of the carrot slices are dried and have a higher temperature, other parts remain wet with a lower temperature, because of the evaporation heat removed from the product. The result of this process is modifying of the non-uniformity temperature coefficient, related to the product surface. Near the end of the drying process, other parts of the slice became dried, and the non-uniformity temperature coefficient goes to the value 1.

In figure 5 was represented minimum, maximum and mean value of axial cutted carrot slice temperature. In figure 6, for the same product it is represented the temperature uniformity index evolution during drying process. In figure 7 was represented minimum, maximum and mean value of radial cutted carrot slice temperature. In figure 8, for the same product it is represented the temperature uniformity index evolution during drying process. Figures 9 and 10 shows a comparison between the mentioned values for the axial and radial cutted cases. It can be observed that the radial cutting gives better result, with o higher uniformity towards the end of the drying process. This can be explain because of the orientation of capillary perpendicular to the cutting process, water being easier remove.

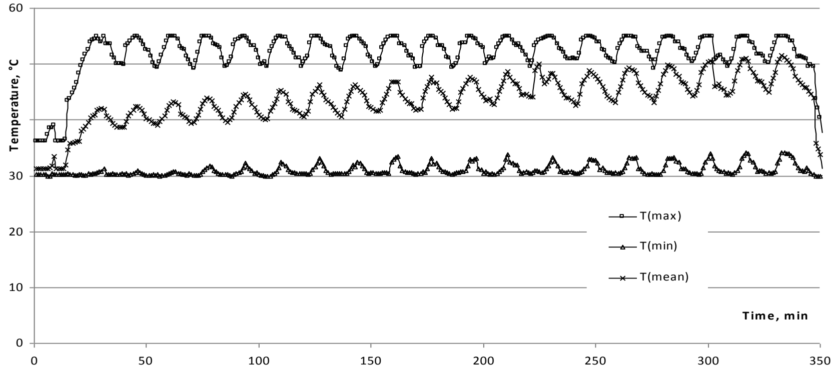

Figure 5 Axial cutted carrot slice: minimum, maximum and mean value of temperature measured by infrared camera, during drying process

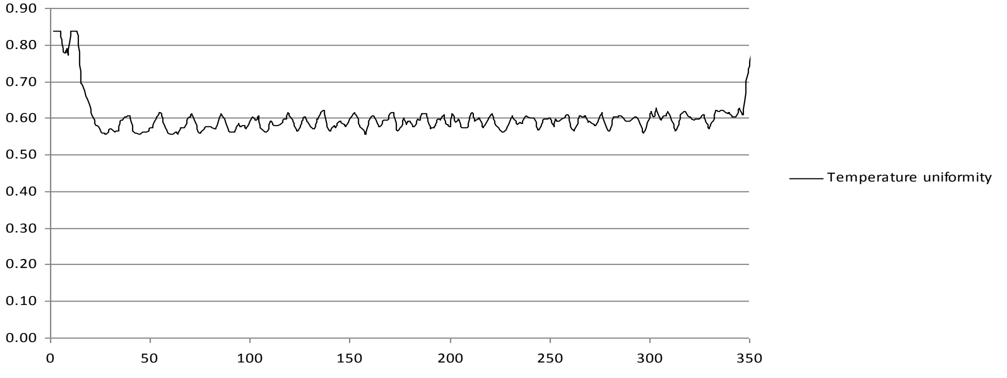

Figure 6 Axial cutted carrot slice: temperature uniformity index evolution during drying process

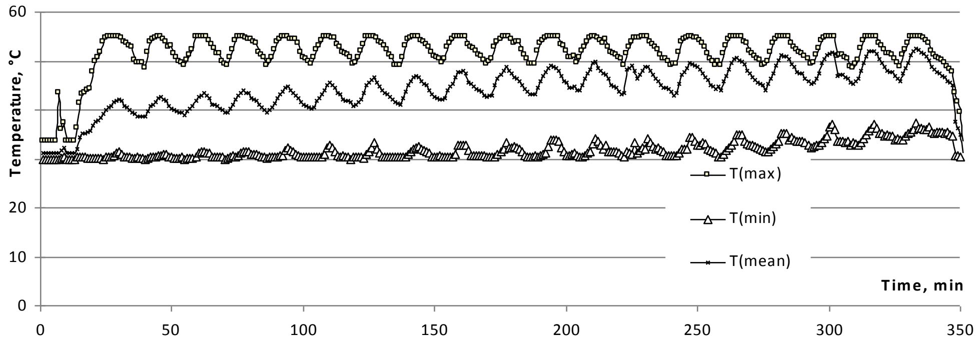

Figure 7 Radial cutted carrot slice: minimum, maximum and mean value of temperature measured by infrared camera, during drying process

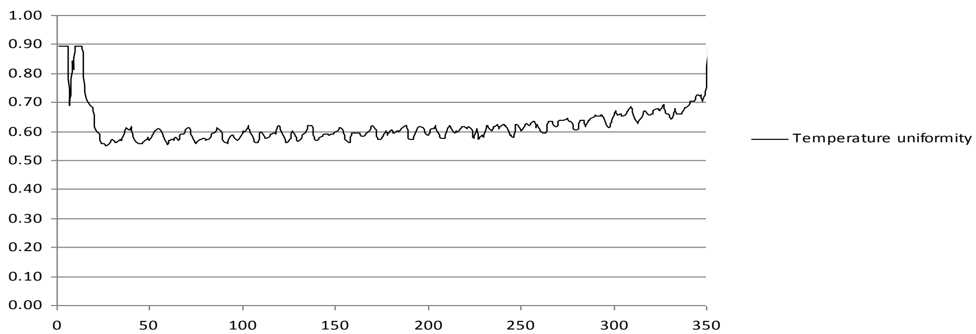

Figure 8 Radial cutted carrot slice: temperature uniformity index evolution during drying process

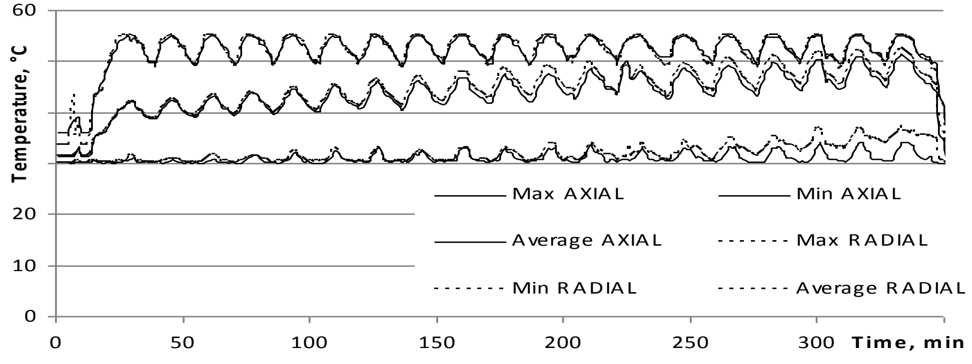

Figure 9 Comparison between values of temperature (min, max, mean) measured by infrared camera, during drying process for radial and axial cutted carrot slice

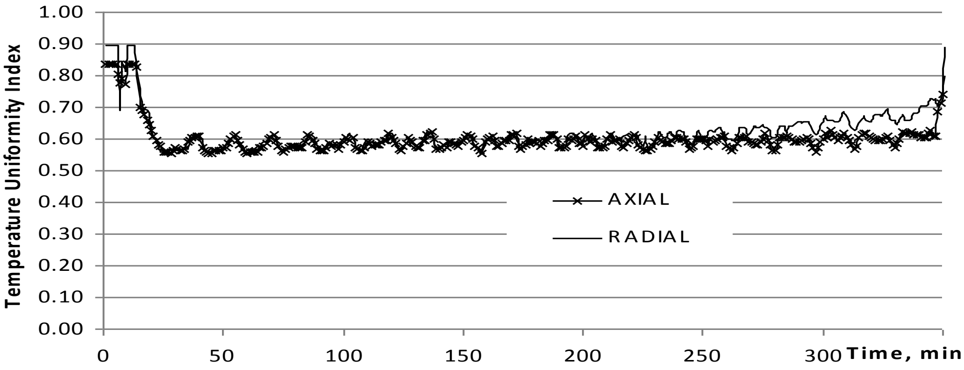

Figure 10 Temperature uniformity index evolution during drying process, for radial and axial cutted carrot slice

CONCLUSIONS

The experimental researches showed the following conclusions:

Temperature is the most important criteria for controlling the drying process and influences drying rate, drying efficiency, process costs and product quality. During conventional drying processes, the temperature of the drying agent is the only controlled parameter, whereas product temperature is the intrinsic parameter influencing product quality. A possibility to control the drying process by product temperature is infrared thermography.

The using of infrared capture images consist a proper non-invasive technique for monitoring the surface temperature of the dried agricultural products.

By processing the temperature value chart, the infrared measuring technique shows the non-uniformity of the surface temperature, an important parameter for avoiding supplemental thermal stress of the products slices. Following the temperature uniformity index can be established for certain kinds of products and make drying process comparable;

For the future, the research will focused on:

- modifying the LabView application using an output card in order to control the heater of the dryer;
- investigation related to the similarities between the pattern of temperature distribution an the shape changes in the process of different product slices.

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44. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

UDC 632.4:633.1
Pregledni rad
Review paper

RISK OF MYCOTOXIN IN CEREALS AND NEW DETECTION METHODS

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SUMMARY

The risk of mycotoxin in cereals is a constant subject in food safety area, having a big impact upon the animal and human health. Ochratoxin A (OTA) is one of the most common naturally mycotoxin founded in a large variety of grain crops such as barley, corn, wheat, rye and oats. OTA is a serious human health hazard, possessing hepatotoxic, teratogenic, carcinogenic and immunotoxic properties.

Recent studies show that the risk remain at high level after thermal cereals processing such: dough baking, extrusion, or expanding. Therefore, farmers need more performant storage monitoring systems and new fast method for determining the presence of mycotoxin. A new electrochemical method was used for developing a new sensor, with a large area of applications, for detection of OTA.

Key words: *ochratoxin detection, mycotoxins, patulin, zearalenone Fusarium, Aspergilius, immunoaffinity*

INTRODUCTION

Micotoxins are toxic substances with small molecule, produced by filamentous fungi as secondary metabolites. Fungi contamination from soil of food products, of grain and even food preparations, is almost inevitable. Most microfungi that develop on food products are innocuous, but for some of them, development is followed by synthesis and elimination of strong mycotoxins, which produce illness and even death for humans and animals. The presence of mycotoxins in a high variety of food products and feed, had determined an increase of interest for their monitoring because of the negative impact on human health and also significant economic losses related to animal productivity and national and international trade.

At European level it is considered that the level of mycotoxin contamination is 20%, even in the developed countries, but this percentage is for sure higher in situations of less competitive agriculture. In developed countries of Europe it is estimated a harvest loss of 5-10% because of fungi contamination. In agricultural and zootechnic farms the fungal contamination has a reduction effect on the harvest and also decreased productivity of animals due to illness and possibly death resulted after contaminated feed consumption. Mycotoxins are not homogeneously dispersed in feed, making it difficult to detect it in samples [Binder, 2007].

Classification, effects and zoning

After the toxicity degree, mycotoxins are divided into three groups:

- Mycotoxins with high toxicity: aflatoxins, patulin, zearalenone, T2 toxin, ochratoxin, deoxynivalenol;
- Mycotoxins with average toxivity: aspergilic acid, penicilic acid, citrinin, gliotoxin, ipomearin, rugulosin;
- Mycotoxins with low toxivity: oxalic acid, fusaric acid, chetomin, trichotecin, tardin.

Depending to the effects on the responsive cells, there are distinguished 4 types of mycotoxins: teratogenic, mutagenic, carcinogenic and allergenic and depending on the clinical effects, there are distinguished other types of mycotoxins: hepatotoxic, nefrotoxic, neurotoxins, immunotoxins etc. [Mihăescu et al., 2005]. Among the thousands of existing mycotoxins, only a few pose a threat to food safety and these are fungi belonging to the *Aspergillus*, *Fusarium* and *Penicillium* [Murphy et al., 2006].

Trichotecens are a number of 148 toxins produced by *Fusarium, Trichoderma, Cephalosporium, Myrothecium, Stachybotrys* etc., which develop on the grain seeds, being characterized by a *tetraciclic sesquiterpenoi* structure. The fungi from the *Aspergillus* genera, infest a high number of vegetal and animal feed (fibres, concentrated, bone meal), and also most of the improperly stored food products. The most important mycotoxins produced from *Aspergillus* are **aflatoxins**. Aflatoxins belong to the group of coumarin-bifurano derivatives, with 4 principal products, noted with B1, B2, G1 and G2, according to the blue fluorescence or green, which are emitted in the ultraviolet light, with length 254 and 365 nm and to the separation order in chromatography [Bennet and Klich, 2003].

Ochratoxins together with citrinin and oxalic acid, are part of the nefrotoxic mycotoxins group, involved in the renal etiopatogenic diseases in humans and animals. **Ochratoxin A** is classified [IARC, 1993] as “possible human carcinogen” (2B group) [Varga et all., 1996; Pohland et all., 1992]. OTA is considered the cause for two chronic diseases: *balkan endemic nephropathy and chronic interstitial nephropathy* and for renal tumors in humans. Also, it may be an association between human exposure to OTA and the incidence of testicular cancer; in Denmark, exposure through increased consumption of rye and pork meat explains the high frequency of this type of neoplasia [Pitt, 2000].

Fungi that are produced from patulin, often contaminate apricots, grapes, peaches, pears, apples, olives, cereals and fruit juices with low acidity (especially apple, pear and grape) [Speijers, 2004]. **Patulin** is not found in intact fruits, the presents of *Penicillium* species, that produce the patulin is obvious on the exterior of fruits [Sewram et all., 2000], so that critical point for quality control is the entering in time in the industrial process.

Zearalenone is a mycotoxin produced by different species of *Fusarium: F. graminearum, F. nivale, F. roseum*. These species colonize the grain and develop in the growing season as well as during storage in humid conditions and is produced particularly on the substrate grain, maize, wheat, barley, rice. Zearalenone, in small quantities has an anabolic effect, but the main pathogen is the estrogenic effect and produces infertility, abortion, negative influences on spermatogenesis [Crivineanu et all., 1996].

The spread of different species of fungi and the concentration of mycotoxins in food are influenced by climatic conditions. The distribution of mycotoxins in different parts of the world is characterized by the following:

- In the cold regions (Canada, North of USA and most of the European countries), sways the aflatoxin (exceptions are imported products from warmer countries), but very important are vomitoxin, zearalenon, ochratoxin, DAS, T-2 and HT-2 toxin;
- In South and Central Europe, where maize is cultivated (Sweden, Austria, Hungary), sways the fusariotoxi (vomitoxin, zearelon, T-2 toxin);
- In North Europe (Denmark, Poland) first is ochratoxin A;
- In the hot and humid regions from Latin America, Asia, Africa and some parts of Australia, more common are aflatoxins.

Mycotoxins, especially the major ones, aflatoxin, ochratoxin, patulin, deoxinivalenol, zearalenon, T2 toxin, produce important economical losses through:

- Direct effects: determination of pathological status;
- Associated effects: reduced resistance to infectious agents, decreased immunity;
- Qualitative impairment of animal and vegetable products in which mycotoxins are present as residues that threat human and animal health.

MATERIALS AND METHOD

The incidence of mycotoxins in feed materials and samples of wheat from Romania were analyzed in the framework of national programs but also by independent researchers.

Data were reported to the European Regulations no. 1881/2006 and no. 1126/2007, maximum permissible levels in food and cereals for aflatoxin, ochratoxin A, deoxinivalelol, zearalenon. Through the EC no. 165/2013 regulation, there were established indicative levels of T-2 and HT-2 toxin amount in cereals and cereal products.

The most important methods for ochratoxin A detection were next presented, emphasizing the advantages and disadvantages of each approach.

RESULTS AND DISCUSSION

Due to the important effects of ochratoxin A and because of specific regulations, it is important to have specific, sensitive and rapid methods for its detection from different matrices. This work present, the most used clean-up methods of OTA from real samples (using immunoaffinity columns, molecular imprinting polymers-MIP, and aptamers coated columns), before to be used in HPLC, ELISA or biosensor detection procedures.

Table 1 Specific extraction systems of OTA from different cereal matrices

Sample	Sample quantity	Reagent quantity	Reagent	Reference
Cereals	1 g	2 mL	acetonitrile/water = 60/40	Ali et all, 2010
Quick cook, red/brown/black/basmati/jasmine/white rice, Cereal-based feed, cereals	1 g	4 mL	acetonitrile/water = 60/40	Bansal et all, 2011; Cismileanu et all, 2008
Cereals	1 g	5 mL	acetonitrile/water = 60/40	Chan et all 2004
Barley, wheat, oats, rye	1 g	5 mL	acetonitrile/water = 5/1	Kononenko et all 2000
Nut slurries	3 g	7 mL	acetonitrile/water = 60/24	Chan et all 2004
Barley	20 g	150 mL	144 mL acetonitrile/ 16 mL of 4% aqueous solution of potassium chloride acidified by 0.32 mL sulfuric acid	Dohnal et all 2010
Barley, wheat	1 g	4 mL	methanol/water = 60/40	De Girolamo et all, 2011
Corn	1 g	10 mL	methanol/water = 60/40	Chen et all, 2012
Maize bread	1 g	5 mL	PBS/methanol = 50/50	Trucksess et all, 2006
Rice, flour, beer, barley	1 g	5 mL	methanol/3%sodium bicarbonate = 50/50	Yamazaki et all, 1970
Breakfast cereals, cereal baby and beer	1 g	4 mL	methanol/1%sodium bicarbonate = 70/30	Park et all, 2005
Maize	1 g	5 mL	PBS	Bansal et all, 2011

Before proceeding to the cleaning step it was decided to evaluate different methods of extraction (reagents, time and proportionality) by highlighting with a more synthetic table (table 1 - *Specific extraction systems of OTA from different cereal matrices*), based on the scientific literature.

Immunoaffinity columns (IAC) are based on a specific antibody-analyte binding technology. Immunoaffinity columns contain a gel bed with toxin-specific antibodies coupled to the gel particles. These antibodies will capture a specific mycotoxin present in a sample and release them again after an elution step. Specific procedures are presented in literature (Table 2 *Immunoaffinity procedures based on different kind of columns*).

Table 2 Immunoaffinity procedures based on different kind of columns

Column	Conditioning step	Dilution system	Washing columns	Elution system	Reference
Ochratest Vicam Inc. (Watertown MA, USA)	10 mL of the filtrate were diluted with PBS and then filtered once more through a glass microfiber filter	20 mL	5 ml of PBS and 5 ml of water	3 ml of methanol (2 drops/s)	Araguas et all, 2005
OchraTest Vicam L.P. (Milford, MA, USA). (wheat test)		5 mL extract + 15 mL binding buffer	2.5ml wash buffer (2.5 % NaCl, 0.5% $NaHCO_3$,0.01% Tween 20) and 10 ml distilled water	1.5 mL methanol	De Girolamo et all, 2011
Ochraprep R-Biopharm Rhone (Glasgow, Scotland)		See reference	20 mL PBS	1.5 ml of acetic acid: methanol mixture (2:98) and 1.5 ml of pure water.	Cismileanu et all, 2008
Ochratest vicam (Watertown, MA, USA) (maize test)		20mL aliquot of the filtered was diluted with 30mL of PBS	10mL of water	3 mL methanol	Juan et all, 2007

Molecular imprinted polymers (MIPs) are highly stable polymeric molds that possess selective molecular recognition properties for various kinds of molecules. MIPs consist of highly cross-linked polymers that are synthesized in the presence of a template (imprint) molecule. After removal of template, a cavity is left, which retains affinity and selectivity for the template.

MIP has the advantages to be not only highly selective and specific but also chemically and thermally stable, compatible with all solvents and cost effective. This polymer is used as a powerful technique for clean-up and pre- concentration applications of Ochratoxin A.

Table 3 (*Molecular imprinted polymer procedures (AA – acetic acid; ACN- acetonitrile*) shows different the elution and washing method used for testing different samples with different columns using molecular imprinting polymers.

Table 3 Molecular imprinted polymer procedures (AA – acetic acid; ACN- acetonitrile)

Column	Dilution system	Conditioning of the cartridge	Washing system	Elution system	Reference
AFFINIMIPTM OTA cartridges (100 mg) containing 25-80_m beads (Loading volume 4ml)	diluted by a factor 2 with an aqueous HCl solution 0.1 M, spiked with OTA	5mL ACN and 5mL water	1mL of HCl 0.1 M, 1mL of acidified water (HCl 0.1 M)/CAN 60/40 (v/v), 10mL of purified water, a drying step of 5min, 4mL of ACN containing 0.01% AA	2mL of MeOH containing 2% AA.	Ali et all, 2010
AffiniMIP for OTA from Polyintell (Val-De-Reuill) (Loading volume 4ml)	5 mL extract diluted with 5 mL HCl 0,1 M	3 mL acetonitrile 3 mL water	6 mL solution 60/40 HCl/acetonitrile	2 mL of methanol (2% acetic acid)	AFFINIMIP catalogue

Cleaning up using aptamers columns

Aptamers are short single-stranded oligonucleotides chains are synthesized by SELEX (systematic evolution of ligands by exponential enrichment) [McKeague et all, 2014]. Aptamers are able to recognize and bind to targets with high affinity and selectivity through non-covalent interactions. Table 3. shows the elution and washing method used when different matrices are tested. Specific chromatographic methods and previous extraction procedures are used for OTA detection (Table 4 *The extraction procedures and chromatographic method s for OTA analysis from different matrices*).

Abreviations: SPE– solid-phase extraction; IAC - immunoaffinity columns; UPLC – ultra performance liquid chromatography; LC-MS/MS – liquid chromatography-mass detector; ABS - absorbance wavelength; EMS – emission wavelength; HPLC - high performance liquid chromatography; SP - solid-phase; LC – liquid chromatography; FLD – fluorescence detection.

Table 4 The extraction procedures and chromatographic method s for OTA analysis from different matrices

Extraction Method	HPLC characteristics	LOD	Reference
Solid-liquid extraction IMA HPLC-FD (feeds)	SP: C18 column (4.6 mm × 150 mm, 5 µm, Dikma, Beijing, China) MP: acetonitrile: water: glacial acetic acid (99: 99: 2, v/v/v) with the flow rate set at 0.9 mL/min.	0.035 ppb	Li et all, 2014
HPLC with FD IAC: Zorbax Extend ABS- 200-420nm EMS- 300-500nm (barley)	SP: C18 and ODS-Hypersil MP: acetonitrile/water/acetic acid = 99:99:2 (v/v/v) Flow rate: 1ml/min	0.3 ng/ml	Dhonal et all, 2010
DNA aptamer – SPE columns, Vicam, USA HPLC with FD, analytical column Symmetry C18. ABS-333nm, EMS- 460nm. (barley)	SP: Symmetry C18 (150 mm 4.6 mm, 5 µm) MP: acetonitrile/water/acetic acid = 99:99:2 (v/v/v) Flow rate: 1mL/min	23 pg/g	De Girolamo et all, 2011
Reversed-phase HPLC with FD and IAC; HPLC-MS/MS (Rice, flour, beer, barley)	SP: C18 (150 mm x 3.9 mm 5 µm) MP: acetonitrile/water/acetic acid = 57:43:2 (v/v/v) Flow rate: 0.5 mL/min	Polished rice: 1.0 Barley: 0.8 Wheat flour: 0.5 Beer: 0.2 Makkolly:0.2	Park et all, 2005
HPLC with FD IAC: Ocraking, Horiba, Japan ABS: 333 nm, EMS: 460 nm (rice)	SP: 4.6 mm by 250 mm by 5 µm; MP: acetonitrile-methanol-water (1:3:6) (v/v/v) flow rate of 1.0 mL/min	0.1 ng/g	Sakuma et all, 2013
IAC LC/MS/MS (maize)	SP: Gemini1 C18 column (150mm2 mm, 5 µm) precolumn Gemini C18 guard column (4mm2 mm, 5 µm) MP: methanol/water 40:60 (v/v) containing 1 mM ammonium acetate and 0.1% acetic acid) flow rate 200 µL/min	0.6mg/kg	Lattanzio et all, 2007

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Extraction Method	HPLC characteristics	LOD	Reference
aptamer-SPE column or IMA column. HPLC-FLD (wheat)	SP: Symmetry C18 (150 mm 4.6 mm, 5 μm). MP:acetonitrile:water:acetic acid 99:99:2 (v/v/v) flow rate 1.0 ml/min.	23 pg/g	De Girolamo et all, 2011
HPLC with FD IAC OCHRAPREP R-Biopharm, Rhone, Scotland ABS-333nm, EMS-443nm. (feed)	SP: ZORBAX SB-C18 (250x4.6 mm, 5 μm) MP: acetonitrile/water/acetic acid (aq) = 51:47:2 (v/v/v) Flow rate: 1ml/min	5 ng/g	Cismileanu et all 2008
IAC Ochratest LC-FLD ABS = 225 nm; EMS = 461 nm. (Breakfast cereals, cereal baby and beer)	SP: 5 μm (25 cm · 0.4 cm) Tracer Extrasil ODS-2 precolumn with a Tracer Extrasil ODS-2 MP: 29:29:42 (v/v/v) methanol–acetonitrile–5 mM sodium acetate acidified to pH 2,2 with phosphoric acid flow rate 1.5 ml/min	0.066 μg/kg, for breakfast cereals, 0.035 μg/kg for cereal-based baby food 0.012 μg/kg for beer.	Araguas et all, 2005

Incidence of ochratoxin A in feed materials, wheat and food products

Mycotoxicology analysis was performed by ELISA immunoassay test, for determination of ochratoxin A, with detection limit of 1μg/kg. The obtained results were reported to the Order no. 249 from 31st of March 2003, emitted by the Ministry of Agriculture, Food and Forestry and the Ministry of Health, which sets maximum limits for ochratoxin A in feed, of 10 mg/kg. [Milita 2005, 2008, 2009, 2013].

From the 170 analyzed samples (maize, sunflower, soybean, oatmeal, barley and wheat) for determining the concentration of ochratoxin A, aprox 41% were contaminated with OTA. From these, in 60% of cases, the concentration of OTA was under the immunoassay kit detection limit of 1 μg/kg. Variation limits of ochratoxin A concentration for feed materials were between 1 μg/kg and 26,4 μg/kg. The highest values of ochratoxin A were of: 6,48μg/kg for maize, 23,75 μg/kg for soybean meal, 26,4 μg/kg for sunflower meal, 13,61 μg/kg for barley and 7,05 for wheat.

For wheat and food product samples, the results were reported at the maximum limits under the EC Regulation no.1881/2006, for setting maximum levels of certain contaminants. From a total of 76 analyzed samples for OTA, zearalenone and deoxynivalenol detection, in aprox. 37% it was determined the presence of one mycotoxin, in aprox. 11% it was determined the presence of two mycotoxins, in a sample were detected all three mycotoxins and in 50% mycotoxins were not detected.

The results show that from the analyzed wheat samples, the variation of the concentration limits was: 1,07 μg/kg-3,28 μg/kg for ochratoxin A, 19,23 μg/kg – 868,13 μg/kg for deoxinivalenol and 1,79 μg/kg - 14,88 μg/kg for zearalenone.

CONCLUSIONS

In food industry, destruction of mycotoxins by conventional processing methods is difficult due to a very high resistance, complexity and analysis method limits [Murphy et al., 2006]. Mycotoxins are a major impediment to international trade, taking into account the severe regulations regarding their presence in food and feed and banning the commercialization in cases of non-compliance of maximum limits.

The European Commission had established through the EC no. 1881/2006 and EC no. 1126/2007 regulations, maximum permissible levels in food and cereals for aflatoxin, ochratoxin A, deoxinivalelol and zearalenon. Through the EC no. 165/2013 regulation, there were established indicative levels of T-2 and HT-2 toxin amount in cereals and cereal products.

The manuscript discusses (a) sample pre-treatment methods such as liquid–liquid extraction (LLE), supercritical fluid extraction (SFE), solid phase extraction (SPE), (b) separation methods such as (TLC), high performance liquid chromatography (HPLC), gas chromatography (GC), and capillary electrophoresis (CE) and (c) others such as ELISA.

ACKNOWLEDGEMENT

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44. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

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Prethodno priopćenje
Preliminary communication

THE COATING PROCESS OF CORN GRAINS USING A TREATMENT MACHINE WITH BRUSH SCREW CONVEYOR

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SUMMARY

Cereal and seed treatment technology represents an area of great interest within Processing and Post Harvest Technology with high impact on environmental and food industry. Establishing a suitable seed and grain crops coating technology involves a thorough analysis of all the factors involved in the coating seed process, as: seed quality, destination, special characteristics depending on the variety of seed conditioning, etc. By "seed treatment" it is means any process that they have undergone before sowing in order to obtain high and stable yields. The worldwide research conducted in this field, highlighted a series of aspects relating to the need for further research of these coating technologies. The paper presents experimental research results of conducted on a special stand which allowed the variation of operating parameters such as: feed flow rate, the flow rate coating substance, the speed coating system and speed of brush screw conveyor used for mixing, that lead to different seed corn degrees of coating that will be graphically represented.

Therefore has been determined the interdependence of degree coverage depending on functional parameters that has been tested and formulated recommendations for the use of machines equipped with brush screw conveyor.

Key words: *seed corn, coating process, screw conveyor*

INTRODUCTION

Research can contribute to diversification, by providing seed technologies and performing genotypes for farmers and that increase the attractiveness of neglected crops in the present [1],[4].

Although for most crops there is available a wide assortment of varieties or hybrids efficient and appropriate different conditions from our country, to high surfaces are still sown with poor seed, especially because of the economic inability of many farmers to buy quality seed

Success in growing cereals seed starts with effective treatment, so one of the criteria for assessing the quality of their seed is chemical treatment with major implications for future crop development [2],[5],[6].

Achieving a proper seed treatment technology of cereals and technical plants requires a thorough analysis of all the factors involved in the process of coating seed, such as (seed quality, destination, special characteristics depending on the variety of seed conditioning, etc.) [3],[7], [8].

To perform seed treatment operation are used complex machines and equipment specific to this area, which composed of rotating disc system for the spreading of the substance to treat and screw conveyor brush for better uniformity of coating substance on the surface of seeds. Speed rotating disc and screw conveyor speed are two basic elements in determining the degree of coverage.

This paper presents on one hand the main parameters variation who contributing to coverage and on the other hand preliminary experimental researches testing on a mobile seeds treatment with scattering rotary disc and screw conveyor brush for identify an optimal work to obtaining the best coverage degree

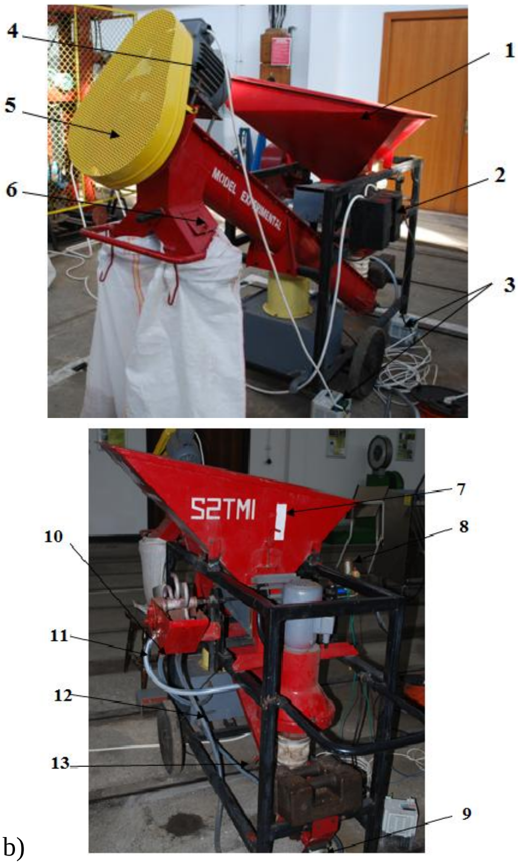
MATERIALS AND METHODS

Research and experimental tests were performed using a Seeds Treatment Mobile Installation (IMST 2), Figure 1 which has been designed and developed within the INMA Bucharest.

The seeds that were used in experimental tests was hybrid maize seeds of Limagrain Genetics variety, Lg 2275 - France, of different sizes with a humidity of 13% determined in laboratory.

The seeds that were previously cleaned, sorted and calibrated are directed to the intake hopper (1), by gravity. The amount of the seed is adjusted by regulating flap feeding (7) built into the intake hopper. Once that, is taken from a vibrating table that is positioned under the intake hopper and distributes them uniformly on the external surface of the internal cone drum.

On the external drum cone are positioned the spray nozzles with solution (concentrated treatment and water), which carries out the spraying. The amount of solution applied is dosage by a paddle mechanical system that transmits the motion to the of the dosage unit. Inside the cone, the liquid is fine sprayed with spreading disc, with variable speed.



a)

b)

Fig 1 Seeds Treatment Mobile Installation (IMST 2), a) Right side view, b) Left side view

1- The feed hopper;
2- Control panel switch ON/OFF;
3- Speed control converters;
4- The motor of screw conveyor;
5- Protective housing for chain transmission;
6- Evacuation holes bag;
7- Regulating flap feeding;
8- Drive system of the dosing mechanism;
9- Liquid feed pump;
10- Recovery liquid hose;
11- Liquid supply hose drum;
12- Liquid supply hose dispenser;
13- Fluid power hose pump.

The dosing unit is powered by an electric pump with curing solution enters the vessel with adjustable level. Out dosing system has a complex geometry and is constructed to manage the amount depending on the flow solution in the seed. Excess fluid dozer is directed to tank and fed back into the hydraulic circuit.

Operating conditions of the pump (13) is synchronized with the screw conveyor with brushes. These hairs of rayon yarn serve to equalize film solution administered over the surface of the grain, and to transport the product to the top of the chute, which is discharged through two holes bag who alternately working.

The testing methodology for treatment equipment has been developed according to thereof construction features and functional parameters (feed flow rate, dosing device substance flow, rotation speed of drum spray, screw conveyor homogenizer rotational speed, drive power of the engine, specific consumption energy, etc)

Because not all parameters have a high influence in the experiments were performed measurements for just a few of them.

In this sense were made determinations with corn pursuing the variation of the main parameters:

- Seed flow, Q, [kg/s];
- The flow of treatment substance Q_l, [l/min];
- Rotational speed centrifugal drum distributor, n, [rev/min];
- Screw conveyor rotational speed, n_t [rev/min];
- The degree of initial seed treatment, leaving the centrifugal drum G_{a1} [%]
- Seed treatment degree at the exit of the screw conveyor with brushes G_{a2} [%]

In table 1 they are listed seed flow values corresponding to the three positions of regulating flap feeding (fig 2)

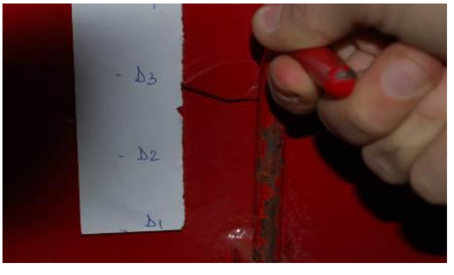


Fig 2 Regulating flap feeding

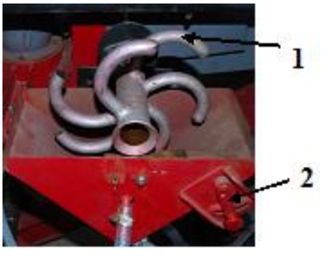


Fig 3 Liquid dispenser
1- dosing system with tubes
2- adjusting system

Table 1 Experimental data for the feed rate

Flap feeding position	Seed mass (kg)	Time (s)	Seed flow (kg/s)
D1	30	104,5	0,287
D2	30	87,7	0,342
D3	30	70,5	0,425

In table 2 are listed values for the position of the liquid flow adjusting system of the liquid. To meet manufacturer's specifications substance for treated they were used in experiments values at no. 2 position

Table 2 Experimental data for the three control positions of the fluid dispenser

Dosing system speed (rev / min)	Debit minimum dosage $Q_{l\ min}$ (l/min)	Debit medium dosage $Q_{l\ med}$ (l/min)	Debit maximum dosage $Q_{l\ max}$ (l/min)
5	0.14	0.44	0.95
10	0.36	0.65	1.20
15	0.59	0.81	1.41

In table 3 and table for are listed the experimental values obtained at disk drum and screw conveyor, with the help of two converters and one tachometer.

Table 3 **Experimental data disk drum speed**

Working frequency converter (Hz)	Speed drum with disk (rev/min)			Approx average value (rev/min)
10	598	603	599	600
20	1189	1201	1198	1200
30	1825	1803	1811	1800
40	2403	2410	2404	2400
50	2998	3000	3000	3000

Table 4 Experimental data for screw conveyor speed

Working frequency converter (Hz)	Approx average value (rev/min)
10	54
20	110
35	190
40	217
50	282

Degree of covering (Ga) is determined after harvest samples and visual analysis in the laboratory, using the following formula:

$$G = (NBT / NTB) \times 100\ [\%], \tag{1}$$

in which:

NBT - Number beans treated;

NTB – Number of total beans.

A seed is considered treated if it has the outer surface covered at least 90% treated with chemicals. [9]

The determination was made on at least 500 seeds and is repeated at least 3 times, the result is the arithmetic mean of the measurements.

RESULTS AND DISCUSSION

In table 5 are listed the values obtained after the seeds out of the conical disc drum spreading. Seed sample was collected, then analyzed in the laboratory and coverage degree was registered in table

Table 5 Covering degree from the exit of drum disc

Exp.no	Q		Q l	n dtc	G ac 1
	kg/s	kg/min	l/min	rev/min	%
1	0.287	17.22	0.36	2000	32
2	0.287	17.22	0.65		33
3	0.287	17.22	1.20		34
4	0.342	20.52	0.36		27
5	0.342	20.52	0.65		28
6	0.342	20.52	1.20		30
7	0.425	25.50	0.36		23
8	0.425	25.50	0.65		25
9	0.425	25.50	1.20		26
10	0.287	17.22	0.36	2500	39
11	0.287	17.22	0.65		40
12	0.287	17.22	1.20		41
13	0.342	20.52	0.36		33
14	0.342	20.52	0.65		34
15	0.342	20.52	1.20		36
16	0.425	25.50	0.36		25
17	0.425	25.50	0.65		27
18	0.425	25.50	1.20		29
19	0.287	17.22	0.36	3000	38
20	0.287	17.22	0.65		42
21	0.287	17.22	1.20		46
22	0.342	20.52	0.36		35
23	0.342	20.52	0.65		37
24	0.342	20.52	1.20		39
25	0.425	25.50	0.36		28
26	0.425	25.50	0.65		29
27	0.425	25.50	1.20		29

where:

n dtc – revolution of spreading disc

G ac1 – coverage degree at the exit of conical drum

After analyzing the obtained data it was made graphic interpretation of results.

In figure 4 show the represented coverage of seeds variation when spread disk speed is varied. In this chart we see that with increasing disk speed, coverage significantly increases.

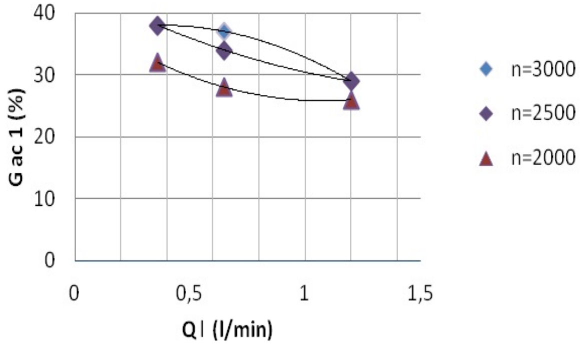


Fig. 4 Degree of coverage variation according to the flow of liquid from the 3 revolutions of the drum to disc

Figure 5 represented the evolution of coverage degree depending on the amount of seeds at 2,000 rpm spreading disc .As you can see it constantly varies coverage degree along with varying the amount of liquid.

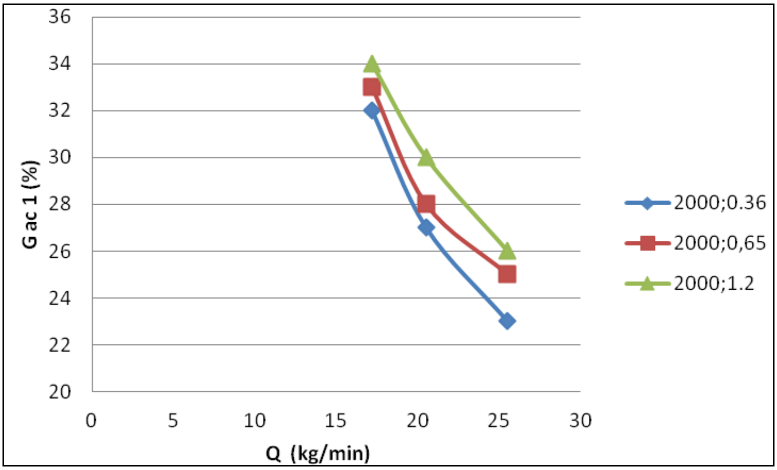


Fig. 5 Comparative analysis of degree of coverage variation depending on seed flow at 2,000 rpm disc and three liquid flow

Figure 6 represented the evolution of coverage degree depending on the amount of seeds at 2,500 rpm spreading disc. As you can see it constantly varies coverage degree along with varying the amount of liquid, as seed flow is less coverage degree is higher.

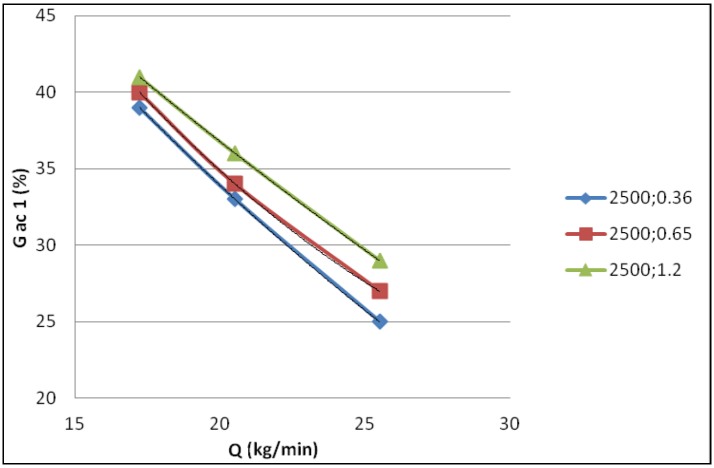


Fig. 6 Comparative analysis of degree of coverage variation depending on seed flow at disc drum with 2500 rpm and three liquid flow

Figure 7 represented the evolution of coverage degree depending on the amount of seeds at 3000 rpm spreading disc. As you can see it constantly varies coverage degree along with varying the amount of liquid, as seed flow is less coverage degree is higher. At a higher flow rate seeds rate of coverage degree is not influenced by revolution.

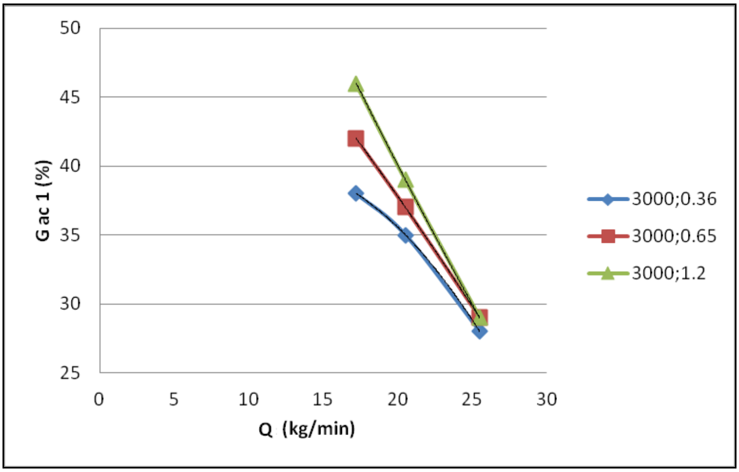


Fig. 7 Comparative analysis of degree of coverage variation depending on seed flow at disc drum with 3000 rpm and three liquid flow

In table 6 are listed the values obtained after the seeds out of the conical disc drum spreading. Seed sample was collected, then analyzed in the laboratory and coverage degree was registered in table.

Table 6 Covering degree from the exit of the screw conveyor without drum disc

Nr. exp.	Q		Q l	n te	G ac 2
	kg/s	kg/min	l/min	rev/min	%
1	0.287	17.22	0.36		59
2	0.287	17.22	0.65		60
3	0.287	17.22	1.2		60
4	0.342	20.52	0.36		54
5	0.342	20.52	0.65	110	56
6	0.342	20.52	1.2		57
7	0.425	25.5	0.36		50
8	0.425	25.5	0.65		51
9	0.425	25.5	1.2		54
10	0.287	17.22	0.36		61
11	0.287	17.22	0.65		61
12	0.287	17.22	1.2		63
13	0.342	20.52	0.36		59
14	0.342	20.52	0.65	190	60
15	0.342	20.52	1.2		60
16	0.425	25.5	0.36		57
17	0.425	25.5	0.65		58
18	0.425	25.5	1.2		59
19	0.287	17.22	0.36		64
20	0.287	17.22	0.65		64
21	0.287	17.22	1.2		65
22	0.342	20.52	0.36		62
23	0.342	20.52	0.65	282	62
24	0.342	20.52	1.2		63
25	0.425	25.5	0.36		58
26	0.425	25.5	0.65		59
27	0.425	25.5	1.2		60

where:

n te – revolution of screw conveyor;

G ac2 - coverage degree at the exit of the screw conveyor

After analyzing the obtained data it was made graphic interpretation of results.

In figure 8 show the represented coverage of seeds variation when screw conveyor speed is varied. In this chart we see that with increasing screw conveyor speed, coverage significantly increases.

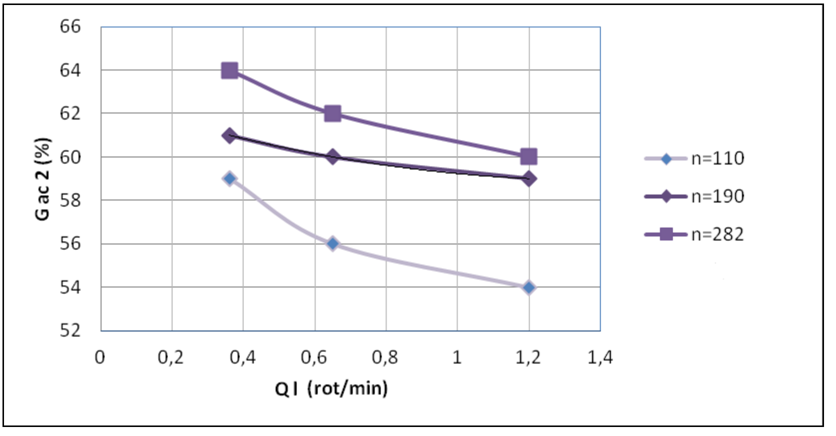


Fig. 8 Comparative analysis of coverage degree variation depending on the elected flow of liquid at three speeds screw conveyor

Figure 9 represented the evolution of coverage degree depending on the amount of seeds at 110 rpm screw conveyor. As can be seen at this speed coverage degree is not influenced significantly by the amount of liquid.

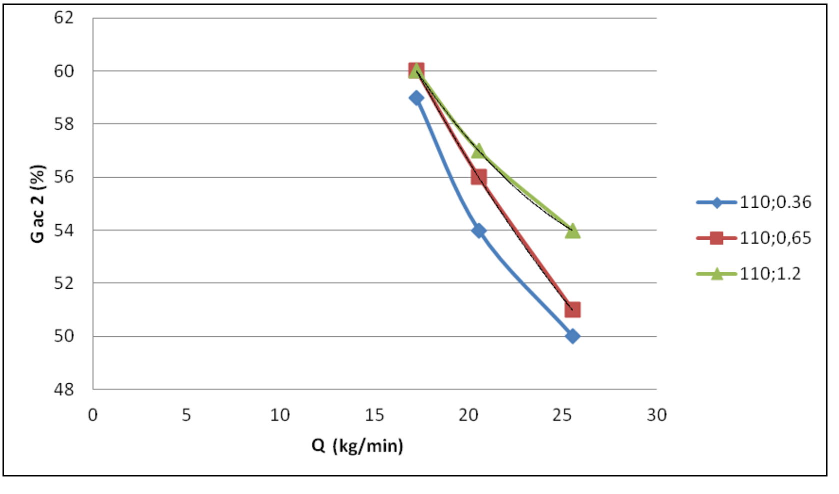


Fig. 9 Comparative analysis of coverage degree variation depending on the flow of seeds at 110 rev / min of the screw conveyor and the three flow rates

Figure 10 represented the evolution of coverage degree depending on the amount of seeds at 190 rpm screw conveyor. As can be seen it vary constantly coverage degree along with varying the amount of liquid as seed flow is less coverage degree is higher.

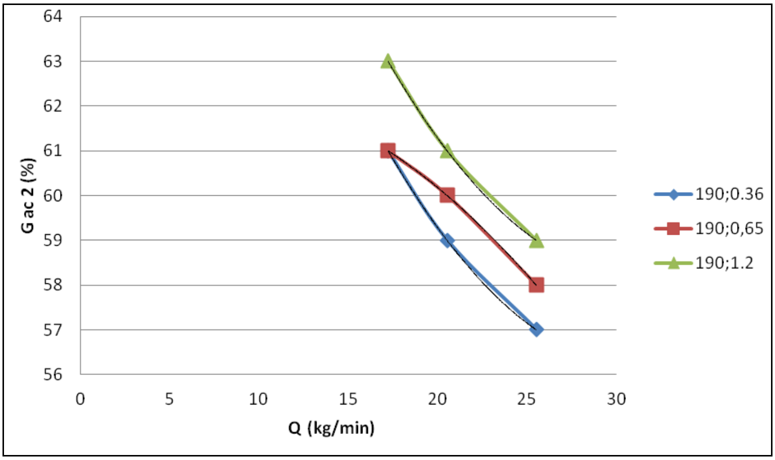


Fig. 10 Comparative analysis of coverage degree variation depending on the flow of seeds at 190 rev / min of the screw conveyor and the three flow rates

Figure 11 represented the evolution of coverage degree depending on the amount of seeds at 282 rpm screw conveyor. As can be seen it vary constantly coverage degree along with varying the amount of liquid as seed flow is less coverage degree is higher.

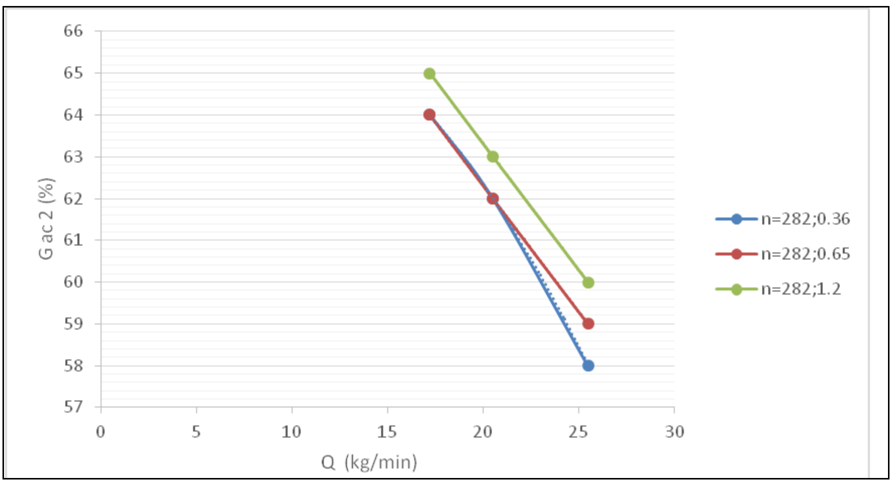


Fig. 11 Comparative analysis of coverage degree variation depending on the flow of seeds at 282 rev / min of the screw conveyor and the three flow rates

ACKNOWLEDGEMENTS

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CONCLUSIONS

Because experimental researches in the field of seeds treatment equipment with inclined screw conveyor brush is quite small and in literature not found enough data influence constructive elements for the quality of work, this paper aims at completing data experiments and it wish to make an important contribution on the interdependence of its working qualitative indices, constructive and functional.

All working parameters have influence on the final level seed treatment, and they must be optimized depending on the nature of the treatment for more precision.

The coverage of seeds at the exit of drum cone with spreader disc is about 20-45% and the coverage degree at the exit of the screw conveyor without being passed through drum disc is somewhere around 60%

In the time of experiments, we seen as the two main bodies that contribute to seed treatment the spreading disc from conical drum and screw conveyor with brush cannot achieve high coverage independently and that is why there is interdependence between them.

The data presented may be important for all professionals and workers in the processing and conditioning of seeds, referring primarily to the operation of the technological process of seed treatment.

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44. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

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Original scientific paper

THE EXTRACTION OF POLYPHENOLS FROM GRAPE POMACE BY SUBCRITICAL WATER

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ABSTRACT

This paper presents the performance of subcritical water extraction when extracting polyphenols from grape pomace. Extraction was performed in the temperature range T 100°C ÷ 160^{0}C, pressure P = 12 MPa, exposure dose τ from 30 to 90 min., hydronic modulus 1: 5 and 1:10. The most effective yield of polyphenols - 5.534% was under process parameters: T = 100°C, P = 12 MPa, τ = 60 min, hydronic modulus 1:10. The results obtained in the study showed that the selectivity for individual polyphenolic substances for subcritical water is much less than for organic solvents, but there is a significant increase in their yield due to the tannins. It is advisable to extract and use not separated fractions of polyphenols, but all polyphenols complex.

Key words: *extraction, subcritical water, polyphenols, grape pomace*

INTRODUCTION

For extraction of biologically active substances in the vast majority as the basis they use water and ethanol mixtures (Gironi F., Piemonte V., 2011; Boussetta N. et al., 2011), methanol (Rockenbach I. et al., 2011; Ruberto G. et al., 2007), and other organic solvents, sometimes with the use of additional physical extraction techniques. For example, water and ethanol mixtures with high voltage electric discharge (Boussetta N. et al., 2011), ethanol with microwaves (Li Y. et al., 2011), ultrasound (d'Alessandro L. et al., 2012), etc.

However, their use is problematic due to the toxicity, high cost, recycling problems, and they lead to a low yield of extractives. Moreover, phospho- and glycolipids, acylglycerols, ethers of sterols and other simple and alcohol ethers having biological activity almost completely disappear from the composition of extracts.

In recent years, it was proposed to use as extraction agents the solvents with low boiling temperature - liquefied gases: carbon dioxide, propane, ammonia, methane, ethylene and some other compounds with low critical temperatures (Zapletuhin D. et al., 2006; Seabra I. et al., 2010).

However, it should be born in mind that carbon dioxide is one of major greenhouse gas as well as methane, ozone, nitrogen oxides as the gases that contain fluorine. The presence of these gases in the atmosphere leads to the greenhouse effect. In addition, some fluid substances, such as methane, belong to toxic substances influencing on the central nervous system; first signs of asphyxia appear with the contents 25-30% of methane in the air (Kucenko S., 2004). There is evidence that some of them, such as ethylene, propane and others have narcotic actions.

Therefore, we propose a new perspective process where as the extrication agent they use subcritical water (SCW, superheated water under pressure at temperatures of 100°C to 374°C) (Petrova Y., Lagovskiy I., 2010; Sukmanov V. et al., 2011*a*; 2011*b*; Sukmanov V. et al., 2012; Khuwijitjaru P. et al., 2012; Hanim S. et al., 2012; Singh P., 2011). Subcritical water is an effective solvent for both polar and nonpolar compounds. Water is the most efficient and environmentally friendly tool of extraction due to changes in its physico-chemical properties (dielectric conductivity, ion product, diffusion properties and density) with an increase in pressure and temperature. The dielectric conductivity determines the polarity of SCW. The versatility of SCW as a solvent is associated with changeable polarity of water. At lower temperatures, the hydrogen bonds are strong and the dielectric constant is higher. When the water temperature rises, the increase in the thermal motion reduces the strength of hydrogen bond of each leads reduction of dielectric constant. Reduction of strength of hydrogen bonds in water molecules, and decrease of the polarity in water results in increase of solubility in water.

Thus, when the water temperature rises, the polarity of the water decreases. As a result, the solubility of nonpolar organic compounds increases, and the solubility of polar organic compounds decreases (*Galkin A., Lunin V., 2005*). When the water temperature rises above 100°C, the dielectric conductivity of water becomes similar to organic solvents. If at normal pressure and temperature water is a polar solvent, then sub- and supercritical water dissolves almost all organic substances (Ved A., 2007). The possibility to adjust the dielectric conductivity of water to simulate the solubility of organic solvents for nonpolar compounds was used for the selective extraction of a large amount of hydrophobic organic compounds (HOC) from plants, soil and food.

Due to the change of dielectric conductivity of water the SCW extraction technologies ensured high extraction yields and fast time for extraction for a series of HOC. Yield of SCW target components is comparable to methods with the use of organic solvents. However, there are advantages of using SCW as solvent for extraction compared to organic solvents. These solvents are often toxic.

In addition, strict removal of organic solvent is often required, particularly where the extract is ingested in an organism in the form of food or pharmaceutical drugs. Removal of organic solvents is costly and time consuming. Water, on the other hand, is everywhere; it is not toxic and has a low recycling cost. Therefore, SCW is an ideal candidate to be used as a solvent in the food and pharmaceutical industries.

Replacement of toxic organic solvents, greenhouse and narcotic liquefied gases with eco-friendly subcritical water will reduce the economic and environmental consequences of their use as extraction agents.

The above-discussed approach to technology development and extraction processes in the environment of subcritical water can be very helpful in solving economic and environmental problems for European countries with their unique flora, which determines the relevance of the research in this area.

MATERIALS AND METHODS

Plant material

Moldova grape variety is purchased in late September in the retail network in Donetsk (Ukraine) from the manufacturers - the Republic of Moldova. Moldova is table grape. The average weight of a bunch is up to 350 grams. The berry is big (2,5 x 1,9 cm), oval, dark purple, with a thick waxy coating. The skin is thick, dense and tough. The flesh is meaty and crispy. The taste is simple.

Preparation of raw materials

Crushing of berries with peduncles was carried out on an industrial juice extractor to a moisture content of grape pomace - 55% (Razuvaev N., 1975). Drying of original pomace at 75°C ± 2°C to constant weight was carried out in porcelain bowls placed in cabinet drier ТРЦ02 ТП-1 with occasional stirring. Drying continued up to 25 hours in the open air. Residual moisture of pomace after drying was 4-7 (% abs.). The resulting agglomerates were crushed to fraction passing through a sieve with aperture of 3 mm. Samples in powder form were packaged in paper bags to protect them from light, and plastic bags to protect them from ambient moisture. The samples were stored at room temperature in a dark place in a Laboratory of Fluid Technologies of Donetsk National University of Economics and Trade named after M. Tugan-Baranovsky (DonNUET), Ukraine.

Extraction by sub-critical water

Equipment used for the extraction in the subcritical water (SCW) was designed and manufactured at Laboratory of Fluid Technologies of Donetsk National University of Economics and Trade named after M. Tugan-Baranovsky. Extraction was performed in a laboratory reactor under steady-state conditions. Applied ratio of raw material and extraction agent (water) was 1: 5 and 1:10. The temperature varied from 100 to 160°C with change size of 10°C. The temperature was maintained by a controller with an accuracy of ± 1°C. Maturity time was 30 min, 60 min and 90 min. Time countdown was started after reaching the set temperature. Three parallel experiments were performed at each point.

The pressure level P = 12 MPa, which provides subcritical conditions and a high yield of extractable substance, as the cell membranes are broken, was set and maintained based on the thermodynamic properties of water. Differential equations of thermodynamics of the International System of Equations of 1997, hereinafter referred to as Formulation IF - 97, used for calculations, are intended for manufacturing industry (Alexandrov A., 1998). These equations describe the properties of water and steam, together covering the range of parameters,

$$273.15 \leq T \leq 1073.15K \quad with \quad p \leq 100\, MPa\,;$$

$$1073.15 \leq T \leq 2273.15K \quad with \quad ð \leq 100\, MPa\,,$$

in p, T - diagram shown in Fig. 1. Areas 1, 2, 5 are described with the fundamental equations for the Gibbs energy g (p, T), area 3 - the fundamental equation for the Helmholtz energy f (p, T), and the saturation line is represented by the equation p_s (N). These five equations constitute a group of basic equations of Formulation IF - 97.

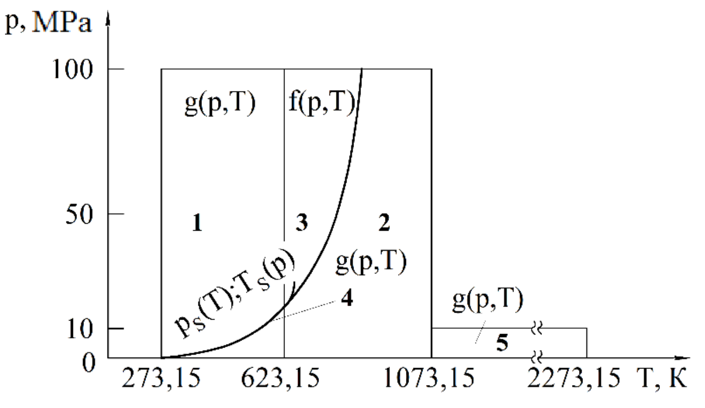


Figure 1 Area of equations of Formulation IF – 97

To create subcritical conditions it is necessary to maintain the parameters of the area 1. At pressures and temperatures in this area corresponding to the points above the saturation line 4, the steam is completely condensed into liquid. In this area, the equation (1) for the specific Gibbs energy is the major one:

$$\frac{g(p,T)}{RT} = \gamma(\pi,\tau) = \sum_{i-1}^{34} n_i (7.1-\pi)^{I_i} (\tau - 1.222)^{J_i} \tag{1}$$

where p - pressure, MPa,

T - temperature, $K,\ \pi = p / p^*; \tau = T^* / T;\ p^* = 16{,}53\ M\Pi a;\ T = 1386\, K$.

Values of the coefficients and index of power for this equation are given in Tables Formulation IF - 97. The coefficients n_3 and n_4 in equation (1) were selected in such a way as to meet the agreement, current since 1954, (Release on the IAPWS Formulation, 1995) on the adoption the zero values of internal energy and liquid entropy in the triple point $(with\ T_{mp} = 273{,}16\ K\ and\ p_{mp} = 611{,}657\ Pa)$, equation 2:

$$u'_{mp} = 0;\ s'_{mp} = 0\,. \tag{2}$$

Enthalpy of liquid at the triple point is $h'_{TP} = 0{,}611783 J/kg$.

All thermodynamic properties of water have been obtained from equation (1) by means of differential equations of thermodynamics. Relations between the most important of them are presented in Table 1

Table 1 The relations for calculating the thermodynamic properties

Property	Relations
Specific volume	$\upsilon p / RT = \pi\gamma_{\pi}$
Specific internal energy	$u / RT = \tau\gamma_{\tau} - \pi\gamma_{\pi}$
Specific entropy	$s / R = \tau\gamma_{\tau} - \gamma$
Specific entropy	$h / RT = \tau\gamma_{\tau}$
Specific isobar heat capacity	$c_p / R = -\tau^2\gamma_{\tau\tau}$
Specific isobar heat capacity	$c_{\upsilon} / R = -\tau^2\gamma_{\tau\tau} + (\gamma_{\pi} - \tau\gamma_{\pi\tau})^2 / \gamma_{\pi\pi}$

*according to equation (1)

$$\gamma_{\pi} = \left(\frac{\partial\gamma}{\partial\pi}\right)_{\tau}, \gamma_{\pi\pi} = \left(\frac{\partial^2\gamma}{\partial\pi^2}\right)_{\tau}, \gamma_{\tau} = \left(\frac{\partial\gamma}{\partial\tau}\right)_{\pi}, \gamma_{\tau\tau} = \left(\frac{\partial^2\gamma}{\partial\tau^2}\right)_{\pi}, \gamma_{\pi\tau} = \left(\frac{\partial^2\gamma}{\partial\pi\partial\tau}\right)$$

Error of calculated values calculated by the equations of Formulation IF - 97, in the liquid at temperatures of 25 ... 200°C and pressures from 5 MPa to 100 MPa is ± 0,005%.

Methodology of evaluation of polyphenols extraction.

The total content of polyphenolic compounds was determined in conversion to gallic acid by the reagent Folin-Ciocalteu.

The method of Folin-Ciocalteu (FC-method) (Singleton V., Rossi J., 1969) represents the colorimetric determination of products of red/ox reactions of phenolic molecules of the extracts under analyzes without differentiation between gallic acid, mono-, di-, oligo- and polymeric compounds. The method is based on the use of an oxidizing reagent - hetero polyphosphate of wolframic and molybdic acids. Blue color appears in the course of the reaction due to formation of mixture of recovered wolframates from $P_2W_{18}O_{62}{}^{-7}$ to $H_4P_2W_{18}O_{62}{}^{-8}$; and a series of restored molybdates from $H_2P_2Mo_{18}O_{62}{}^{-6}$ to $H_6P_2Mo_{18}O_{62}{}^{-6}$.

Aliquot of the obtained extract (solution A) was dissolved in 60 ml of distilled water in measuring bottle of 100 ml, after that they added 5 ml of reagent Folin-Ciocalteu, stirred it, added 15 ml of 20% solution of Na_2SO_3, and adjusted the volume of the measuring bottle to the mark with distilled water (solution B). After 2 hours, they measured the absorbance of the solution B at analytical wavelength of 765 nm relative to the comparison solution (it is prepared similarly but without the addition of solution A).

Simultaneously, they measured the absorbance of solution consisting of 1 ml of a solution of gallic acid reference standard (0.0500 grams in 100 ml of 60% ethanol), 5 ml of reagent Folin-Ciocalteu, 15 ml of 20% solution of Na_2CO_3 and distilled water to 100 ml.

Preparation of reagent Folin-Ciocalteu: 100 g of sodium wolframate (Na_2WO_4*$2H_2O$) and 25 g of sodium molybdate (Na_2MoO_4*$2H_2O$) were dissolved in 700 ml of distilled water in a 2-liter round bottom bottle, 50 ml of 85% H_3PO_4 and 100 ml of concentrated HCl were added. The bottle was refluxed for 10 hours (not necessarily discontinuously). After cooling, 150.0 g of lithium sulfate were added to the bottle, after a few drops of bromine (or small amount of perhydrol) were added and boiled for 15 minutes for oxidation of residues of phosphomolybdic blue; the final solution should be yellow without impurities of green color. The solution was cooled, and the volume was adjusted to 1 liter, filtered and stored in a closed dark glass bottles.

Total amount of polyphenol compounds in % in conversion to gallic acid was calculated according to the formula:

$$X = \frac{D \cdot m_0 \cdot 25 \cdot 1 \cdot 100 \cdot 100 \cdot 100}{D_0 \cdot m \cdot a \cdot 100 \cdot 100 \cdot (100 - w)} \tag{3}$$

where: D – absorbance of the solution under examination;

D_0 – absorbance of standard solution of gallic acid;

m - mass of the extracted pomace, g;

m_o - mass of gallic acid in grams;

a - aliquot of solution A, ml;

w – weight loss on drying of the extract in percentage.

Aliquot was adjusted so that the absorbance was in the range 0.2-0.6.

Statistical analysis

Variance analysis of the results was carried out by least square method with application of coefficient Student and Microsoft Office Excel program version 2007. Differences were considered statistically significant if probability was greater than 95% (p-value <0.05). Experimental results are expressed as average ± SD (standard deviation).

RESULTS AND DISCUSSION

Yield of polyphenols (Tanino-catechin complex) of grape pomace is presented by phenolic acids, flavonoids, tannins, proanthocyanidins and stilbenes.

Yield of polyphenols with hydromodulus of 1: 5 is described by the regression equation (4):

$$F = -5{,}902 + 0{,}164 \cdot t + 0{,}019 \cdot \tau - 0{,}00019 \cdot t \cdot \tau - 0{,}00069 \cdot t^2 . \tag{4}$$

Table 2 Yield of polyphenols

Temperature ^{0}C	Extraction time, min	Experimental values of yield of extract, %, with hydronic module		Calculation according to regression equation,%, with hydronic module		Residue, %, with hydronic module	
		1:5	1:10	1:5	1:10	1:5	1:10
100	30	3,431	4,835	3,628	5,043	-0,197	-0,208
100	60	3,086	5,534	3,630	5,113	-0,544	0,420
100	90	4,063	4,703	3,631	5,183	0,431	-0,480
110	30	3,905	4,725	3,760	4,832	0,144	-0,107
110	60	3,415	5,165	3,703	4,902	-0,288	0,262
110	90	3,900	4,785	3,647	4,971	0,252	-0,186
120	30	4,388	4,622	3,752	4,621	0,635	0,001
120	60	3,757	4,801	3,638	4,690	0,118	0,110
120	90	3,501	4,873	3,523	4,761	-0,022	0,112
130	30	3,745	4,480	3,606	4,409	0,138	0,070
130	60	3,495	4,514	3,434	4,479	0,060	0,034
130	90	2,955	4,635	3,261	4,549	-0,306	0,085
140	30	3,116	4,347	3,322	4,198	-0,206	0,148
140	60	3,242	4,225	3,091	4,268	0,150	-0,043
140	90	2,417	4,406	2,860	4,337	-0,443	0,068
150	30	2,635	4,071	2,898	3,987	-0,263	0,083
150	60	2,725	3,766	2,609	4,057	0,115	-0,291
150	90	2,180	4,285	2,320	4,126	-0,140	0,158
160	30	2,168	3,809	2,335	3,776	-0,167	0,032
160	60	2,210	3,311	1,988	3,845	0,221	-0,534
160	90	1,953	4,178	1,641	3,915	0,311	0,262

Yield of polyphenols with hydromodulus of 1: 10 is described by the regression equation (5):

$$F = 7{,}086 - 0{,}021 \cdot t + 0{,}002 \cdot \tau \,, \tag{5}$$

where: t - the extraction temperature, ^{0}C;

τ – maturity time, min.

The results of calculations of yield of polyphenols in the experimental points and the obtained regression equations (4) and (5) are shown in Table. 2.

The regression results of yield of polyphenols of grape pomace are shown in Table 3.

Table 3 Results of regression analysis of yield of polyphenols

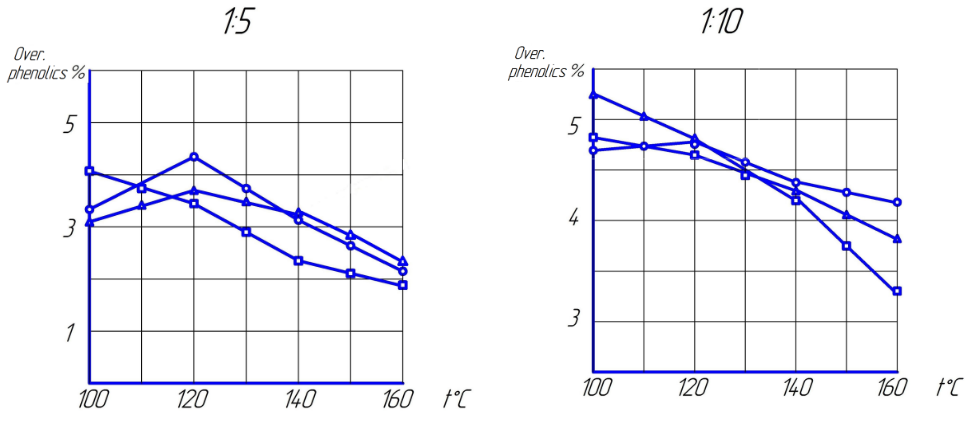
Regression parameters		Hydronic module 1:5	Hydronic module 1:10
Correlation coefficient, R		0,906	0,881
Determination coefficient, D		0,821	0,775
Mean square deviation, σ		0,776	0,750
Fisher's ratio test, $F_{calc.} < F_{tab.}$	$F_{calc.}$	3,94	18,08
	$F_{tab.}$	5,80	19,40
Confidential interval of model coefficients with error level α = 0,05 (reliability level 95%)	a_0	-13,687÷1,882	6,289÷7,884
	a_1	0,047÷0,281	-0,026÷-0,015
	a_2	-0,021÷0.061	-0,002÷0,007
	a_3	-0,0005÷0,0001	-
	a_4	-0,0011÷-0,0002	-

Multiple correlation coefficient of the regression equation (4) R = 0,906, equation (5) - R = 0,881. The high values of R indicate the adequacy of the resulting equations.

Dependence of yield of polyphenols of grape pomace on time, temperature and hydronic module is shown in Figure 2., and *Response surface* - in Figure 3.

The data obtained as a result were considered the flow of two opposing processes: 1) the transition of polyphenolic compounds in solution; 2) secondary transformation of polyphenolic compounds leading to degradation or transition to insoluble state and settling-out.

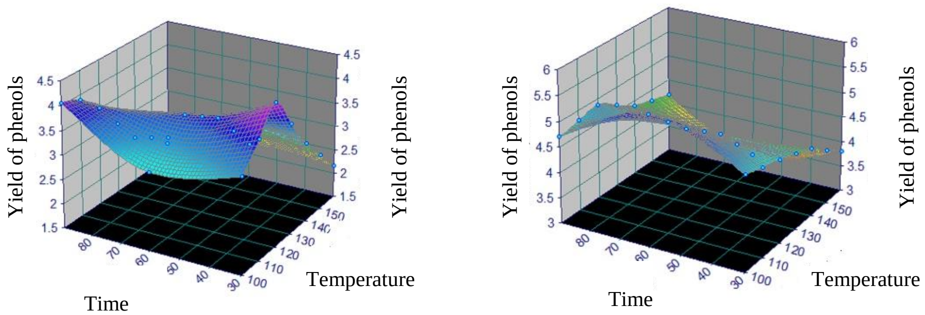
A significant increase in the yield of polyphenols can be explained by the transition to a solution of tannins and products of their hydrolysis under high temperatures and acidic environment.



a) b)

Figure 2 Yield of polyphenols of grape pomace
a) with hydronic module 1:5, b) with hydronic module 1:10

○ - 30 min, △ - 60 min, □ - 90 min



a) b)

Figure 3 Response surface of yield of polyphenols of grape pomace
a) with hydronic module 1:5, b) with hydronic module 1:10

As is well known (Obolenskaya A. et al., 1991), tannins can be extracted from wood or bark with water at a temperature of 80-120°C. The temperature of 90°C is considered to be optimum.

The content of tannins in plant materials varies considerably: in the bark and wood of oak - 5-6,6%, in the bark of Norway spruce - 11-12%, in the root of Bergenia - 23-26%, in the leaves of smoke tree - 14-16%, etc. (Afanasyeva A. et al., 1984). The amount of tannin (enotannin) in grape pomace may reach 10% (per dry weight) (Denshikov M., 1963). It exceeds its content in oak which is traditionally used for tannins.

CONCLUSIONS

The maximum number of total polyphenols - 5.534% of yield was at T = 100°C, maturity time = 60 min, pressure P = 12 MPa, hydronic module 1:10.

Yield of polyphenolic compounds during the extraction with subcritical water exceeds the number of polyphenols obtained in the extraction by organic solvents and water at temperatures to 60°C (Ptitsyn A., 2007; Rubchevskaya L., 2001).

High yield of tannins enables their economically viable extraction. On the other hand, this complicates the extraction of narrow fractions of other polyphenols, especially different groups of flavonoids.

A disadvantage of extraction of polyphenols by subcritical water is its low selectivity for certain groups of flavonoids. Because of this, the content of phenols in the dry extract is low. In extraction by organic solvents the proportion of phenolic substances in the extract is significantly higher and they are mainly presented by non-tanning substances. This fact complicates the selection, separation and purification of polyphenol compounds from the extracts by subcritical water.

Thus, selectivity as to polyphenolic substances for subcritical water is considerably less than for the organic solvent, but there is a significant increase in their yield due to their tannins. It is advisable to extract and use not separated fractions of polyphenols, but all Tanino-catechin complex.

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44. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

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Prethodno priopćenje
Preliminary communication

SIMULATION OF DOUGH KNEADING PROCESS, FOR A KNEADER WITH VERTICAL ARM AND MOBILE VAT

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ABSTRACT

This study approaches tridimensional numerical simulation for bread making dough, kneaded with a vertical arm and mobile vat machine – Diosna SPV 160 AD model, with the purpose of pinpointing how the chafe of vat's bearings influence the energy consumption and the rheological properties of dough.

The first part of the paper contains a comparative analysis of kneading curves obtained on the same kneader, but using a vat with chafed bearings and one with new bearings. For the resulting diagrams, was registered data from the kneader's engine, using a measuring device for current intensity. Based on these kneading curves, dough rheological properties can be compared with the ones given by Brabender device.

In the second stage, it is verified a mathematical model which measures the mechanical energy transferred to the dough for the analysis of previously obtained measurements on the vats of Diosna SPV 160 AD machine.

The final part of the paper presents the breaking stress a vat's wall is subjected to during kneading process. The results were obtained by generating a tridimensional model with the parameters from the analysis of the kneading curves, using Simulation in Solid Works program. Due to the graphic results, it is possible to interpret the differences between energetic fluctuations and applied forces to the system, factors with a major impact on the final dough used in industrial bread making.

It is important to specify that the efficiency of the kneading process is influenced also, by the imposed kneading conditions, the amount of introduced air, the quantity of added water and the quality of the flour being used. In this study, these conditions were maintained constant for the tests. Knowing that the speed with which the energy is transmitted to the dough is influenced by its *consistency which is interdependent with the kneading process, it is extremely important that the dough kneading process to be optimum, in the established amount of kneading time.*

The comparative analysis between the two kneading processes has concluded with a rise of 22% of the maximum resistant moment at the kneading arm and a lower consumption of electrical energy at the kneader's engine, with 15% for the vat with new bearings.

The main objective for the 3D simulation of the kneading process for bread making dough is the complex study of dough behavior during kneading.

Key words: *dough, kneading process, kneading curve, torque, mechanical energy, simulation.*

INTRODUCTION

The rheological properties of wheat flour doughs are largely governed by the contribution of starch, proteins and water [2,3]. The main characteristic of wheat flour is that, mixed with water, it has the ability to form a continuous macromolecular viscoelastic network. By hydrating the protein content it forms gluten which acts as a balloon and traps the carbon dioxide gas bubbles produced by fermentation.

The mixing process is the crucial operation in bakery industry by which the wheat flour, water, and additional ingredients are changed through the mechanical energy flow to coherent dough. The dough properties are strongly influenced by the way of their mixing [3,9,11]. The dough development is a dynamic process where the viscoelastic properties are continuously changing. Consequently, this causes very low correlations between the dough rheological parameters (development time, stability of dough, breakdown, and others) obtained from different mixers. Furthermore, the lab mixing devices like Farinograph or Mixograph do not exert identical mixing actions not only between them but also in comparison with industrial mixers [5]. Some of the values can be well correlated. Farinograph stability is well correlated to the mixing requirements of dough [8] while the Mixograph development time is well correlated to the bakery mixing time [12]. Due to the dissimilarities between laboratory analysis (such as the dough development, energy or stability) and industrial application, the flour's profile and its behavior has to be validated through tests in the industrial bread making process with a closer inspection of the real behavior of dough and the characteristics of the end product.

From the industrial view, the requirements for the mixing process can be formulated as a cost effective way for processing of dough with proper quality. The requirements of the doughs for the mixing energy are related to the dough strength; therefore the costs of the end-products of mixing are different. Different industrial mixers can be evaluated through their efficiency [10].

The energy consumption (work input) for the dough formation at the peak resistance depends on the flour used, mixer speed, and mixer type. During mixing, the energy flow and the hydration processes are accompanied with a temperature increase. The temperature growth is dependent on the speed of mixing [9], but it is assumed that heating of dough during mixing is influenced by the type of the flour used and also by the type of mixer.

Through the determination of the proper energy input, optimal changes during mixing can be probably achieved (in the case of one type of mixer). It is possible in this way to manage the process of dough developing.

The difficulties in the determination of an exact model for energy flow to the arising dough system and thus defining the mixing requirements of flours with a defined composition (mainly in starch and protein characters) reside in the complexity and variability of emergent mixing forces inside the dough during its deformation (shear, stress, extension, creep), where each mixer type imparts mixing energy by a dissimilar way [4,6].

The purpose of the paper is to demonstrate the necessity of a monitoring system, attached to a conventional industrial dough kneader, in order to control the kneading process, technologically, as well as technical.

The main objectives of this study are: 1) the analysis of the differences between a kneading process using a vat with new bearings, versus a kneading process using a vat with chafed bearings; 2) the influence of equipment usage on the optimum forming of dough; 3) the comparative analysis between the energy level introduced in both experiments; 4) the analysis of the obtained results, after introducing the data in a 3D simulation.

MATERIALS AND METHODS

For the experiments, it was used a type of wheat flour with 0.480% ash, from the 2015 production, produced by SC 7 Spice SA – Valcea. The characteristics of the flour are shown in table 1. The dough was prepared from 100 kg of wheat flour and 58 l of water, with a kneading time of 11 minutes, using an industrial kneader - Diosna SPV 160 AD model provided with a spiral kneading arm and mobile vat. The dough preparation was accomplished at room temperature, 20–22^{o}C.

Table 1 Physio – chemical characteristics of the flours used in the experiments

Flour type	Moisture content, [%]	Wet gluten, [%]	Ash, [%] d.s.	Gluten deformation [mm]	Acidity, [degrees]	Falling number, [sec]	Gluten index
FA - 480	13,4	29	0,48	3,5	2	318	92

Flour acidity is expressed in acidity degrees and is determined using the water suspension method, titrated with sodium hydroxide 0.1 n solution.

For the comparative analysis between vats with different abrasive wear of the bearings, it was used a device for measuring and data acquisition. The working principle of this method consists in connecting the measuring and data acquisition device to the engine of the kneader, where it measures the consumed electricity by the engine during kneading, a consumption that is growing/descending depending on the opposition force of the dough at the kneading arm, and more so on the torque at the kneader's working arm. Before starting the kneading process, a clamp which registers the intensity of the current, was connected to the power supply of the engine. The clamp was also connected to a data acquisition device

(Supco type –figure 1b), which downloads real time information on a computer. The registered signals were filtered based on the intensity's current variation, and the variation curves for the dough consistency during kneading, were drawn, at a second's interval.

In order to filter the obtained data, functions like max, min, average, count and others in the Excel program were used. The next step was to correlate the measuring unit between the one used for the Brabender farinograph (figure 1a), which is Newton multiplied with meter, and the one on the results obtained by the consumption at the kneading arm. This stage made it possible to verify the correctness of the interpretation of the acquired data.

At first, the mixer was left working without load (out-current), in order to establish the energy losses of the kneader, which were decreased from the final calculation of the torque (Nm) consumed by the spiral blade, in relation with the opposing force of the dough.

Considering the general relation for calculating the necessary driving power on the working arm, it can be written:

$$P_m = M_m \frac{\pi n}{30} \text{ [Kw]} \tag{1}$$

where: Mm is the resisting torque at the kneading arm, maximum, respectively medium and Pm is the corresponding power, [11].

For finding the power consumed by the mixer's engine, the following relation was used:

$$P_m = \sqrt{3} U I cos\phi \text{ [Kw]} \tag{2}$$

where: U is tension of the current, I is the intensity of the current and which is the value measured by the clamp and is the power factor.

In order to establish the consumed power by the kneading process, without the energy losses, the next relation was used:

$$P_{mf} = P_m - P_{mg} \text{ [Kw]} \tag{3}$$

where: P_{mf} is the consumed power only for the kneading process, P_m is the total power consumed by the mixer's engine and P_{mg} is the consumed power of the engine, on out-current.

Knowing the consumed power for the kneading process and the angular speed described by the kneading arm, it is possible to calculate the medium torque, as it follows:

$$M = \frac{P_m}{\omega_m} \text{ [Nm]} \tag{4}$$

where: M is the opposing medium torque at the kneading arm, P_m is the power consumed by the engine only for the kneading process and ω_m is the angular speed of the arm when kneading [7].

a. b.

Fig. 1 a. Brabender farinograph; b. Portable device used for measuring the consumed current when kneading dough

For the second stage of the paper, the same data acquired with the portable device, was used in a different mathematical model, in order to calculate the amount of mechanical energy transferred to the dough. The following expression was used:

$$E = \frac{CNt}{M} \text{ [J]} \tag{5}$$

where: C is the average torque (Nm), N is the angular velocity (rad/sec), t is the mixing time (sec), and M is the weight of the mixed dough (kg). The amount of heat absorbed by the dough during mixing was determined by calculating the difference between the temperatures of the dough at the beginning and the end of the mixing (°C), multiplying by the heat capacity of the dough (calculated as the weighed sum of the heat capacity of each component (1.9 J/g/°C) and multiplying by the weight of the mixed dough [1].

For the simulation presented in the third part, the dough was formed of flour and water added in 58% proportion. The numerical results were obtained for a density of dough (ϱ) of 1200 kg/m^3, the angular speed of the kneading arm being 180 rpm and the angular speed of the vat being 15 rpm.

The 3D simulation of the kneading process for bread making dough has as main objective, the study of bread dough behavior during kneading. In the first phase of this modeling the geometrical model is generated, with which the final simulation is run. The steps for this phase can be followed in figure 2.

In this tridimensional study, the flowing conditions were considered to be for balance. In order to simulate the dough’s behavior, during the kneading process, the following hypothesis were considered: the flow corresponds to the equilibrium state, it is laminar and isotherm, the vat is full with dough, the dough is considered to be incompressible and viscous, non-newtonian, with negligible inertia. The gravitational effect is taken into consideration only for large quantities of dough, in the case of the limit section, the effect of gravity, being negligible.

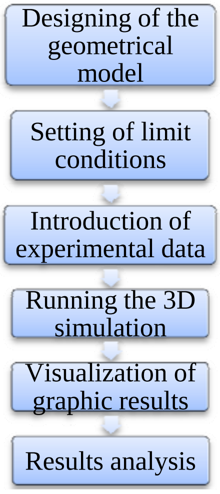


Fig 2 Steps for obtaining the 3D simulation in Solid Works

RESULTS AND DISCUSSION

Mechanical development of dough is obtained when, in the kneading process, a sufficient quantity of mechanical work is transferred to the dough. Through the movement of the kneading arm, in the mass of formed dough speed gradients appear, which submit the dough to deformations and becomes a material with rheological characteristics governed by consistency, elasticity and extensibility.

The relation between force (F) and the moment of the force (M) for a body in rotation is written bellow.

$$M = Fb \tag{6}$$

$$F = M/b \tag{7}$$

where: M is the moment, F is the force and b is the arm.

In figure 3, it is explicated the difference between the resistant torque at the kneading arm for a kneading process using a vat with 30% chafed bearings and one with new bearings.

In the results, it can be observed an increase of maximum consistency with 18%, from 570 Nm to 700 Nm for the dough kneaded in the vat with new bearings, versus the one kneaded in the vat with chafed bearings, as well as doubling the stability time of dough with a better development of the gluten structure.

The speed with which the energy is transmitted to the dough in the kneading process is influenced by the dough’s consistency.

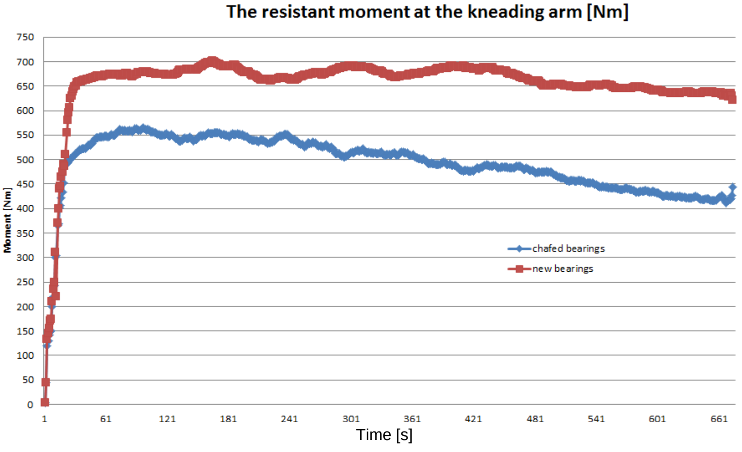


Fig. 3 The kneading curves drawn for a kneading process in a vat with chafed bearings, respectively, in a vat with new bearings

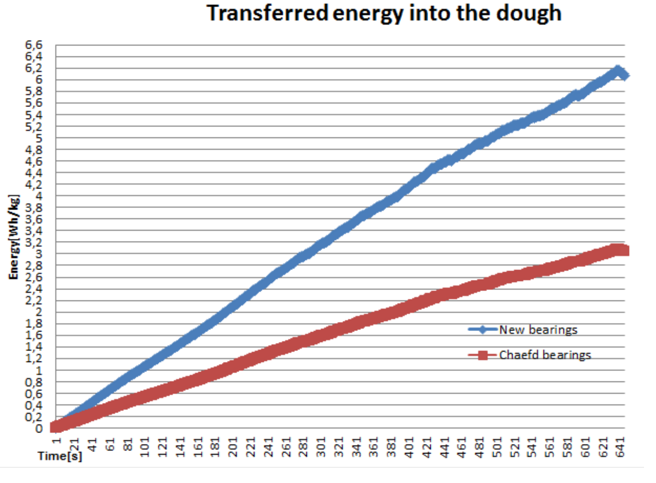


Fig. 4 Curves describing the amount of energy introduced into the dough in the 2 tests

Here is how to calculate the friction factor: prior to making the dough, the exact temperature of the room, flour, and water, must be noted. After the dough is made, its temperature must also be noted. Because there are three main factors that influence the dough's temperature, it is necessary to multiply it by three. After doing this, it is necessary to add the three temperatures - room, flour, and water and subtract the sum from the temperature of the dough multiplied by three. The result is the energy or heat of the friction generated either manually or mechanically [13].

In order to verify the mathematical model with which the energy is transferred to the dough, method illustrated in table 2 was used.

Table 2 Mathematical model of calculation for friction [13]

Operation	Chafed bearings	New bearings
Dough temperature obtained [˚C]	26	28,5
Multiplied by 3	78	85,5
Room Temperature [˚C]	24	24
Flour Temperature [˚C]	24	24
Water Temperature [˚C]	22	22
Sub Total	70	70
Subtract Total from	78	85,5
	70	70
Friction/Energy [◦C]	8	15,5

In order to calculate the amount of introduced energy into the dough, the experimental data were introduced in the following general formula [1]:

$$\text{Friction Temperature [°C]*Weight [g]*Calories = J*g*°C} \tag{8}$$

$$\text{(Temperature friction [C]*Weight [g]*0.0027)/1000=Wh/Kg/°C} \tag{9}$$

The formula was applied for both studied cases, as it is illustrated bellow:

1. Chafed bearings:

$$(8*158000*0.0027)/1000 = 3.41\ \text{Wh/Kg/°C} \tag{10}$$

2. New bearings:

$$(15,5*158000*0.0027)/1000 = 6.61\ \text{Wh/Kg/°C} \tag{11}$$

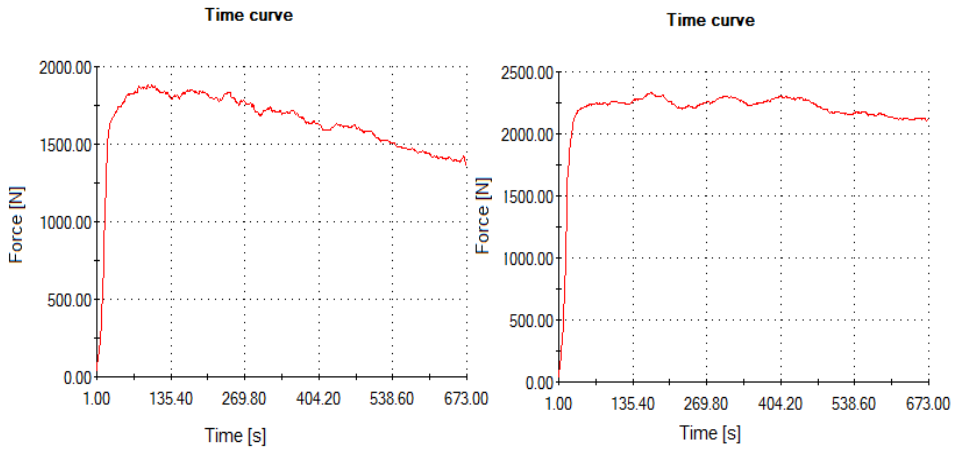
The experimental data was introduced in the simulation program in order to simulate the applied forces by the dough on the vat's walls.

In the third part of the research, it was run the simulation for the kneading process, through which the effect of the tensions that appear on the surface of the vat and kneading arm, was analyzed using Von Mises stress method.

Von Mises theory proposes that the total strain energy can be separated into two components: the volumetric (hydrostatic) strain energy and the shape (distortion or shear) strain energy. It is proposed that yield occurs when the distortion component exceeds that at the yield point for a simple tensile test. This is generally referred to as the Von Mises yield criterion and is expressed as:

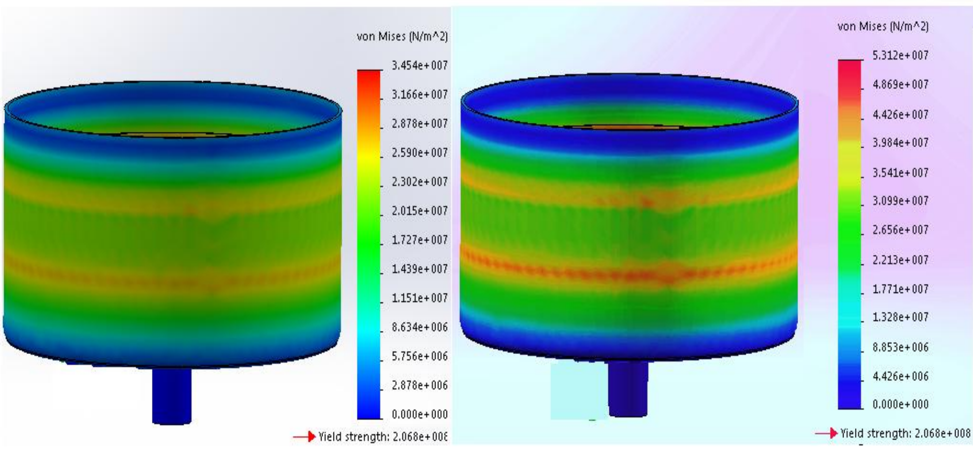
$$\frac{1}{2}[(\sigma_1-\sigma_2)^2+(\sigma_2-\sigma_3)^2+(\sigma_3-\sigma_1)^2] \le \sigma_y^2 \tag{12}$$

This assumes that yield occurs when the shear stress exceeds the shear yield strength: (σy). Since stress and strain are tensor qualities they can be described on the basis of three principal directions; in the case of stress these are denoted by , σ1, σ2, and σ3.



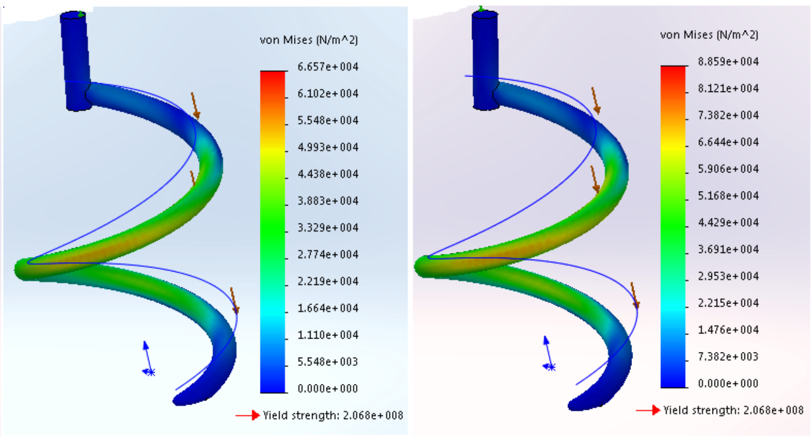
a) b)

Fig. 5 Graph which shows the applied forces by the dough on the vat's walls: a) forces applied for the vat with chafed bearings; b) forces applied for the vat with new bearings



a) b)

Fig.6 3D Simulation for tensions on the surface of the vat during kneading process: a) vat with chafed bearings; b) vat with new bearings



a) b)

Fig.7 3D Simulation for tensions on the kneading arm during kneading process: a) tensions applied on a kneading arm, at the vat with chafed bearings; b) tensions applied on a kneading arm, at the vat with new bearings

Because the section where the dough passes between the kneading arm and the vat's wall is small, the pressure is high, and the energy is directly proportional with the strain force for dough.

CONCLUSIONS

In the experiments, there are used: clamp which measures intensity of current, data and acquisition device, vat with new bearings and vat with chafed bearings, in order to register the differences between torques and energy introduced into the dough, in both experiments.

By replacing the chafed bearings at a vat for Diosna SPV – AD 160 kneader and registering the kneading curves with the system for measuring and data acquisition for the kneading process in both types of vats (with chafed and new bearings), a method for controlling the kneading process was identified. The kneading process was improved by creating a better structure for the gluten, i.e. better gas retention and also by reducing the electrical power consumption of the kneader.

In order to obtain a good quality dough, a very important aspect is not only the optimum amount of energy introduced, but also the speed with which it is applied to the dough. This paper demonstrates the importance of tolerance between the kneading arm and vat, tolerance responsible for transferring the energy to the dough. This way, to an optimum level of energy, it has to correspond a certain kneading time.

In figure 3 it can be observed that the stability time for dough kneaded in a vat with new bearings has doubled in time, which means the gluten network has substantially improved. The volume of the bread has grown from 520 cm^3 to 580 cm^3 as it can be seen in figure 8. It can also be observed in figure 3 a raise in maximum consistency, from 570 Nm to 700

Nm which means 17% more for the vat with new bearings, which also has a positive impact on the stability of dough.

In figure 4 it can be observed a raise in energy of 30% for the vat with new bearings, more energy introduced into the dough in the same time unit, even if the power consumption had equal value in both cases.

The 3D analysis shows differences in energy distribution on the vat's wall and on the surface of the arm. The data obtained in this study can be helpful in designing of kneading equipment and optimization of energetic consumption. The results obtained with the help of the 3D simulation for the kneading process can offer a prediction for the optimum parameters in the bread making process, which can improve it considerably.

By improving the kneading process, higher quality products are obtained. Especially improved, are the volume of the bread, the color of the core, a finer porosity and a tender structure, thanks to the superior rheological characteristic of dough (as shown in figure 8).

The quality of the end products is closely related to the technological parameters and the level of technology used in the process, which can improve significantly, the industrial process of bread making.

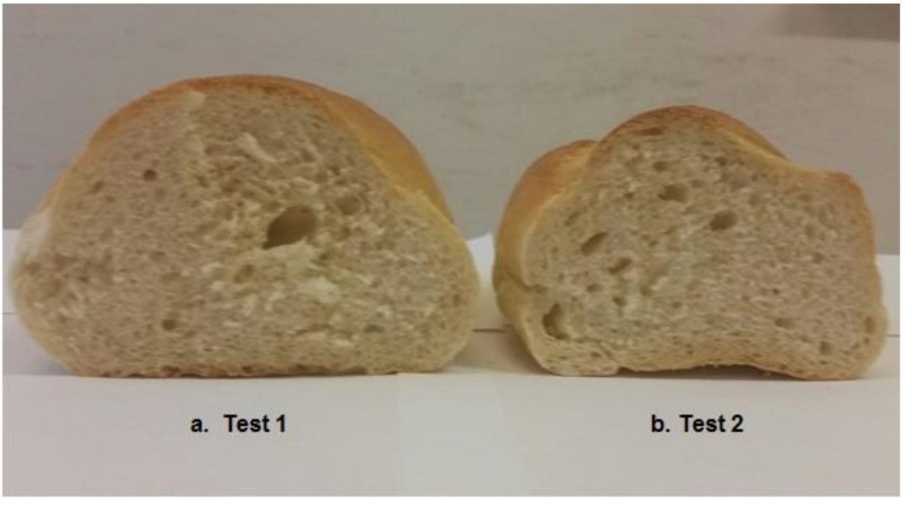


Fig. 8 Effect of energy input on bread quality: a) New bearings and energy input of 6.2 Wh/kg, b) chafed bearings 3.2Wh/kg

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44. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

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Prethodno priopćenje
Preliminary communication

THE RELATIONSHIP BETWEEN DOUGH CONSISTENCY AND ITS DEVELOPMENT TIME, FARINOGRAPHIC CURVES ANALYSIS

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SUMMARY

Farinograph curves are used to assess the rheological of bread dough. Farinograph curve has two branches: one ascendant, which is dough development and formation phase, until reaching the normal consistency, and one descending where the linked dough is kneaded for complete hydration of the flour particles and the consistency preserving a certain time and then start to decline (softening phase of the dough). Both ascending branch and descending branch of farinogram, presents allure that depend on the flour characteristics, the amount of water added, and the added ingredients and their quantities in the recipe. There are no known data on the formulation by mathematical equations of farinograph curve. Therefore, the present study tested the ascending branch of the curve farinograph curve by equations, mainly type Eulerian. Based on the results of farinograph tests made a dough of bread flour wheat FA-650 with different content of salt (0, 0.4, 0.8, 1.2, 1.6, 2.0%), regression analysis in Origin 7.0 program, had a particularly high degree of correlation to gamma function, and exponential.

Key words*: wheat flour dough, farinogram, regression testing, gamma function*

INTRODUCTION AND LITERATURE REVIEW

The kneading of the dough is one of the most important methods for determining and characterizing the quality of flour. The Farinograph method (standard for testing flour quality AACC 54-21, ICC 115/1) is one of the most popular methods for evaluating the rheological properties of dough. The farinograph records by tracing a curve called farinogram, the behavior of dough during kneading.

On a farinograph curve can read more parameters (dough development time, water absorption, dough stability, degree of softening, Farinograph Quality Number index (FQN)), but most important of them is development or forming time of dough (formation of gluten), schematized by the ascending branch of the curve. This shows a steep upwards slope, because time (expressed in minutes), fixed to the abscissa of the diagram, has relatively small values (about 1.2–3 min), while the consistency, fixed on the ordinate of the diagram, reaches the maximum value (normal respectively) of dough. Compared, the branch downward of curve who starting from maximum value of dough consistency, shows a slow downward slope, because the time of kneading (registration farinograph) is extended to 20 minutes and consistency decreases relatively little.

The allure of farinograph curve is the result of developments of dough structure during kneading. For the dough that present a solid behavior (thick consistency), development time and stability are higher [11]. Characteristics of flour used in kneading, amount of water, ingredients added in the recipe (water, salt, yeast, auxiliary materials) and their quantities are so many variables that influence the farinograph curve shape. Many researches have been made in this way. Thus, in the paper [4], from the conducted researches, it was found that farinograph parameters are influenced by storage time and temperature of flour. In the case of flour storage for 1 year at 40^{o} C, the development time increased from 6.75 minutes to 10 minutes [4]. The development time is an indicator of protein content in flour [3]. The addition of whey protein in wheat flour causes a slight decrease of dough development time, and as the lactose content increases the development time significantly change (7.3 min for 100 % wheat flour to 2.4 min for addition of whey permeate) [2]. Same applies in the case of adding in wheat flour the soy protein or mixed with various percentages of flour soybean, [2,7].

The dough made from strong flour need for greater development time unlike the dough made from weak flour, [3].

In the paper [14], by adding bran in wheat flour, in different percentages and derived from several types of grain (wheat, rice, oat and barley), has shown the effect on the rheological characteristics of dough. As regards the development time, it increases significantly if the added bran from wheat or rice (from 2.5 min for simple wheat flour to approximately 11 min and 13 min for 40 % added bran wheat and bran rice).

Automatic driving of work processes of equipment and installations within a technological process is done by software based on mathematical models developed either analytically or based on previous researches and experimental determinations. A system for automatic control of the mixing process in the food industry, is based on measuring the electrical power supply of the motor of the mixer. Thus, with such a system, the authors of paper [6] could monitor the mixing process in the dairy industry. The system can also be used in the baking industry because it can monitor both the viscoelasticity as well as the homogeneity of the blending compound. The changes in the consistency of the dough in relation to the flow of mechanical energy into the dough during mixing with a Diosna SP12 mixer have been studied by Muchova and Zitny [12], the mixing energy as possible be used to obtain a better quality of dough and finished products.

To kneading dough from weak wheat flour with a Hobart mixer, energy consumption profiles were evaluated by spectral analysis of the acquired signals by means of a current sensor to determine the optimum time of mixing, [10]. It was found that the optimal mixing time was from 510-850 seconds, depending on the amount of flour, the water content and the speed of mixer. Development time increases significantly as the mixing speed increase [13].

Anderssen and Kruzik, in [1] examines how mixing can be modeled using a mathematical model rigorously developed as an evolution in time of incremental deformation of an elasto-plastic material, elastic behavior of the dough being described by an density of polyconvex energy. For elementary processes considered, mathematical model presents solutions of Sobolev type. Research on the process of kneading dough in the kneadings with screw and motion considered chaotic were carried out by Hosseinalipour and all. [9], to establish trajectories of kneading arm and of material, developing a mathematical model which is based on the bird Carreau dough model of Dhanasekharan.

Comparative experimental researches regarding the rheological mixing behavior of wheat flours with the Brabender Farinograph were carried out by Voicu et all. [15,16], being tested three kinds of wheat flour FA-480, FA-650 and FN-graham in combination with different salt contents (0-2%). Farinograph characteristics have been established of the dough from these flours. It was found that the higher the percentage of added salt, the amount of water needed for hydration of the flour and salt particles has decreased, it being specified on the farinograph records for the water absorption of flour.

Research on rheological behavior of dough from wheat flour at the kneading were also seen in other papers [5,8], showing both tests of some alveographic tests for doughs, and

also the durum wheat dough strength properties.

Analyzing a farinographic curve, the forming phase of the dough from wheat flour, as the other phases of its kneading may be expressed through different mathematical relationships.

In this paper we present the results of the regression testing for upward branch of farinographic curves obtained with Brabender farinograph, on dough from wheat flour with different salt contents with known laws of variation (Weibull, lognormal, exponential, gamma, hyperbolic). Are presented the used mathematical equations and their degree of correlation with experimental data obtained for this part of the farinographic curve (step of forming the dough, respectively).

MATERIALS, METHODS AND PROCEDURES

On a farinographic curve, drawn using electronic farinograph Brabender are readable: development or forming time of dough, its time of stability (readable on the horizontal axis, in minutes), i.e. maximum moment (maximum dough consistency), the degree of softening of the dough, and it elasticity (on the vertical axis, in farinograph units – FU).

Development (forming) rime of dough is time (in minutes) for the formation of gluten, i.e. to achieve consistency of 500 FU. Dough stability is the length of time in which the farinogram is kept on line of normal consistency. The degree of softening of the dough (the tolerance to kneading) It is represented by the difference between the consistency of 500 FU and consistency which reached the curve after 12 minutes from achieving the standard consistency. Dough elasticity (expressed in FU) It is given by the width of the curve and is measured either at the maximum moment, or after a certain time from the beginning of the plotting the curve (most conclusive).

These rheological characteristics of dough [16] serve to determine the appropriate mixtures of flour, when making the manufacturing recipes, and to establish the parameters of bread making technological regime, so as to obtain the corresponding bread properties. On the basis of experimental data obtained in testing of wheat flour FA-650 (white flour with 0.65% ash content) with different salt contents (0, 0.4, 0.8, 1.2, 1.6 and 2%) with E-Brabender farinograph and presented in the paper [16], was tested the correlation of the experimental points values on the ascending branch of the farinographic curves with known mathematical functions:

a) Weibull type: $$y = a\,x^{b}\,(x-c)^{d} \tag{1}$$

b) Lognormal type: $$y = a\,exp\left[-\frac{1}{2}\left(\frac{ln\frac{x}{b}}{c}\right)^{2}\right] \tag{2}$$

c) hyperbolic 1 type: $$y = a\,\left(1-\frac{1}{1+b\,x}\right) \tag{3}$$

d) hyperbolic 2 $$y = \frac{a\,x}{b+x} \tag{4}$$

e) de tip exponential 1 type: $$y = \frac{a\,\left(exp(-bx)-exp(-cx)\right)}{c-b} \tag{5}$$

f) exponential 2 type: $$y = a\,\left(1-exp(-bx)\right) \tag{6}$$

g) gamma type: $$y = a\,e^{-bx}\,x^{c-1} \tag{7}$$

This was possible due to the acquisition of experimental points values directly from the device software which presents measured values of dough consistency at intervals of 2 seconds. These values have been entered in program Origin, vers. 7.0, and then using regression function were successively tested all the mathematical laws specified.

RESULTS AND DISCUSSION

Based on experimental measurements performed previously [16], were plotted farinographic curves for wheat flour dough with different salt contents, and on the basis of the data acquired for the experimental points of the ascending branch of the curve (midline shown in green on the farinogram chart) were plotted by regression analysis curves given by specified variation laws (figure 1 and figure 2).

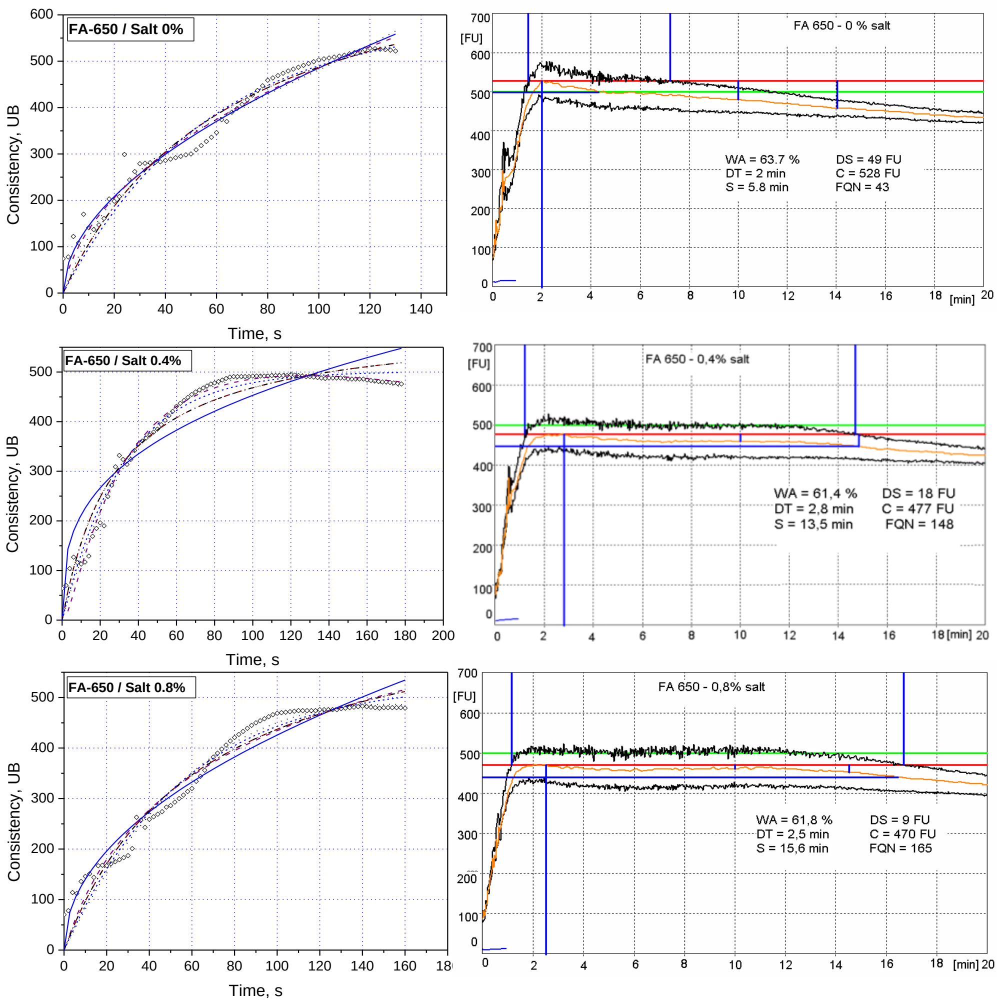

Fig. 1 The curves obtained by regression analysis for the dough development phase (at left) and experimentally plotted farinograms (at right) for wheat flour doughs with three different salt content (0, 0.4 and 0.8%)

—— eq.1; – – – eq.2; – · – · – eq.3; – ·· – ·· – eq.4; ········ eq.5; - - - - - eq.6; - · - · - eq.7

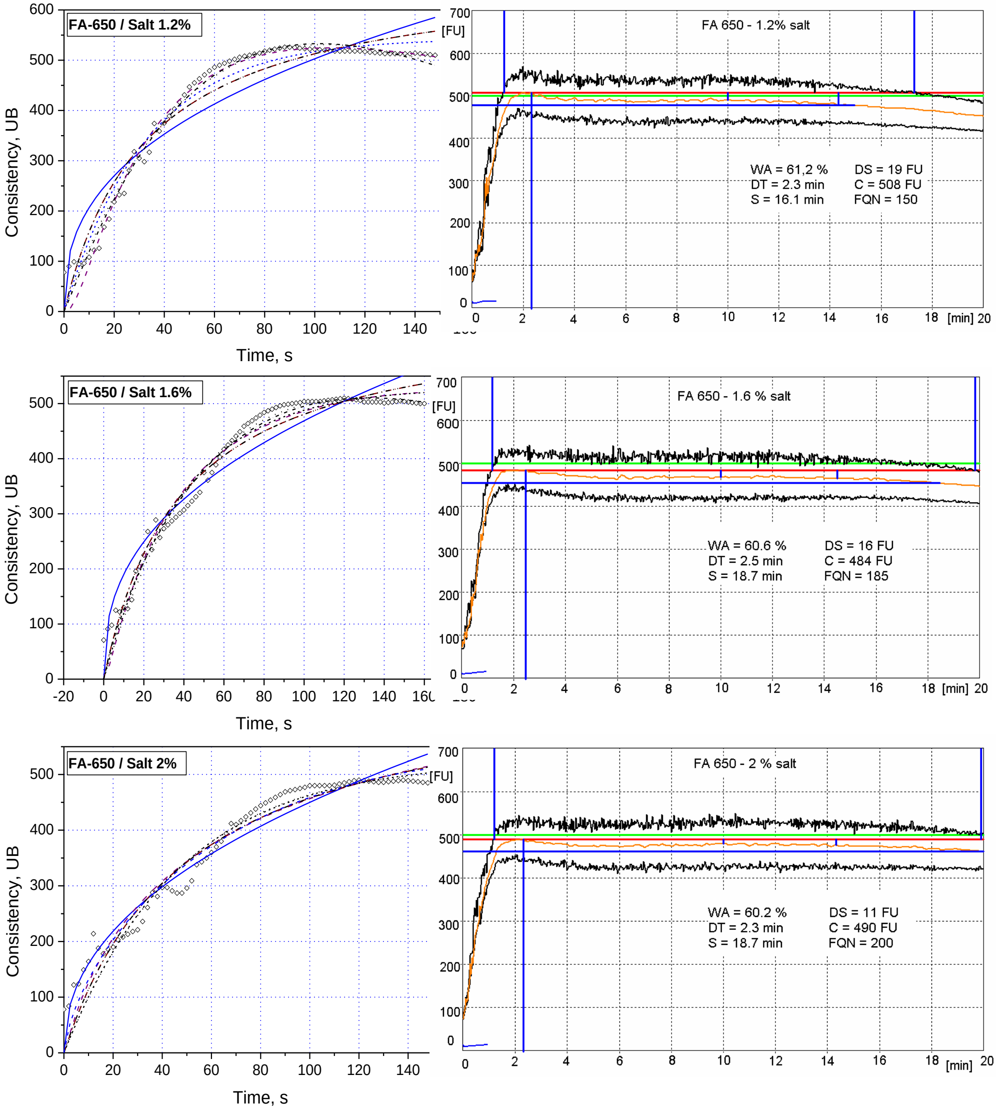

Fig. 2 Curves obtained by regression analysis for the development phase of dough (at left) and experimentally plotted farinograms (at right) for wheat flour doughs with three different salt content (1.2, 1.6 and 2%)

—— eq.1; – – – eq.2; – · – · – eq.3; – ·· – ·· – eq.4; ········ eq.5; - - - - - eq.6; - · - · - eq.7

Values of regression equations coefficients (eq. 1–7), together with the values of correlation coefficient R^2, for each of the seven mathematical relationships are presented in table 1.

From analysis of plotted regression curves, in relation to the experimental points, and from the analysis of the correlation coefficient values R^2 presented in table 1, can see consistency of mathematical laws used with experimental data. There are regression curves which are nearer to the experimental points on the first part of registrations, while others is close to this points more in the second part of the recordings, even if the correlation coefficient R^2 values are close. Still, for the majority development curves of the dough, the best correlation with experimental points, and the best approach to these, it has gamma function (eq.7), followed by the exponential function type 1 (eq.5), in particular in the end region, where curve must interconnect with the other branch of the farinographic curve.

Table 1 Coefficients values for equation (1)-(7) and of correlation coefficient R^2, for the regression analysis of wheat dough farinograms with different salt contents

Eq. \ Cf.	a	b	c	d	R^2	a	b	c	d	R^2
	FA-650 without salt					FA-650 with 0.4% salt				
Eq. 1	0.168	0.519	$-4.9\cdot10^3$	0.656	0.971	0.118	0.329	$-1.6\cdot10^5$	0.561	0.857
Eq. 2	$7.05\cdot10^3$	$4.8\cdot10^6$	4.659		0.972	492.92	127.6	1.453		0.980
Eq. 3	811.4	0.015			0.954	602.13	0.035			0.947
Eq. 4	811.5	66.562			0.954	602.02	28.530			0.948
Eq. 5	14.727	0.046	-0.005		0.957	13.671	0.021	0.002		0.985
Eq. 6	589.1	0.018			0.947	501.2	0.031			0.976
Eq. 7	41.878	0.535	$1.2\cdot10^{-4}$		0.971	19.616	0.857	$7.2\cdot10^{-3}$		0.984
	FA-650 with 0.8% salt					FA-650 with 1.2% salt				
Eq. 1	0.123	0.480	$-1.7\cdot10^4$	0.610	0.947	0.039	0.386	$-1.6\cdot10^6$	0.480	0.861
Eq. 2	693.8	998.7	2.378		0.957	524.6	106.5	1.264		0.982
Eq. 3	716.53	0.016			0.957	681.9	0.030			0.941
Eq. 4	716.52	63.914			0.957	681.8	32.948			0.941
Eq. 5	8.686	0.007	0.007		0.964	13.906	0.010	0.010		0.983
Eq. 6	530.32	0.018			0.961	543.4	0.030			0.967
Eq. 7	15.683	0.824	0.005		0.967	11.543	1.058	0.010		0.984
	FA-650 with 1.6% salt					FA-650 with 2% salt				
Eq. 1	0.186	0.387	$-6.1\cdot10^3$	0.693	0.918	0.150	0.448	$-3.0\cdot10^4$	0.576	0.952
Eq. 2	523.8	193.557	1.712		0.968	625.3	626.078	2.312		0.954
Eq. 3	664.8	0.026			0.963	687.4	0.020			0.951
Eq. 4	664.8	38.286			0.963	687.4	50.242			0.951
Eq. 5	12.159	0.003	0.016		0.977	10.971	$4.9\cdot10^{-4}$	0.020		0.949
Eq. 6	528.7	0.026			0.973	525.2	0.021			0.949
Eq. 7	19.472	0.840	0.007		0.980	29.175	0.669	0.0033		0.963

Values regression coefficients functions have different values, within the same mathematical model (eq.1-7), especially depending on the salt content added at kneading, but could not be evidenced a continuous variation (increasing or decreasing) of these values. Still, for a predetermined operating regime, also including added ingredients and their quantities, the process can be driven after shown models, until the formation and development of the dough (development phase of the farinographic curve). This way of driving the process relates primarily to the continued pursuit of consistency mixture and establishing kinematic regimes of kneading machine which follow growth curve trajectory of the dough (through mathematical relationship considered the optimal).

CONCLUSIONS

By analyzing the curves from Figures 1 and 2 and the data in Table 1 is found a corresponding correlation with experimental data with proposed regression functions to describe dough variation consistency during its formation and development (high values of the coefficient $R^2 \geq 0.918$).

Dough development time, and other parameters of farinographic curves, respectively rheological characteristics of dough, are influenced by the quality of flour and added ingredients, which is given corresponding by analyzes with farinograph. For mathematical modeling of the process of mixing and kneading bread dough, it is necessary to know privacy of process, variation in consistency with its basic parameters, and testing mathematically and statistically of data resulted from experimental measurements with specific devices.

The development phase of the wheat flour dough and his consistency variation during kneading can be mathematically analyzed with the aid of some functions as those proposed in the paper. This area of farinographic curve, completed by mathematical modeling to other areas of the curve, can lead to mathematical models whereby the kneading process can be automatically routed, through some software properly implemented.

The results and the conclusions from paper are relevant for specialists in the bakery industry, both for designers and builders of the kneading machines, and for those that actually work with such machinery on the technological flow of bread manufacturing and bakery products, to establish the optimum working regime, with reduced consumption of energy and materials, but with obtaining of top quality products.

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44. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

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Prethodno priopćenje
Preliminary communication

OPPORTUNITIES FOR THE SUSTAINABLE GREENHOUSE PRODUCTION ON SMALL-SCALE FAMILY FARMS IN SERBIA

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SUMMARY

In this paper a way of improving the greenhouse production on the small scale or family farms is presented. A new type of round shape greenhouse construction is introduced that should lead to more energy, economy and ecology efficient vegetable production. Energy efficiency of the spinach and tomato production in the round greenhouse was compared with common tunnel structure. Results show that, regardless the production surface restrictions, with this type of greenhouse construction financial and energy savings are possible together with the minimization of the plant protection chemical usage. If organic fertilizer is used this type of construction can lead to improved food safety production.

Key words: *round-shaped greenhouse, tunnel greenhouse, spinach, tomato, energy, energy productivity*

INTRODUCTION

Tomato is one of the most consumed vegetables in the human nutrition. It is used as fresh and, more often in form of sauces. Tomato has high nutrition value and it is rich in minerals and vitamins. World tomato production reaches 2.5 million hectares [1] while in Serbia, tomato is produced on 20 000 hectares [4] with the average yield of 8.3 t ha^{-1}. It is commonly grown in the open filed as well as in the greenhouses. In Serbia, greenhouse tomato production is mostly carried in the plastic tunnels without heating. This production enables two up to three weeks earlier harvesting if compared with the production in the open filed. If tomato is produced in the heated greenhouses harvesting can start in the April [7, 3]. Reasons why tomato is produced in the non heated greenhouses can be searched in high energy consumption [2, 9], high investments in the heating systems and investments in the high productive cultivars.

Spinach is also very common in the human nutrition due to its high nutritive value. It is commonly grown in the greenhouses having the yield of 5 to 25 t ha^{-1}, depending on the production technology. One of the most important characteristic of spinach is that in Serbia region you can find it on the market when market is not so rich in the fresh fruit and vegetables.

According to the farmers growing of spinach is highly profitable. Its price does not have very small oscillations during the year. The market is huge and current production in Serbia is not enough concerning the human consumption. If it is properly packed and labeled, it can present a significant export potential.

Research in the area of greenhouse construction and its influence on the energy consumption and energy efficiency in the tomato and lettuce production, show that the farmers need to use greenhouses with the higher production surfaces and higher specific volume in order to have optimal production parameters and better overall efficiency [5, 6, 3, 2]. Current economical situation in Serbia and, especially, in its rural regions urged a need of having a greenhouse construction and production technology that would be energy, ecology and economy beneficial for the producers on the small scale farms. The idea of the round-shaped greenhouse construction is not new [11, 10] but it was forgotten due to the previous mentioned reasons of having larger production surfaces. Researchers show that this type of greenhouse is energy efficient providing optimal production condition in sense of good light and temperature distribution which is very important in the winter period of year [7].

Concerning the fact that tomato and spinach are two in a lot of way different vegetables but also two most important vegetables in the human nutrition, the aim of this paper was to analyze the energy efficiency of their production in the open field and in the two greenhouse construction type, tunnel and round-shaped construction.

MATERIAL AND METHOD

Spinach production was analyzed in season 2010/11 while tomato production was analyzed for the 2011 summer season. The round-shaped greenhouse (Fig. 2) has its base diameter of 7 m while tunnel type greenhouse has its base of 5.5 x 24 m (Fig. 2). Both of the greenhouses were covered with PE UV IR 180 μm folia. Spinach was seeded in the rows with the inter-row distance was 20 cm. The used seed was Sacata variety. In the tunnel greenhouse tomato was planted with the 2.5 plants per m^2. Variety used was Big Bif. In the round-shaped greenhouse 0.78 plants per m^2 of Amati variety were planted.

For production conditions in greenhouse laboratory equipment from the Department for Agricultural Engineering, Faculty of Agriculture Belgrade was used. It consists of data loggers for measuring temperature and relative humidity as well as of the set of solarimeters. Air temperature was measured in the greenhouse and outside of greenhouse. For that purposes WatchDog Data Logger Model 110 Temp 8K, ±0,6° C was used. Temperatures were measured on the 2 m height in the three different points along the greenhouses. Measuring interval was 10 minutes. Air relative humidity was also measured outside and in the greenhouses. WatchDog Data Logger Model 150 Temp/RH, t = ±0,6° C and RH= ±3% was used. Measuring interval was also 10 minutes. For measuring the solar radiation energy WatchDog Data Logger Model 450 – Temp, Relative Humidity was used together with the two solarimeters that have measuring range 1–1250 W m^{-2} and precision of ±5%. Solar energy was also measured on the 2 m height and every 10 minutes.

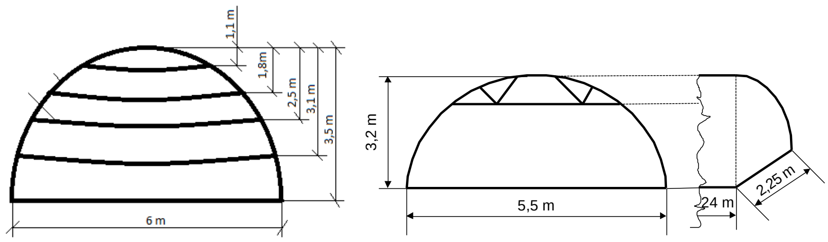

Figure 2 Tunnel and round-shaped greenhouse structure

Energy consumption and analysis were carried using the Ortiz-Chanavate methodology [6, 4, 8]. In this paper results of the microclimatic parameters were show and analyzed as well as the energy efficiency.

RESULTS AND DISCUSSION

Temperature and solar radiation measurements show that they are varying depending on the greenhouse construction.

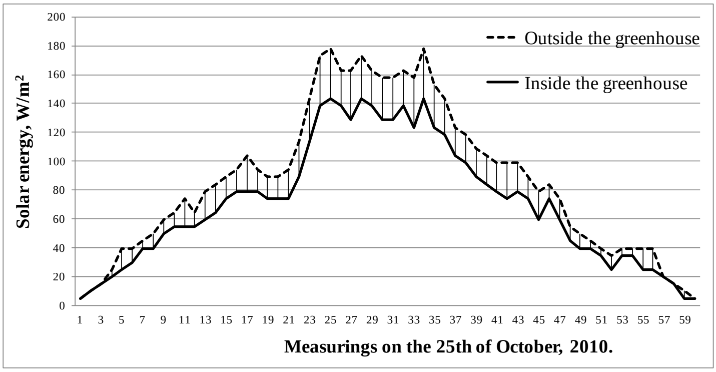

Figure 3 Solar radiation inside and outside the round type greenhouse in spinach production

Results show that the solar radiation variations during the day are smaller in the round-shaped greenhouse if compared with the tunnel structure. During the winter spinach production solar radiation energy losses in the tunnel structure were 29.38% while the round-shaped greenhouse was losing 19.51% of the solar radiation energy. Graphs 1 to 4 show daily oscillation in solar energy for the round-shaped and tunnel greenhouse during the spinach and tomato production.

It can be seen that with the round-shaped greenhouse construction differences in the outside and transited solar radiation inside the greenhouse are smaller. It can be concluded that this kind of construction has a faster “reaction” to the outside conditions. With the tunnel greenhouse construction it can be seen that these differences are larger and that even if solar radiation increases outside the greenhouse, construction needs some time to react.

During the tomato production similar tendencies were found. Solar radiation transmittance in the round-shaped greenhouse was, in average, 83.22% while in the tunnel structure 56.98% solar energy was transmitted inside the greenhouse.

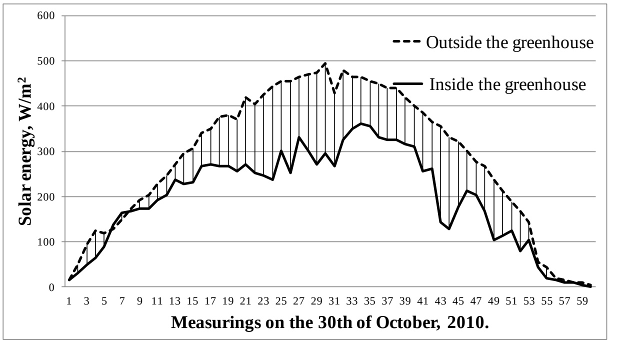

Figure 4 Solar radiation inside and outside the tunnel greenhouse in spinach production

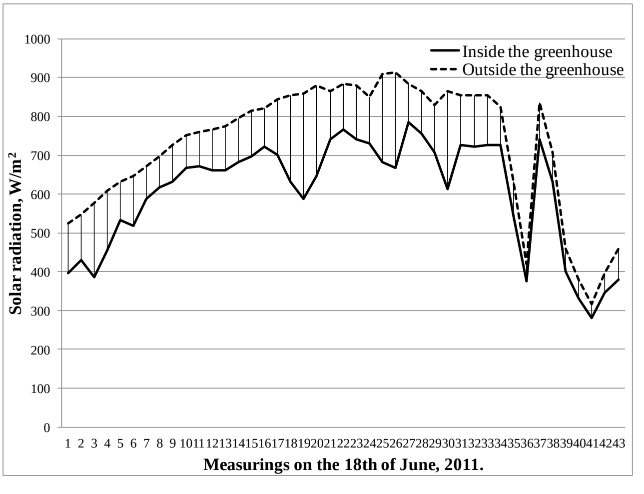

Figure 5 Solar radiation inside and outside the round type of greenhouse in tomato production

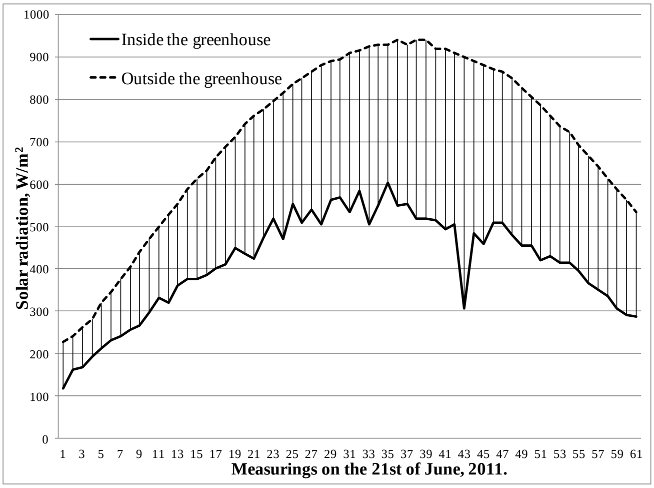

Figure 6 Solar radiation inside and outside the tunnel greenhouse in tomato production

Temperature measurements during the winter and summer production seasons show that there are differences in the production conditions in tunnel and round-shaped greenhouse. During the winter spinach production temperatures in both greenhouses were lower inside compared to the outside temperatures during the night and in the early morning hours. In the round-shaped construction greenhouse temperature difference between outside and inside air was 0.2 ^{0}C while in the tunnel greenhouse this difference was 0.6 ^{0}C. During the day air temperatures in the greenhouses were higher. In the round-shaped greenhouse this temperature difference was 6.5 ^{0}C while in the tunnel structure the difference was 7.35 ^{0}C. These differences are lower than 1 ^{0}C and are not considered to be important for the plants.

During the summer production temperature inside greenhouses were higher when compared with the temperatures outside the greenhouses during the day. During the night air temperature inside the greenhouses were lower if compared with the outside air temperatures. In the tunnel greenhouse night temperature difference was 0.73 ^{0}C while in the round-shaped greenhouse this deference was 0.06 ^{0}C.

Based on the presented results it can be said that round-shaped greenhouse construction can be suggested as energy beneficial in case of intensive plant production, such as tomato. Regarding the production conditions, ecology and production surface, round-shaped greenhouse construction can be proposed to small scale farmers as economically, energy and ecology beneficial solution.

CONCLUSIONS

Greenhouse production is one of the most intensive branches in agriculture. It is intensive in sense of high yields, year-around production and high energy consumption. Rural areas are in a very difficult situation in sense of economy and energy. The aim of this paper was to show the possibility of using simple and cost effective greenhouse construction that can ensure energy and economy sustainability of the small-scale family farms in the rural parts of Serbia.

The proposed round-shaped greenhouse construction showed good results regarding the production conditions in the winter production of spinach and summer tomato production. Concerning the energy sustainability this construction is good solution for summer tomato production. Reasons for lower energy efficiency in the winter production of spinach can be searched in the variety of spinach or in smaller quantities of fertilizer applied. Further research will be concentrated on energy analysis of different vegetables production in order to have a better picture of energy, ecology and economy feasibility of this kind of greenhouse construction in the vegetable production on the small-scale family farms.

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44. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

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Original scientific paper

NON-TRADITIONAL ENERGY PLANT PROPERTIES AND QUALITATIVE INDICATORS

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SUMMARY

Field and laboratory trials with non-traditional energy plants species – fibrous nettle, common mugwort (Artemisia vulgaris L.), cocksfoot grasses (Dactylis glomerata) and common mugwort-cocksfoot grasses mixture were carried out in Aleksandras Stulginskis University and the Lithuanian Research Centre for Agriculture and Forestry.

There were investigated plant biomass and energy productivity as well as biomass suitability for biofuel production in Lithuania. After energy plant chopping by drum chopper and milling by hummer mill was determined the fractional composition of plant chaff and mill on the sieves with holes of various diameters. The highest chaff fraction was accumulated on 8 mm and 16 mm diameter sieves (49.0-64.5 %), meanwhile the highest mill fraction was found on 2 mm sieves (33.5-51.9 %). The milled energy plants were granulated by a small capacity (100-120 kg h^{-1}) granulator with a horizontal granulator matrix, the diameter of the pellets was 6 mm.

After the pellets production their biometric parameters: dimensions, moisture content, volume and density, were evaluated. Investigated plant moisture content ranged from 10.0 % to 13.1 %. Cocksfoot grass pellets density was sufficiently high and reached 983.8±110.6 kg m^{-3} DM (dry matter), and the fibrous nettle density was lowest – 762.8±35.3 kg m^{-3} DM. The ash content of non-traditional energy plants ranged from 6.1 % to 7.0 %. Determined the net calorific value of plant dry mass increased from 17.5 KJ kg^{-1} (fibrous nettle) to 18.5 KJ kg^{-1} (common mugwort).

***Key words**: non-traditional plants, energy, biofuel, granules, properties, calorific value.*

INTRODUCTION

Energy crops wood, straw and other plant biomass is the most important renewable energy source in Europe and Lithuania and now account for a considerable share of local fuel. The start of biofuel production in Lithuania began in 1994 taking over the Scandinavian countries' experience in the boiler room fired with biofuels (chipped wood and sawdust) (Sakalauskas et al., 2012). Usage of these biofuels is particularly successful in those regions of the country where thermal energy was used to produce expensive and highly polluting fuel – fuel oil.

As a new industry, bio-fuels production in Lithuania has established itself in 1999, put into service on the larger-fired boiler plants. And nowadays various vegetable plant biomass are used for energy purposes: wood processing and logging wastes, by-product of agricultural production – straw, specially cultivated trees, tall grass, triticale and other unconventional energy plants – fibrous nettle, common mugwort (Artemisia vulgaris L.), cocksfoot grasses (*Dactylis glomerata*), etc. (Jasinskas et al., 2014; Biekša et al., 2007).

It is important to rapidly expand energy crop plantations, not only of woody but also perennial herbaceous plants (Verbickas et al., 2013). In the unused land areas, it would be purposeful to grow traditional, in Lithuania well-growing and well-adapted to the climate, used for animal feed herbs (preferably of *Poaceae* family). The most productive growing in Lithuania grass is reed canary grass, bromegrass, cocksfoot grasses, common mugwort, *festuca*. These plant species produce from 7.0 to 16.0 t ha^{-1} of dry biomass (Jasinskas et al., 2008). Overgrown or grass unused for feed (which accounts for about 15% of feed cultivated grass) and flooded meadow grass may be used for energy needs (Genutis, 2006).

For energy purpose can be used a well-known perennial herbaceous plant – nettle (*Urtica*). These plants can grow long in suitable spot and be productive for about 10 years. This plant grows like a weed in the bush, polluted areas, by the fence. Apart from stinging nettle (*Urtica dioica*), in Lithuania also grows stinging (*Urtica urens*) and hemp (*Urtica cannabina*) nettle (Jankauskiene, Gruzdeviene, 2010). These plants are propagated by seeds, root suckers and stem pieces (Johnson, 1992).

In the Lithuania, in Upyte testing station of the Lithuanian Research Centre for Agriculture and Forestry, studies on cultivation and propagation of fiber nettle have been performed since 2007 (Jankauskiene, Gruzdeviene, 2010). This plant is propagated by stem cuttings. Compared to flax, nettle fibre is thinner; due to its glossy appearance, it is often blended with other natural and synthetic fibres. Fiber content of nettle stems depends on the growth conditions (natural plant or specially produced). German, Austrian, British and Finnish researchers are very interested in usage of nettle fibre. Average stalk dry matter yields for fibrous nettle range from 3 to 4 t ha^{-1} (maximum 8 t ha^{-1}). Various researches to evaluate the use of nettle for energy needs have been conducted (Lewandowski et al., 2003; Vogl, 2003).

Orchard grass (*Dactylis glomerata*) is the herbaceous plant of *Poaceae* family of orchard grass (*Dactylis*). It grows in meadows, glades, outskirts, fertile soils (Christian et al., 2012). It is a perennial plant, forming large spells, which fully grow in the third year. Orchard grass is usually sown and cultivated in the cultural meadows. Grasslands are evaluated by their fertility and longevity, but these are not the only indicators. Herbs used in the production of feed are assessed according to their nutrition; mainly orchard grass is grown for animal feed preparation. Orchard grass wider use is unknown. Due to the high yield and nutritional indices, this grass is adapted for solid biofuel and biogas production (Jasinskas et al., 2008).

Next plant – common mugwort (*Artemisia vulgaris* L.) is *Asteraceae* family genus, this plant is common in Europe and the Mediterranean region. The genus contains about 250 species, and 11 kinds grow in Lithuania; widely used of them are wormwood (*A. abrotanum*), wormwood (*A. absinthium*), tawny (*A. campestris*) and Artemisia vulgaris *(A. vulgaris)* (Kryžiavičienė et al., 2010). In the US and Britain common mugwort are assigned to future plants due to their wide range of applications in the food industry and medicine (Common mugwort, 2014). Rich chemical composition of this genus determines its sufficiently high biomass combustion, which since ancient times has been observed in plants, fibrous materials are also found in these plants (Kryževičienė et al., 2010).

The aim of this work is to investigate the non-traditional plants: fibrous nettle, common mugwort (*Artemisia vulgaris* L.), cocksfoot grasses (*Dactylis glomerata*) and common mugwort-cocksfoot grasses mixture preparation and utilization for bio-fuels and to determine the properties and qualitative indicators of processed these plants.

MATERIALS AND METHODS

The chopping quality of non-traditional energy plant: fibrous nettle, common mugwort (*Artemisia vulgaris* L.), cocksfoot grasses (*Dactylis glomerata*) and common mugwort-cocksfoot grasses mixture (ratio 1:1) chaff, which is used for fuel, should satisfy the requirements of the combustion chamber, chopped mass transportation machinery and storage. During experimental research of non-traditional energy plant, the drum chopper of a *Maral 125* forage harvester was used (Kadžiulienė et al., 2014). The fractional composition of the chopped biomass from the drum chopper was determined using the standard methodology (Scholz, 2006; DD CEN/TS 15149-1:2006). The fractional composition of the chopped plants was determined using a set of 400 mm diameter sieves with round holes of diameters 63 mm, 45 mm, 16 mm, 8 mm, 3.15 mm and 1 mm. When sieving a 5 kg mass sample with a Haver EML Digital plus sieve shaker, a set of sieves on the horizontal surface is turned in semicircle for 2 minutes. The mass remaining on sieves is weighted, and the percentage of every fraction is calculated. Each test was repeated 5 times.

Before the production of biofuel pellets, the prepared chaff should be chopped to the form of the mill. A *Retsch SM 200* chaff mill was used for the milling.

The milling quality was determined analogously to the chaff fractional composition but using a set of 400 mm diameter sieves with smaller diameter holes: 0 mm, 0.25 mm, 05 mm, 0.63 mm, 1 mm and 2 mm. The mass remaining on the sieves was weighed, and the sample fraction percentages were calculated. Each test was repeated 5 times (DD CEN/TS 15149-1:2006).

The milled plants were granulated by a small capacity (100-120 kg h^{-1}) granulator with a horizontal granulator matrix. The diameter of the pellets was 6 mm. The mill was granulated in the traditional way: before the mill entered the granulator, the mill was mixed thoroughly to achieve homogeneity. Next, the raw material was moistened (if it was too dry for granulation), and the dosage unit was supplied to the press chamber, wherein the mill was moved by rollers through the matrix holes of 6 mm diameter. The biomass was pressed through holes to form pellets.

When the pellets were cooled, their ***biometric parameters***: dimensions, humidity, volume and density, were evaluated. The pellet parameters were determined by measuring their height and diameter (accurate to 0.05 mm). Experimental trials were randomly selected for each plant species with 10 pellets.

Pellets weight was assessed by KERN ABJ scales (accurate to 0.001 g). The weights were calculated for each type of plant using 10 of the granules with the average meaning the error.

Pellets moisture content was determined in a laboratory drying chamber oven according to the standard method (CEN/TC 14774-1:2005). The pellet volume was calculated using the pellet size (diameter and length).

Pellet density. The pellet volume was calculated using the pellet size (diameter and length). After determination of pellet mass and volume there are calculated their density. It also has been determined the bulk density of pellet, granules poured into 3 dm^3 container, weighing and calculating the bulk density (Niedziołka et al., 2015).

Pellets elementary composition, ash content and calorific value were determined at the Lithuanian Energy Institute (LEI) Thermal equipment research and testing laboratory in accordance with the valid Lithuania and EU countries standard methodology:

- using the basic elements analyser Flash 2000, Nr. 2011 F0055;
- according to LST EN 14774-1:2010 standard, in moisture test rig Nr. 8B/1;
- according to LST EN 14775:2010 standard, in ash content test rig Nr. 8B/5.

*Calorific value (*KJ kg^{-1}) of the plant chaff was determined by a C 2000 calorimeter (IKA, Germany) by the standard methodology (BS EN 14918:2009).

A three-way analysis of variance with three replications design was performed on the data of the following factors: cultivation year, soil pH and nitrogen rate, using analysis of variance (*ANOVA*) to determine significance at 95% probability level (LSD_{05}) (Tarakanovas et al., 2003).

RESULTS AND DISCUSSION

Plant chopping and milling quality. The fraction composition of the chopped non-traditional energy plants was determined by applying methodology common in EU countries. It was performed using sieves with holes of various diameters. The highest chaff fraction was accumulated on 8 mm and 16 mm diameter sieves (49.0-64.5%).

For preparation plant chaff to the pellet production there were produced the mill and determined the mill fraction composition of non-traditional energy plant.

Determined fractional composition of the fibrous nettle mill is presented in Fig. 1.

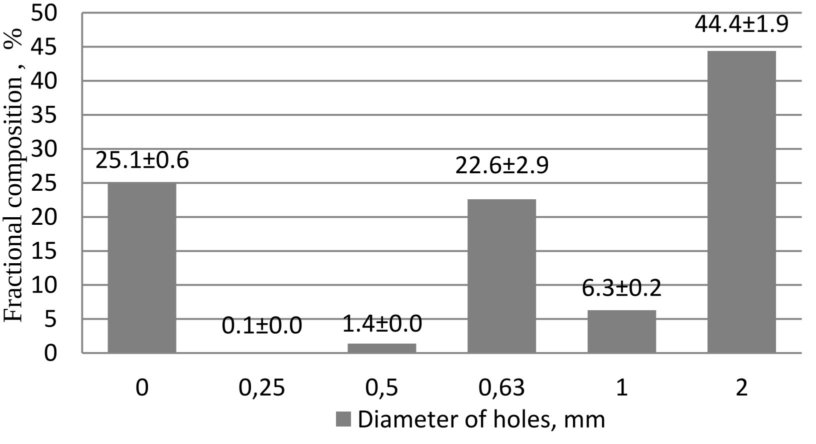

Fig. 1 The dependence of the fibrous nettle mill fractional composition on the sieve holes

After evaluation of the fibrous nettle mill fractional composition it was found, that the highest mill fraction was accumulated on the 2 mm holes sieve – 44.4±1.9 %. The lowest fraction of mill was accumulated on the sieves with 0.25 mm holes – only 0.1 %.

Determined fractional composition of the common mugwort mill is presented in Fig. 2.

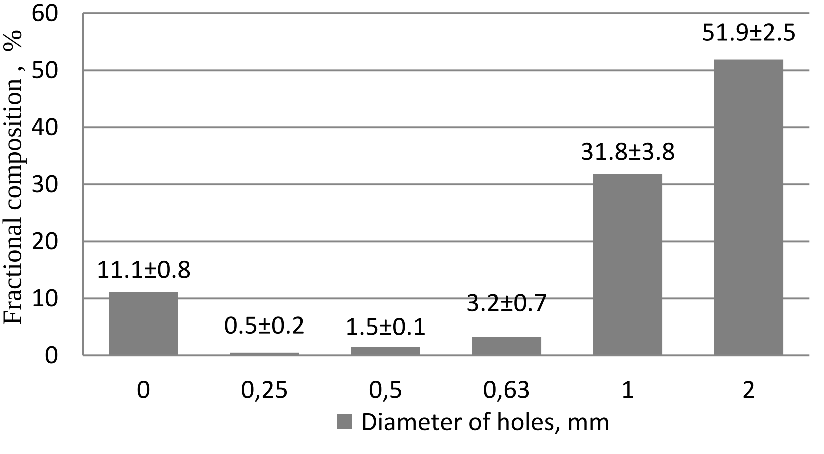

Fig. 2 The dependence of the common mugwort mill fractional composition on the sieve holes

After assessment of the common mugwort fractional composition, it was determined that the largest fraction of the mill was accumulated on the 2 mm sieve holes – 51.9±2.5 %. A smaller fraction of mill was accumulated on the sieve with 1 mm holes – 31.8±3.8 %, and the lowest fraction of mill was accumulated on the sieves with 0.25 mm holes – 0.5±0.2 %.

Established fractional composition of the cocksfoot grasses mill is presented in Fig. 3.

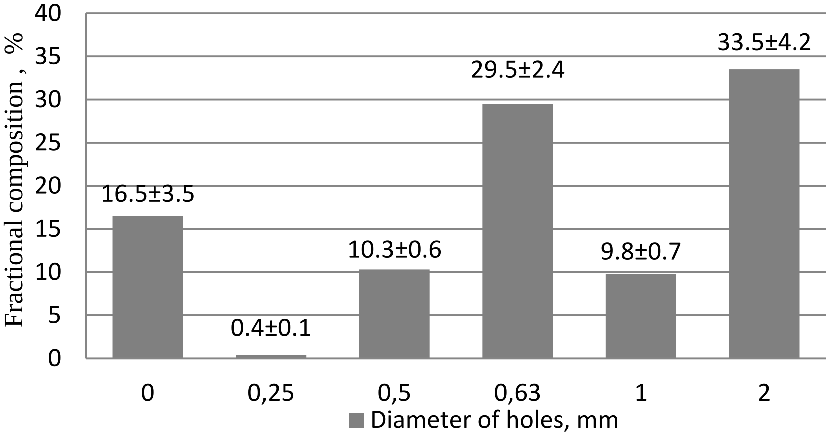

Fig. 3 The dependence of the cocksfoot grasses mill fractional composition on the sieve holes

After evaluation of the cocksfoot grasses mill fractional composition it was found, that the highest mill fraction also was accumulated on the 2 mm holes sieve – 33.5±4.2 %, and significantly less fraction of mill was accumulated on the sieves with 0.65 mm holes – 29.5±2.4 %. The lowest fraction of mill was accumulated on the sieves with 0.25 mm holes – 0.4±0.1 %.

Summarizing the evaluation of non-traditional energy plants milling quality results it can be stated that the highest mill fraction was accumulated on the 2 mm holes sieve – 33.5-51.9 %, and the lowest mill fraction was accumulated on the sieves with 0.25 mm holes – only 0.1-0.5 %.

The milled non-traditional plants were granulated by a small capacity (100-120 kg h^{-1}) granulator, the diameter of pellets was 6 mm. All main properties of produced pellets were investigated.

Non-traditional energy plant pellet biometrical properties: Moisture content has a great influence on biofuel heating values. Dry raw materials with the moisture content up to 15 % should be used for pellet production. Moisture content affects energetic indicators of pellets, combustion efficiency and calorific value. Therefore, it is necessary to estimate biofuel‘s humidity.

Research has shown that moisture content of different types of pellets vary from each other, even if storage conditions of pellets were the same. The obtained moisture content of pellets is shown in Table 1. According to the presented in table data it may be stated that the highest moisture content is in fibrous nettle pellets – 13.1 %, and the lowest is in cocksfoot grass pellets – 10 %. Assessing the moisture content of the pellets it appears that fibrous nettle pellets do not fully meet the requirements for production. The recommended humidity of pellets used for fuel should not exceed 12 % (Sakalauskas et al., 2012).

Weight of pellets has also been determined, and the pellets' volume, density and dry matter content were calculated. The results of the computed values are presented in Table 1.

Table 1 Physical properties of non-traditional energy plant pellets

Plant sort	Pellet parameters			
	The sample average moisture content, %	Mass, g	Volume, m^3	Density, kg m^{-3}
Fibrous nettle	13.1 ± 1.3	0.67	$7.66 \cdot 10^{-6}$	877.8±40.6 (762.8±35.3 DM)
Common mugwort	11.6 ± 0.4	0.75	7.04·10-6	1048.3±41.3 (926.7±36.5 DM)
Cocksfoot grass	10.0 ± 6.4	0.85	7.61·10-6	1093.5±122.9 (983.8±110.6 DM)
Common mugwort +Cocksfoot grass	10.8 ± 3.2	0.80	7.32·10-6	1070.5±82.1 (955.2±73.2 DM)

After investigations of *pellet density* it is determined, that the highest density is of cocksfoot grass pellets – 983.8 kg m^{-3} DM (dry matter), with small variation is the mixture (common mugwort +cocksfoot grass) and common mugwort pellet density – 955.2 and 926.7 kg m^{-3} DM, and the lowest density is of fibrous nettle pellets – 762.8 kg m^{-3} DM (Table 2).

The set bulk density of fibrous nettle pellets is the lowest – 385.0 kg m^{-3} DM, the highest bulk density is of cocksfoot grass – 419.0 kg m^{-3} DM.

Pellet elemental composition, ash content and calorific value: The non-traditional plant pellet elemental composition analysis showed a similar C (carbon) content of 45.7-48.4 %, H (hydrogen) content of more than 5.5 %, and other chemicals composition of N (nitrogen) and S (sulphur) small in volume % (Table 2).

The ash content of all the tested plants was not high and it amounted to 6.1-7.0 %, which was similar to that of traditional herbal plants and straw ash content. The fibrous nettle and cocksfoot grass ash content was the highest and reached 7 %. The high ash content indicates that these plant pellets insufficiently burned, and compared with other investigated non-conventional energy plants, their calorific value was also lower – 17.5-17.7 MJ kg^{-1}.

The highest calorific value was of the common mugwort – 18.5 MJ kg^{-1}. So high calorific value of common mugwort show, that according to the thermal properties this plant is equivalent to the woody plants and wood (Jasinskas et al., 2008).

Presented research results suggest that investigated non-traditional plants can be used as a solid biofuel; its main parameters satisfy the requirements for solid biofuels.

Table 2 Pellet elemental composition, ash content and calorific value

Parameters	Value	Deviation, ± %
Fibrous nettle		
C (carbon) content, %	45.76	1.13
H (hydrogen) content, %	5.60	0.46
N (nitrogen) content, %	0.87	0.31
S (sulphur) content, %	0.10	0.27
O (oxygen) content, %	32.26	-
Ash content, %	6.93	0.13
Calorific value, MJ kg^{-1} (DM)	17.48	1.04
Common mugwort		
C (carbon) content, %	48.41	1.36
H (hydrogen) content, %	5.59	0.53
N (nitrogen) content, %	1.14	0.37
S (sulphur) content, %	0.12	0.27
O (oxygen) content, %	38.57	-
Ash content, %	6.17	0.08
Calorific value, MJ kg^{-1} (DM)	18.46	0.67
Cocksfoot grass		
C (carbon) content, %	46.40	1.19
H (hydrogen) content, %	5.76	0.45
N (nitrogen) content, %	1.40	0.33
S (sulphur) content, %	0.12	0.27
O (oxygen) content, %	39.30	-
Ash content, %	7.02	0.05
Calorific value, MJ kg^{-1} (DM)	17.74	0.73
Common mugwort +Cocksfoot grass		
C (carbon) content, %	47.04	0.11
H (hydrogen) content, %	5.65	0.45
N (nitrogen) content, %	1.24	0.33
S (sulphur) content, %	0.14	0.27
O (oxygen) content, %	39.86	-
Ash content, %	6.07	0.18
Calorific value, MJ kg^{-1} (DM)	18.00	0.71

CONCLUSIONS

1. There were investigated non-traditional energy plants – fibrous nettle, common mugwort, cocksfoot grasses and common mugwort-cocksfoot grasses mixture, properties and plant biomass suitability for biofuel production.
2. After energy plant chopping and milling was determined the fractional composition of plant chaff and mill. The highest chaff fraction was accumulated on 8 mm and 16 mm diameter sieves (49.0-64.5 %), and the highest mill fraction was found on 2 mm sieves (33.5-51.9 %).
3. The milled energy plants were granulated to the 6 mm diameter pellets by a small capacity (100-120 kg h^{-1}) granulator and there were evaluated pellets biometric parameters: dimensions, moisture content, volume, density.
4. Investigated plant moisture content ranged from 10.0 % to 13.1 %. Cocksfoot grass pellets density was sufficiently high and reached 983.8±110.6 kg m^{-3} DM (dry matter), and the fibrous nettle density was lowest – 762.8±35.3 kg m^{-3} DM.
5. The ash content of non-traditional energy plants ranged from 6.1 % to 7.0 %. Determined the net calorific value of plant dry mass increased from 17.5 KJ kg^{-1} (fibrous nettle) to 18.5 KJ kg^{-1} (common mugwort).
6. Investigated non-traditional energy plants can be used as a solid biofuel, because its main parameters satisfy the requirements for solid biofuels.

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44. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

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SLOW PYROLYSIS PROCESS IN THE CASE OF ENERGETIC WILLOW FROM BANAT REGION

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SUMMARY

The paper presents the results of pyrolysis process in the case of energetic willow using thermo gravimetric experiments. Experiments were conducted on a fixed bed pyrolysis reactor, under different conditions, temperatures ranging from 20 ºC to 800 ºC and heating rates from 10 ºC x min^{-1} to 65 ºC x min^{-1}. The pyrolysis reactor is equipped with a thermo balancer to analyze the thermal decomposition of energetic willow and his individual kinetic parameters. Three important parameters: activation energies, frequency factor and reaction order, have been determined using a mathematical method. To calculate the Differential Thermo gravimetric data was used a non-linear square fitting. Measured results on slow pyrolysis are compared with values from different biomass species from literature. Results of the analysis will be applied for designing an equipment used in industrial application based on slow pyrolysis.

Key words: *slow pyrolysis, thermo gravimetric method, willow, kinetics.*

INTRODUCTION

One of the most used resource for renewable energy is biomass, with the highest potential towards sustainable development in the near future [8], thanks to its special advantages. To exploit the full potential of this energy source, new approaches and modern technologies are needed.

For Romania, the biomass is also interesting, according with the national potential of renewable energy estimated, based on the evaluation presented in the National Action Plan for Renewable Energy (PNAER), which is presented in the table 1[9].

Results a biomass potential evaluated as more than 50% from the total potential of renewable energy recourses evaluated in Romania, also representing more than the expected target of energy from renewable sources, corresponding to 2020 for Romania [9].

From another approach, the co-generation - heat and electricity - using biomass could improve the social-economic benefits in the rural-agricultural environment [5].

Unfortunately, in underdeveloped countries - rural areas, the most important renewable fuel is wood, and represents a significant proportion as source for house heating. Such situation could be changed using other unexploited biomass resources which can be converted and used as fuel: agricultural residues - such as wheat straw, corn cobs, rice hulls, coconut, energetic plants, residues from forest and wood exploitation etc.

Table 1 National potential of renewable energy estimated in Romania

Energy renewable source	Annual energetic potential	Field of application
Thermal solar energy	$60*10^6$ GJ	Thermal energy
Photovoltaic solar energy	1200 GWh	Electrical energy
Wind energy	23000 GWh	Electrical energy
Hydro energy	46000 GWh	Electrical energy
Biomass	$318 *10^6$ GJ	Thermal energy
Geothermal energy	$7* 10^6$ GJ	Thermal energy

This paper proposes the use of pyrolysis as method for small conversion technology for biomass, especially residues and stems from willow cultures, starting at its energy efficiency and the important advantage that gas, liquid fuels and solid char formed, being easy to store and to transport.

There are two main pyrolysis processes: rapid pyrolysis, and slow pyrolysis for active carbon preparation [5] (used in present paper).

Rapid pyrolysis at high temperature is the first step in gasification or combustion of biomass in fluidized bed reactors [7].

As the reaction progresses the carbon becomes less reactive and forms stable chemical structures, and consequently the activation energy increases as the conversion level of biomass increases [1], [4], [3].

METHOD

The study supposed a methodology based on experimental work in laboratory and scientific analysis by using statistical and mathematical methods.

The experiments were made in Laboratories of Institute of Agricultural Engineering from the Faculty of Life Sciences and Technology – Wroclaw University of Environmental and Life Sciences, April - June 2015.

Material: willow from Ghilad, Timis County, Romania, Inge variety, 3 years old, grinded at 3,2 mm medium diameter.

Figure 1 presents, using simple block diagram, the slow pyrolysis equipment, used for thermogravimetry determination in order to provide useful analytical data in the form of Thermogravimetric Analyze (TGA) Curve.

The main components of the experimental stand from laboratory are: 1- Balancer; 2-Furnace (heating device); 3-Unit for temperature measurement and control (Programmer); 4-Recorder (automatic recording unit for the mass changes); 5- Inert gas; 6-Flow meter; 7-Regulator (regulation of the pressure and flow of the inert gas); 8-Temperature sensor; 9-Fume cupboard; 10-Sample container; 11- Computer.

The stainless steel tube or pyrolyzer was externally heated in the electrical muffle furnace. During the pyrolysis process, temperature and mass lost were continuously measured and recorded on the computer to obtain data for kinetic study. The hot gasses released in the process, raised up and led out of the reactor, being extracted from the laboratory through a ventilated fume cupboard. Once the experiment reached the terminal temperature, it was maintained for 20 minutes until no further significant lost of weight and release of gas was observed.

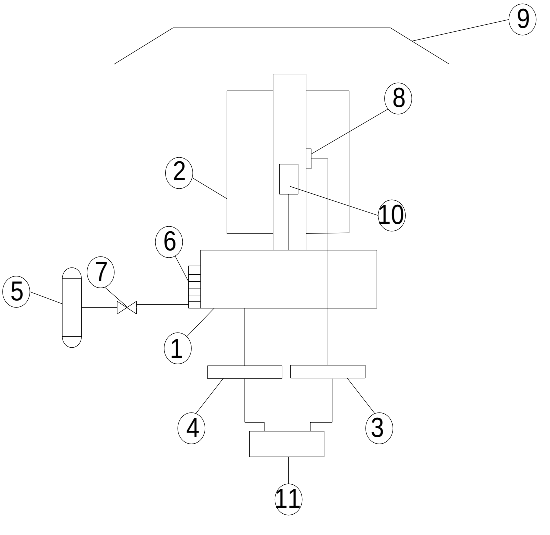

Figure 1 Pyrolysis equipment (block diagram)

The crops from willow plantation used in this study, were dried to insure a higher efficacy of heating process during pyrolysis.

Firstly, it was necessary to study the characteristics and components of biomass samples in order to establish if they are suitable for pyrolysis. For a high efficiency of pyrolysis process is important to introduce in the system feedstock with high volatile matter content, low ash and sulfur content [2].

For determination of four important elements of biomass samples (moisture, volatile, carbon and ash content), was used the thermobalancer. Using the recommendations of ASTM E1131 normative for temperature programming, the following steps were applied: a sample of 1.2 g was introduced in to the furnace under following conditions of temperature, heating rate and time:

- For moisture content determination, the samples were heated from room temperature up to 110 °C, with 15 minutes holding time, under inert atmosphere (90 mL min^{-1});
- For volatiles determination, the temperature was raised from 110 °C up to 600 °C and an isothermal of 30 min was applied, under inert atmosphere (90 mL min^{-1}).

In both steps, the same heating rate is maintained (50°C* min-1).

Once a mass loss plateau is established, the furnace environment is switched from inert to air atmosphere for 30 min, resulting the carbon content.

The results from the proximate were presented in weight percentage on moisture free basis (mf wt. %).

The moisture, volatile and fixed carbon content where calculated using Eq. 1,2,3, as shown below:

$$\text{MO (mf wt. \%)} = (m - m_{tMO}) \text{ x } m^{-1} \text{ x } 100 \quad (1)$$

$$\text{VM (mf wt. \%)} = (m_{tMO} - m_{tVO}) \text{ x } m^{-1} \text{ x } 100 \quad (2)$$

$$\text{FC (mf wt. \%)} = (m_{tVO} - m_{tFC}) \text{ / x } m^{-1} \text{ x } 100 \quad (3)$$

Nomenclature:

MO – moisture, [%]	m - initial mass, [g]
FC - fixed carbon content, [%]	m_{tMO} - mass at final temperature for MO, [g]
VM - volatile matter, [%]	m_{tVO} - mass at final temperature for VO, [g]
AC - ash content, [%]	m_{tF} - mass at final temperature for FC, [g].

Thermogravimetric and differential thermogravimetric analysis (TGA/DTG) were carried out using 1.2 (± 0.5) g of raw biomass sample.

The experiments were performed at following different heating rates: 10 °C/min, 20°C/min, 40 °C/min, 65 °C/min, from room temperature up to 800 °C, in inert atmosphere.

(DTG is the first derivate o TGA, and was determinate as a function of mass lost in period of time with the following equation:

$$F(x) = \frac{x_i - x_{i-1}}{t_{i+1} - t_i}$$

where i = 1,n number of data readings; x_i –mass measured; t_i – time from start of experiment till i determination).

Based on resulted data, TGA and DTG graphics were represented in the case of willow, Inge variety, from Banat Area.

According to Ozawa method [6], mechanism to calculate the activation energy is related to heating rate and temperature for a constant degree of conversion (details in reference 6).

Value of activation energy is obtained from the the slope of the graphic represented between 1/T (T represents temperature, [K]), and lnβ (were β represents the heating rate, [K $*s^{-1}$]).

RESULTS AND DISSCUTION

Proximate analysis was performed to measure the moisture, volatile matter, fixed carbon and ash contained in the feedstock.

Table 2 Proximate analysis

Proximate analysis	Value (% dry basis)
Moisture	8.91
Fixed carbon content	19.80
Volatile	67.32
Ash	3.96

The graphic analyze for thermogravimetric (TG) and differential thermogravimetric analysis (DTG), are present in figure 2, respectively figure 3.

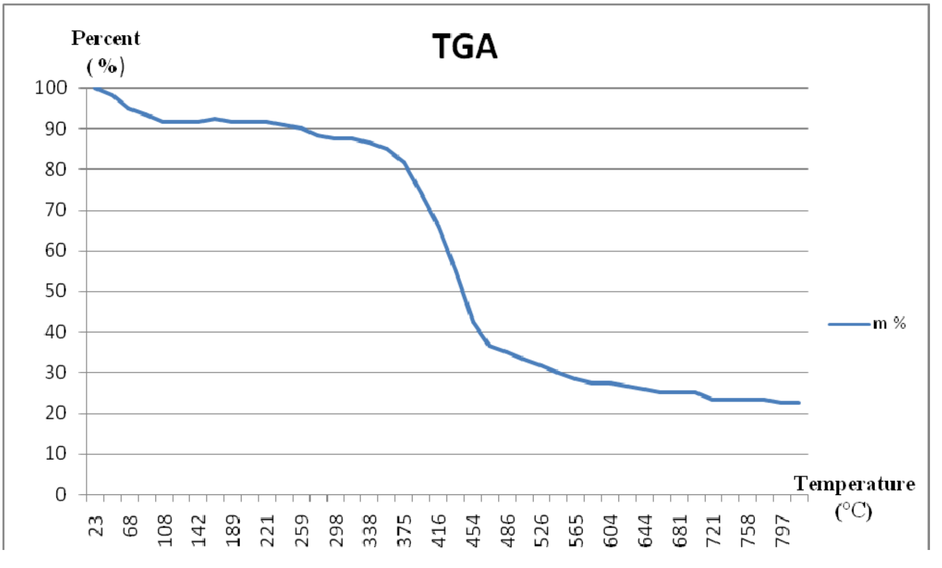

Figure 2 TG analysis

Dependence for Value of activation energy, and regression equation (graphic and formula), are presented in figure 4,.

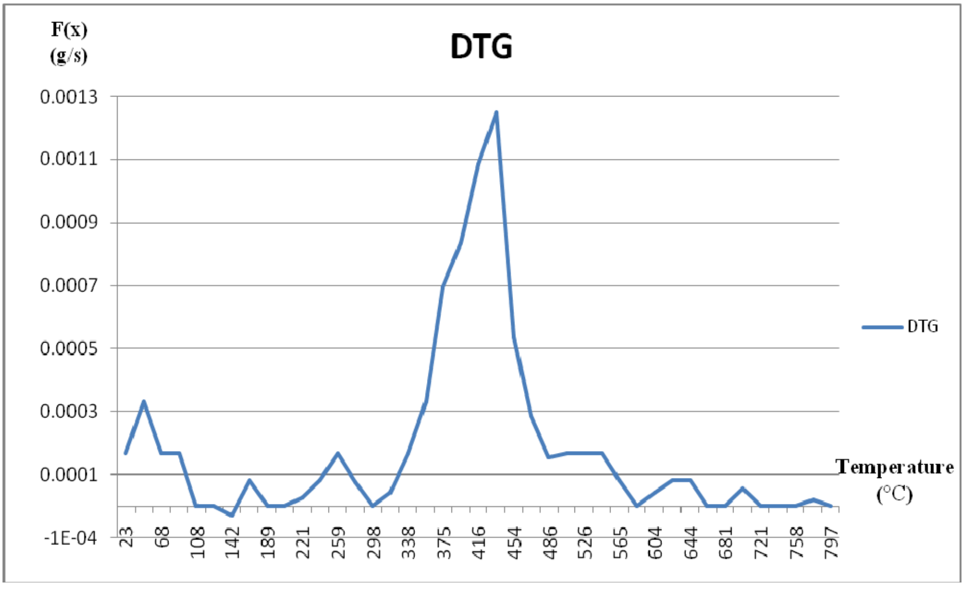

Figure 3 DTG analysis

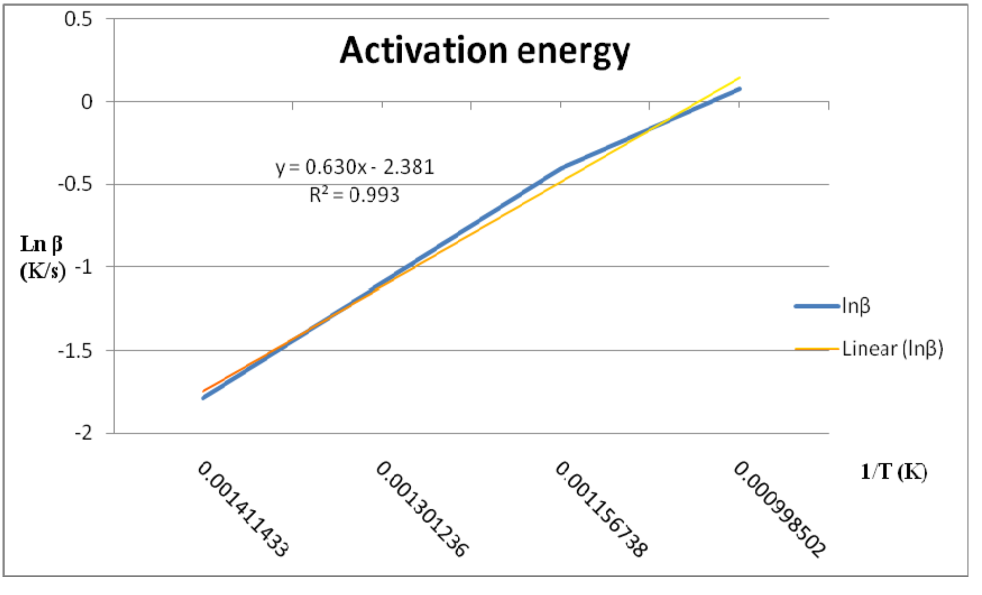

Figure 4 Activation energy

CONCLUSIONS

Present paper proposed to study kinetic aspects of pyrolysis process regarding the possibilities to convert energetic willow in char, bio-oil and syngas, to give an alternative for valorising the energetic willow from Romania.

The fixed-bed pyrolysis experiments in this study tested biomass feedstocks and variable process parameter. Given the results from the proximate analysis, we can assume that structure of energetic willow is similar with other biomass materials, showing a high percent of volatile component, that facilities the conversion in pyrolysis process.

The activation energy was determined usig the Ozawa method, obtaining values between 38 and 52 kJ*mol^{-1}.

However beside the activation energy, drying, grinding and operational consumptions for pyrolysis process, must be estimated to determin conversion efficency of energetic willow into bio-products.

Based on present results, next step of the researches will be designing of equipment, manufacturing and testing pilot plant.

ACKNOWLEDGEMENTS

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44. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

UDC 582.5:630
Stručni rad
Expert paper

SOME SPECIFIC ASPECTS OF AGRICULTURAL TECHNOLOGY AND THE BIO-ECONOMY FOR THE TREE *PAULOWNIA*

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ABSTRACT

The Paulownia tree is known for exceptional growth performance, being appreciated as a revolutionary and multifunctional tree. The analysis includes some experiments realized in Romania for to observe both the peculiarities of cultivation and some different applications. It presents some results after the research on agro-technology of this tree cultivation and crop management. Also are presented some results on the possibilities of capitalizing on young plants (first 2-3 years) and the mature tree (after 8-10 years). A greater emphasis is placed on the possibility of energy recovery plant on the growth steps. The paper shows a complex state of the Paulownia tree bio-economy especially as bio-energetic resource.

Key words: *Paulownia tree, agro-technology, crop, bio-economy, capitalization*

INTRODUCTION

Currently, a lot of researches on human development based on the advancement of knowledge always bring in attention the need for the efficient use of natural resources. Paulownia tree has the best capacity of growing, and represent a very important resource, both bioenergetics and environmental, untapped in the European countries. In just 3/5 years reach maturity, and it can reach a height about 20 m. Also, the quality of wood offers to the Paulownia tree, the reputation: „*the tree of the future*" [20, 21, 22]. *Paulownia* is a tree with a genus of between 20–23 species (depending on the taxonomic authority) from the monogenetic family *Paulowniaceae*, related to and sometimes included in the *Scrophulariaceae*. *Paulownia* is a genus of Asian hardwood trees native of China and which have been cultivated there for the past 3000 years (Bergmann, 1997). The genus was named in honor of Queen Anna Pavlovna from The Netherlands (1795–1865), daughter of Tsar Paul I of

Russia. Due to its relatively rapid rate of growth *Paulownia* is still relatively undeveloped as a crop species. However, over the late 1980's and 1990's *Paulownia* has been attracting more interest [20], especially in Asia and USA, and in last 3 years that phenomena has begun also in Romania. For the developing of a new culture in Europe requires both strengthening technological knowledge and a study on it bio-economy.

The term of *bio-economy* is known since the early 20th century, when this was used by the biologists T.I. Baranov and Gr. Antipa, for to describe the analysis of production dynamics in ecosystems. Also, N. Georgescu-Roegen, at the early 70s of the 20th century use this term for to describe the biological origin of the economic processes by developing a „plan bio-economic", but it was an example of progressive thinking [16]. Generally, the "*bio-economy*" is an economy based on an intelligent use of land and sea resources, biological sources as raw materials for food and feed and industrial production and energy, where the basic building blocks for materials, chemicals and energy are derived from renewable biological resources [1]. It also includes the use of ecological processes for sustainable industries. For example, bio-waste has considerable potential as an alternative to chemical fertilizers or for conversion to bioenergy [2, 18, 19].

The Europe 2020 Strategy calls for a *bio-economy* as a key element for smart and green growth in Europe, for improving the management of its renewable biological resources and to open new and diversified markets in food and bio-based products. The establishing a bio-economy in Europe holds a great potential, and create an economic growth and jobs in rural, coastal and industrial areas, reduce fossil fuel dependence and improve the economic and environmental sustainability of primary production and processing industries [3].

The *bio-economy* thus contributes significantly to the objectives of the Europe 2020 flagship initiatives "*Innovation Union*" and "*A Resource Efficient Europe*". It is necessary to make o lot of investment in knowledge, innovation and skills [6, 19]. That fore the *bio-economy* requires continued and increasing support from public funding and private investment and must contribute to better coherence between national, European and global research and innovation efforts [9]. The bio-refineries replace these fossil resources by renewable ones (including wastes), creating new sources of income and jobs for the agriculture, forestry, fisheries and aquaculture sectors. Bio-based products and bioenergy can be "bio-based versions" of traditional products or novel products with entirely new and innovative functionalities and potential for new and existing markets [6, 11]. The principal products of the bio-economy are bio-based products and bioenergy, while the fundamental technology, which will be introduced to replace petroleum-based refineries, is known as bio refineries [14]. First generation biofuels are made from food crops, such as wheat, sugar beet and oil seeds, while second generation biofuels are based on non-food biomass, such as lignocellulosic materials, including cereal straw and maize stalks [14, 17]. Also, the *bio-economy* is defined by the EC in its policy package as "*the production of renewable biological resources and the conversion of these resources and waste streams into value added products, such as food, feed, bio-based products and bioenergy*" [13, 14, 18]. The success of the *bio-economy* will likely depend on active engagement both in policy formulation and specific projects. While there is an increasing effort on research and development, the deployment of technologies is critical to making the advanced *bio-economy* a reality [7].

In the European Union the bio-economy encompasses the sustainable production of renewable biological resources and their conversion and that of waste streams into food, feed, bio-based products [1] such as bioplastics, biofuels and bioenergy. Its sectors have a strong innovation potential due to their use of a wide range of sciences (life sciences, agronomy, ecology, food science and social sciences), enabling industrial technologies (biotechnology, nanotechnology, information and communication technologies (ICT), and engineering), as well as local and tacit knowledge [2, 8, 18].

The EU bio-economy already has a turnover of nearly €2 trillion and employs more than 22 million people, 9% of total employment in the EU (see Table 1). It includes agriculture, forestry, fisheries, food and pulp and paper production, as well as parts of chemical, biotechnological and energy industries [1].

Table 1 The bio-economy in the European Union

Sector	Annual turnover (billion €)	Employment (thousands)	Data source
Food	965	4400	CIAA
Agriculture	381	12000	COPA-COGECA, Eurostat
Paper/Pulp	375	1800	CEPI
Forestry/Wood ind.	**269**	**3000**	**CEI-BOIS**
Fisheries and Aquaculture	32	500	EC***
Bio-based industries			
Bio-chemicals and plastics	50 (estimation*)	150 (estimation*)	USDA, Arthur D Little, Festel, McKinsey, CEFIC
Enzymes	0.8 (estimation*)	5 (estimation*)	Amfep, Novozymes, Danisco/Genencor, DSM
Biofuels	6**	150	EBB, eBio
Total	**2078**	**22005**	

*Estimation for Europe for 2009;
**Estimation based on a production of 2.2 million tonnes bioethanol and 7.7 million tons of biodiesel at average market price in Europe;
***EC, Facts and figures on the CFP, Basic Statistics Data, ISSN 1830-9119, 2010 Edition [5].

A broadly-based European research has been developing many innovative ways in which wood-derived fibers and forestry by-products could replace some petro-chemicals products, in a wide array of products [22].

In this case, it is considered appropriate to investigate the most productive species of trees that can bring a beneficial effect, in same time for the bio-economy from communities local and/or regional. In this category may fall this study about the Paulownia tree, with some results summarized in this paper.

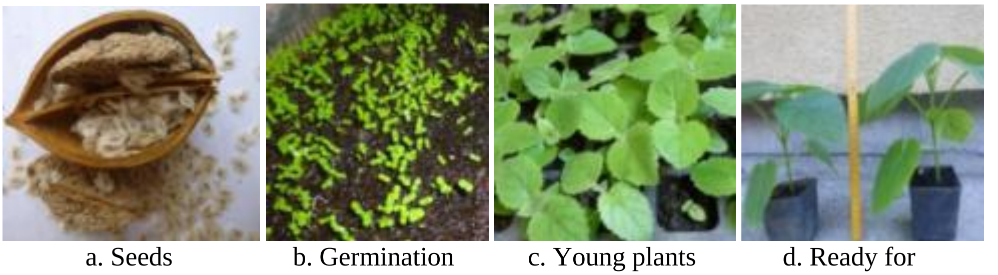
METHODS

The first year (2012), the survey was oriented to investigate the entire forest found from Timis County, where it were identified 12 trees from Paulownia family, recommended and planted just as ornamental trees, unknown being the other features. After a visual analysis of their specific characteristics, it was been recognized three species known in the literature (out of 32 known on the globe) *Tomentosa*, *Elongata*, and a combined species, Paulownia hybrid, better adapted for the Romanian climatic conditions. From the last category it was selected a tree reached full maturity (11 years), with the largest tree size and performance. From this tree were collected over 100 seed capsules. This specimen was discovered in Timisoara, in a private garden, where it was used only as an ornamental tree.

In the second year, (2013), in relation to how the creation of a plantation, this study addresses 3 variants:

Development of Paulownia plants from seeds.

Seeing as high growth rate, were collected seeds from an adult Paulownia tree and these was germinated, and after that was planted. From a capsule can result in up to 2,000 seeds. Were put seeds in the ground in late March, and after 5 months having a height of about 25-30 cm, were ready to be planted (Figure 1).



a. Seeds b. Germination c. Young plants d. Ready for cultivation

Figure 1 Development of Paulownia plants from seeds.

Development of plants from pieces of root

On the land where, in February 2014, it was cut, a mature tree (11 years old), during May-June over 30 seedlings sprouted from small pieces of root. (Example in Figure 2, a.) The seedlings replanted in the pots in 4 months were increased to 50-70 cm (Figure 2, b). Those who remained in the soil had a strong increase up to 3-4 m (Figure 2, c).

a. plant rises from the piece of root b. replanted in pots c. increased without replanting

Figure 2 Development of plants from pieces of root

Development of plants from the root, in the second year after cutting of the green stem.

a. April 2014 b. July 2014 c. July 2014 d. October 2014

Figure 3 Development of plants from the roots, in the second year, after cutting of the green stem

Very good results have been obtained using the procedure by cutting the stem green in the second year when the plant results also from the root (Figure 3).

After four months the plant has risen to 4.5 m, with a stem diameter more than 15 cm.

a. Pieces of branches and stems **b**. Petiole pieces and limb of Paulownia in the second year II year

Figure 4 Exploitation of green plants

For to study the valorization aspects, are considered two ways:

1. - Exploitation of green plants
2. - Exploitation of adult Paulownia tree wood.

In the first case the green biomass can be to the basis for obtaining: bioethanol, biogas and / or fertilizer for soil. It was determined the amount of green biomass 25-30 kg / year, can be obtained from a plant.

For to study the possibility of capitalization of Paulownia was cut an tree which after 11 years has reached a height of 14 m and a diameter at the base was 82 cm. It was resulted a volume of timber over 2 m^3 for and another 2.5 m^3 (included the roots), for sawn wood for pellets or chips good for burning.

a. Cutting of an adult Paulownia tree (11 years) b. tree trunk section c. Sawdust

Figure 5 Exploitation of adult Paulownia tree wood

It was tested and the ignition temperature of wood timber, resulting a temperature of about 380-400^0 C, favorable characteristics for using this wood for construction of houses.

RESULTS AND DISCUSSION

These results attest to the undeniable Paulownia tree, both in economic terms and the role they can play in raising of the environmental quality. For to design the structure of the bio-economy on development of the cultivation of the Paulownia tree in Romania, with further expansion throughout Europe, joins this results to other considerations of another specialists.

It was considered three scenarios to exploit the Paulownia tree:

A. Harnessing as the green table
B. Dry biomass recovery
C. Exploitation of mixed crops

Harnessing as the green table

The Paulownia leafs is rich sugar production in warm conditions. The potential of the leaves as an ensiled fodder crop may warrant investigation, perhaps in mini-silos. When the leaves fall, they can be a valuable source of organic matter and nutrients for the soil and can also be used for compost [22].

Thicker plantations allowing many stem growing are appropriate for certain conditions and certain purposes which are having aspects for maximum possible output. The growing technology could be modified and applied up to each specific case by the accumulation of knowledge or the change of the circumstances. The use of young planting material from especially selected hybrid cultivars of *Paulownia.*

The first growing season should be regarded as a period of root establishment and any trees less than 3 meters tall (in mono-stem plantation) at the end of this season should be coppiced to promote a stronger trunk to regenerate. The first harvest is expected to be around 3 years after planting. Each subsequent regenerated crop is likely to take 2 years to reach harvest size. In areas with warm climate a stem diameter around 10-12 cm is normal for the plant. Due to the statistical generalization of the results used for the tables it could be expected stem diameters less than 10 and more than 15cm for mono-stem paulownia plantation.

Dry biomass recovery

Paulownia wood is used in house construction, for paper pulp, furniture making, farm implements and musical instruments [22]. The various end uses for *Paulownia* for furniture making are comprehensively. These authors stated that the wood is about 40% lighter than ordinary wood and is very promising for pulp and paper. *Paulownia* timber air dries readily and has excellent thermal and electrical insulation characteristics. Japanese researchers described some of the properties of particle board made from low quality *P. tomentosa* and concluded that low quality *Paulownia* trees offer potential as a raw material for particle board manufacture [22]. That the branches of the tree can be used for household energy and a 10 year old tree has been reported to produce 350-400 kg branches for fuel [22]. *Paulownia* is said to require minimal management and little investment and has been receiving greater attention as a short-rotation woody crop in recent years [21].

At that time the reduction of timber accumulation will be reduced. Biomass could be obtained also from waste material after harvesting of Paulownia cultivated for fine timber, generally planted at a density of 550-600/ha or less and grown for a period of 10 years. However the annual yield tons of dry matter (TDM) per hectare will be low relative to that possible from dedicated Paulownia biomass plantations.

Paulownia can be used as an energy source in a number of ways including:

- Burning directly for heat for an individual home or a community heating scheme
- Burning to generate steam for the production of electricity
- A feedstock for pyrolysis to generate gas
- A feedstock for ethanol production

Annually, huge quantities of Paulownia biomass can be used as raw material the production of pellets and also as raw material for alternative renewable bio-fuel. The pellets could be used for small house boilers, heating of single buildings and apartments and for large installations and power plants. They are produced from pressed and extruded dry timber in pellet press machines. Pellets has many favorable characteristics: volume of the raw material decreases 10 folds, deeply processed biomass in eco-friendly fuel, compact sizes, low moisture content (less than 10%), minimum CO_2 emissions. Biofuel (bioethanol) is a fuel, used for substitute of the petrol in vehicles. With the use of bioethanol the greenhouse emissions will be lowered, because during its growth the trees absorb CO_2 that is emitted during their burn. The biomass in global aspect of energy consumption is evaluated between 11 and 14%. Climate changes and fossil fuel supply insecurity has led to increasing interest and realization of sustainable biomass production systems [21].

Paulownia can be used as a "*cellulosic ethanol generator*", where cellulosic ethanol is a blend of ethanol produced from biomass including waste from urban, agricultural and forestry sources. The *Paulownia* biomass can provide the feedstock for cellulosic ethanol production (figure 6). Cellulosic ethanol is said to reduce greenhouse gas emissions (GHG) by 85% over reformulated petrol. For comparative purposes, it is interesting to note that sugar-fermented ethanol reduces GHG emissions by 18-29% over petrol [22]. This would suggest that ethanol from *Paulownia* is capable of providing an opportunity for carbon credits [4].

The calorific value of Paulownia biomass is little over 50% than the one of the coal (as with the rest of the wooden biomass species) but the lower content of pollutants such as sulfur and the fact that Paulownia is a renewable resource clearly points to its environmental benefit. Paulownia wood has the advantage of lightness and substantially reduces the transportation costs comparative to other woods – at normal conditions it will rapidly air dry to moisture content between 10 and 15%. Open air dried the wood density generally ranges between 260-330 kg/m^3 [21, 22].

Figure 6 Exploitation of Paulownia for bio-mass in the second year

Exploitation of mixed crops

The Chinese are presently intercropping with *Paulownia* on some 1.3 million ha of land throughout the country. If a field will be planted with another crop, for example wheat, it is recommended that the planting density should be no more than 500 trees/ha, perhaps being as low as 300 trees/ha at 3 m x 6 m. The whole size should be 70-80 cm on each side and 50-60 cm deep. After the trees are planted, 15-20 cm soil should be placed around the saplings, with the sapling being at least one year old with an established root system.

Also, is it possible to combine the cultivation of Paulownia with Lucerne. In this case of symbiosis it increases the production nitrogen naturally. If it cultivates 10 ha, 3 ha will be with Paulownia effectively and in rest 7 ha with Lucerne. For this 7 ha with harvest 4 -5 times results 50 tons/ha, and 10-15 t/ha hay.

The results of this analysis highlight the simplicity of the agricultural technologies and the great bio-economic availability of Paulownia tree, insufficiently known and exploited so far in Europe.

CONCLUSIONS

The growing and the efficient capitalization of the Paulownia tree in the European countries can lead to tenfold of the values invested in over 10 years of exploitation. The multiply of the benefits of developing of this culture can be through beneficial effects on the environment, on business expansion, creating alternative energy development and other related industries.

These concerns can be included in the research programs from Horizon 2020, more emphasis being placed on innovation and applied research. These will also contribute to the Europe 2020 objectives of the Commission and the good way for moving to a low- carbon dioxide by 2050.

About the bio-energy recovery from the Paulownia tree, it can be appreciate that can obtain the equivalent of 1 liter of bio-diesel from 2 kg of wood.

The rapid growth, with vertical increase, is ideal to harvest at 3 years (can be harnessed to at least 70 000 Euro) Ability strain recovery after the winter but after cutting - Paulownia tree *should not be replanted after cutting*, new rebuilt tree cut out of the stem. This superior quality wood and his extensive use proves the wood products is the easiest hardwood, but is *very durable* and *aesthetically* (fine texture without knots) is used industrially to manufacture: musical instruments, luxury furniture, and yachts and light aircraft, etc.

Paulownia is 30% lighter than any comparable wood, resistant to twisting, consumes 10 *times more* CO_2 than any other tree. The cultivation of Paulownia can assurances a quantity of biomass more than 60-70 t/ha, with in the environment a chemical conversion and a good biochemical conversion. From the economical point of view, after an efficient management the profit could be more than 10.000 Euros/ha.

A strong *bio-economy* of the Paulownia tree will can help Europe to live within its limits. The sustainable production and exploitation of biological resources will allow the production of more from less, including from waste.

Paulownia tree is the source of *wood advantageous worldwide.* The characteristics of the bio-economy of Paulownia tree is: best efficiency after an optimum management.

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44. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

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Expert paper

MOŽNOSTI PROIZVODNJE BIOPLINA IZ GOSPODINJSKIH ODPADKOV V MAJHNI OBČINI V SLOVENIJI

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POVZETEK

Gospodinjski odpadki zbrani v gospodinjstvih majhne občine v Sloveniji imajo določeno energetsko vrednost, ki predstavlja neizkoriščen energetski potencial. Namen raziskave je predstaviti energetski potencial zbranih organskih odpadkov v občini ter pokazati možnosti za zmanjšanje kmetijskih zemljišč za potrebe bioplinarn. Podatke o zbranih količinah organskih odpadkov v občini smo pridobili od izvajalca javne službe. Podatki kažejo, da se v občini na letni ravni zbere 215,22 t organskih odpadkov. Skupni energetski potencial teh odpadkov znaša 135,18 MWh. Z obdelavo gospodinjskih odpadkov v bioplinarnah bi lahko zmanjšali potrebo po kmetijskih površinah od 2,7 ha pa vse do 8,85 ha.

Ključne besede: *gospodinjski odpadki, bioplin, anaerobna obdelava*

UVOD

Biološko razgradljive snovi oziroma organske snovi, so snovi, ki se pod vplivom mikroorganizmov ali drugih živih organizmov v določenem času razkrojijo do osnovnih spojin. Biološko razgradljiva organska snov je tudi ločena frakcija gospodinjskih odpadkov, ki jo imenujemo bio-odpadki. Ti odpadki so primerni za anaerobno fermentacijo. Razvite države so se šele v 70-ih in 80-ih letih prejšnjega stoletja začele resneje ukvarjati s problemom onesnaževanja okolja z odpadki, ko je do onesnaženja že prišlo (poluttion control). Šele na koncu 20 stoletja se je pojavila skrb za naravo in ukrepi, ki bi naj zmanjševali onesnaževanje okolja (Škafar 2005).

Poznamo več kategorij biološko razgradljivih odpadkov, zato jih klasificiramo (Uradni list republike Slovenije, številka 39/2010).

Organski odpadki, ki jih ločeno zbiramo po gospodinjstvih so sestavljeni iz različnih biološko razgradljivih materialov. V komunalnih odpadkih predstavlja biomasa približno

38% vseh odpadkov. Sem spadajo vse vrste ostankov hrane, pokvarjena hrana, razni olupki sadja in zelenjave, listje dreves, trava od košnje, plevel z vrta, lesni pepel in tako naprej (Škafar 2005).

Zakonodaja na področju ravnanja in obdelave gospodinjskih odpadkov je urejena z uredbami o ravnanju z biološko razgradljivimi kuhinjskimi odpadki in zelenim vrtnim odpadom in z uredbo o obdelavi biološko razgradljivih odpadkov (Uradni list Republike Slovenije, številka 39/2010). Slednja določa mejne vrednosti težkih kovin in ostalih nezaželjneih snovi v odpadkih, kot prikazuje preglednica 1. Ob prekoračitvi teh mejnih vrednosti se organski odpad ne sme uporabljat za proizvodnjo bioplina.

Table 1 The parameters of quality of compost and digestate (Official Gazette of the Republic of Slovenia, No. 39/2010)

The environmental parameters of quality	Compost or digestate: 1st class quality (mg/kg dry matter)	Compost or digestate: 2 st class quality (mg/kg dry matter)
Cd	0,7	1,5
Celotni Cr	80	200
Cu	100	300
Hg	0,5	1,5
Ni	50	75
Pb	80	250
Zn	200	1200
PCB	0,4	1
PAH	3	3
unwanted impurities	(% mass of dry matter)	(% mass of dry matter)
solid particles made from glass, plastic or metal, larger than 2 mm	< 0,5 %	<2%
mineral solid, particles larger than 5 mm	<5%	<5%

Anaerobna presnova je proces pri katerem mikroorganizmi v odsotnosti kisika razgrajujejo organsko snov. V procesu anaerobne presnove nastaja plin metan (CH_4), ogljikov dioksid (CO_2) ter v manjših količinah vodikov sulfid (H_2S), amonijak (NH_3), vodna para (H_2O), vodik (H_2), dušik (N_2) ter kisik (O_2). Donos bioplina je odvisen od več dejavnikov, kot so razgradljivost organske snovi, zadrževalni čas v reaktorju, temperatura, Ph in dovolj velika masa mikroorganizmov v reaktorjih (Mes in sod. 2003).

Pozitivne lastnosti anaerobne obdelave gospodinjskih odpadkov prispevajo k zmanjšnju emisij toplogrednih plinov. Surovine za bioplinarne so obnovljivi viri energije. Anaerobna obdelava organskih odpadkov prispeva k zmanjšanju potreb po fosilnih gorivih. V veliki večini odpravi neprijetne vonjave, zmanjša se kaljivost semen plevelov in uničijo se določene škodljive bakterije, ki so prisotne v organskih odpadkih. V procesu anaerobne digestije nastane bioplin in stranski produkt – pregnito blato, ki je primerno kot gnojilo na kmetijskih površinah. S tem se zmanjša tudi potreba po umetnih gnojilih (Monet 2003).

Uspešnost anaerobne presnove je odvisna tudi od kakovosti surovine, ki jo dodajamo v reaktorje. V organskih odpadkih zbranih iz gospodinjstev so velikokrat prisotni tudi neželeni materiali, kot na primer razne embalaže, vrečke, kovinski delci in plastika. V izogib neželenim materialom v organskih odpadkih je najpomembneje kakovostno ločevanje odpadkov na izvoru. Če pa ločevanje odpadkov ni na zadovoljivi ravni je potrebno neželeni material mehansko odstraniti pred nadaljnjo obdelavo (Al Seadi in Lukehurst 2012).

Za potrebe izračuna potenciala organskih odpadkov za pridobivanje bioplina v občini bomo uporabili podatke, ki jih navaja Ostrem 2004. Iz ene tone organskih odpadkov zbranih iz gospodinjstev se lahko s postopki anaerobne obdelave v bioplinski napravi pridobi med 80-130 m^3 bioplina s povprečno vsebnostjo metana v bioplinu okoli 60%. Al Seadi in sod. (2010) navajajo, da je donos metana iz organskih odpadkov 61% in donos bioplina 100 m^3/t svežega substrata. En kubični meter metana ima energijsko vrednost 9.97 KWh. Bioplin, ki vsebuje približno med 55% in 60% metana ima energijsko vrednost 5.5 do 6 KWh na kubični meter bioplina (Bioenergy in Germany 2012). Za potrebe naših izračunov bomo uporabili povprečni donos bioplina 100 m^3/t svežega substrata in povprečno vrednost metana 60% v bioplinu pridobljenem iz gospodinjskih odpadkov.

Iz preglednice 2 je razviden donos bioplina iz nekaterih najpogosteje uporabljenih surovin, ki jih uporabljajo za pridobivanje bioplina v bioplinarnah pri nas.

Table 2 Biogas yield from some of the most commonly used raw materials (Bioenergy in Germany 2012)

Raw material	Biomethane yield (%)	Biogas yield (m^3/t fresh material)
Grass silage	54	180
Sweet sorghum	54	108
Corn silage	53	200
Sudan grass	55	128

METODE DELA

Predstavitev občine

Občina se nahaja na skrajnem vzhodnem delu Slovenije ob Madžarski in Hrvaški meji. Prebivalstvo občine je v večini Slovenske, Madžarske in Hrvaške narodnosti. Občina je sestavljena iz 23-ih naselij. Po podatkih statističnega urada Slovenije je imela občina v letu 2012 10.881 prebivalcev. Na letni ravni se zbere v občini 298.6 kg komunalnih odpadkov na prebivalca. Občina se razprostira na 123 km^2 površine.

Izvajalec javne službe zbiranja in odvoza ločenih frakcij komunalnih odpadkov v občini je javno podjetje. Podjetje izvaja ločeno zbiranje mešanih komunalnih odpadkov ter biološko razgradljivih odpadkov (Eko-park 2014). Za zbiranje organskih odpadkov je izvajalec javne službe zagotovil primerne zabojnike. V občini Eko-park izvaja odvoze le teh na 14 dni in v dveh terminih.

Enačbe za izračun raznih vrednosti za potrebe naše raziskave

Po naslednjih enačbah smo preračunali posamezne parametre da smo prišli do želenih rezultatov.

Donos metana smo izračunali po naslednji enačbi:

$$D_m = \frac{D_{bp} \times P_v}{100} \quad [1]$$

kjer je:

D_m- donos metana (m^3/t svežega substrata)

D_{bp}- donos bioplina (m^3/t svežega substrata)

P_v (%)- povprečna vrednost metana v substratu (%)

Izračun skupne količine metana iz organskih odpadkov (m^3) smo izračunali po naslednji enačbi:

$$S_{Km} = D_m \times S_{Ko} \quad [2]$$

kjer je:

S_{km}- skupna količina metana v (m^3)

D_m- donos metana v (m^3/t svežega substrata)

S_{ko}- skupna količina zbranih odpadkov v (t)

Izračun energijske vrednosti zbranih odpadkov smo izračunali po naslednji enačbi:

$$E_o = E_m \times S_{Km} \quad [3]$$

kjer je:

E_o- energijska vrednost zbranih organskih odpadkov (KWh)

E_m – energijska vrednost metana v (KWh/m^3)

S_{km}- Skupna količina metana v (m^3)

Hektarski donos metana smo izračunali po naslednji enačbi:

$$H_{Dm} = D_m \times H_{pr} \quad [4]$$

kjer je:

H_{Dm} – hektarski donos metana (m^3/ha)

D_m – donos metana (m^3/t svežega substrata)

H_{pr} – hektarski pridelek (t/ha)

V kolikšni meri bi bilo možno zmanjšati potrebo po kmetijskih zemljiščih smo izračunali po naslednji enačbi:

$$ZI_{kz} = \frac{S_{km}}{S_{kmp}} \quad [5]$$

kjer je:

ZI_{kz} – zmanjšanje izkoriščanja kmetijskih zemljišč v (ha)

S_{km} - skupna količina metana iz organskih odpadkov (m^3)

S_{kmp} – Skupna količina metana iz pridelkov (m^3/ha)

REZULTATI Z RAPRAVO

Zbrane količine organskih odpadkov v občini

V letu 2013 so v občini zbrali 215220 kg organskih odpadkov. Zbrani organski odpadki iz gospodinjstev v občini se predajo na takojšnje kompostiranje ali gredo na skladiščenje. Na takojšnje kompostiranje se preda 146020 kg odpadkov, preostali delež 69200 kg pa se skladišči pred nadaljnjo obdelavo.

Energijska vrednost zbranih organskih odpadkov iz gospodinjstev

V občini se je v letu 2013 zbralo 215,220 ton gospodinjskih odpadkov. Po formuli 1 smo izračunali, da je donos metana iz 1 tone gospodinjskih odpadkov 60 m^3/t svežega substrata, nato smo s pomočjo formule 2 izračunali, da bi bil teoretični skupni donos metana iz zbranih odpadkov 12913,2 m^3. Nato smo po formuli 3 izračunali, da bi energijska vrednost teh odpadkov znašala 128744,6 KWh oziroma 128,74 MWh.

Hektarski donosi metana različnih poljščin

V preglednici 3 so prikazani hektarski donosi metana različnih poljščin, ki smo jih izračunali po formuli 4. Za izračun donosa metana smo uporabili podatke o povprečnih pridelkih posameznih poljščin, ki smo jih določili na podlagi večletnih lastnih izkušenj na tem področju.

Iz preglednice je razvidno, da ima največji hektarski donos biometana koruzna silaža. Koliko biometana je mogoče pridobiti iz posameznih surovin pridelanih na enem hektarju je odvisno od več dejavnikov kot so: količina pridelka silaže posamezne kulture na ha, količina zrnja, ki se nahaja v silaži in od energijske vrednosti posameznih pridelkov.

Table 3 The average yield of raw material and biomethane yield per hectare

Raw material	The average yield of fresh mass (t/ha)	Biomethane yield (m^3/ha)
Grass silage	15	1458
Sweet sorghum	55	3206
Corn silage	45	4770
Sudan grass	35	2464

Zmanjšanje potreb po kmetijskih površinah na račun zbranih gospodinjskih odpadkov

Za primerjavo, v kolikšni meri bi lahko nadomestili energetske rastline pridelane na kmetijskih površinah z zbranimi gospodinjskimi odpadki v občini, bomo za primerjavo uporabili podatke o povprečnih pridelkih in donosih biometana najpogosteje uporabljenih energetskih rastlin v bioplinarnah v naši okolici. Kot glavni vir surovin za bioplinarne pri nas uporabljajo koruzno silažo, kateri sledijo sladki sirek, sudanska trava in travna silaža. Po naših izračunih je potencialni donos biometana iz gospodinjskih odpadkov zbranih v občini lendava 12913,2 m^3. Za izračun v kolikšni meri bi bilo možno z gospodinjskimi odpadki zmanjšati potrebo po izkoriščanju kmetijskih zemljišč smo izračunali po formuli 5.

Iz preglednice 4 je razvidno v kolikšni meri bi bilo možno zmanjšati potrebe po kmetijskih zemljiščih za pridelavo surovin za bioplinarne, če te surovine nadomestimo z odpadki zbranimi iz gospodinjstev občine.

Podatki kažejo, da bi z zbranimi odpadki nadomestili potrebo po kmetijskih površinah za pridelavo surovin od 2.7 ha pa vse do 8.85 ha v odvisnosti od tega katero energetsko rastlino gojimo na kmetijskih površinah.

Table 4 Reduced demand for agricultural land per hectares

Raw material	Reduced demand for agricultural land per hectares
Grass silage	8,85
Sweet sorghum	4,02
Corn silage	2,70
Sudan grass	5,24

ZAKLJUČEK

V letu 2013 je bilo v občini zbranih 215,22 t organskih odpadkov iz gospodinjstev.

Na podlagi podatkov o zbranih količinah organskih odpadkov v občini smo v raziskavi izračunali, da bioplinski potencial za zbrano količino odpadkov znaša 12913,2 m^3 biometana, oziroma da je energetski potencial 135,18 MWh.

V nadaljnje smo izračunali, da bi bilo možno z organskimi odpadki nadomestiti pridelek koruzne silaže pridelan na približno 2,7 ha, pridelek sladkega sirka na 4,02 ha, pridelek sudanske trave na 5,24 ha in pridelek travne silaže na 8,85 ha kmetijskih zemljišč.

Ne glede na to, da energijski potencial teh odpadkov ni zelo velik, ni zanemarljiv. V prihodnje bi bilo smiselno preusmeriti te odpadke v bioplinarne, saj bi na ta način v neki meri razbremenili kmetijska zemljišča, ki so primarno namenjena za pridelavo hrane, za ljudi in krmo za živali.

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OPTIONS FOR BIOGAS PRODUCTION FROM HOUSEHOLD WASTE IN THE SMALL MUNICIPALITY IN SLOVENIA

ABSTRACT

The household waste, collected in the municipality in Slovenia, represents an untapped energy potential. The purpose of this study is to present the energy potential of the organic waste collected in the municipality and to indicate the options to reduce the farmland area used for the needs of biogas plants. The data about the collected quantity of organic waste in the municipality was provided by public service contractor. The data shows that 215.22 t of organic waste is collected annually with the energy potential of 130,89 MWh. The farmland area used for biogas production purposes could be reduced by 2.75 - 9 ha with household waste processing in the biogas plants.

Key words: *household waste, biogas, anaerobic processing*

44. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

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Prethodno priopćenje
Preliminary communication

DECREASE OF ECOLOGICAL FOOTPRINT IN GREENHOUSES BY REPLACING THE CONVENTIONAL FUELS WITH RENEWABLE ONES

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SUMMARY

Since intensification of vegetable production in greenhouses has led to activities that profoundly influence the ecosystem, estimating environmental impact is essential. Tomato (Solanum lycopersicum L.) production for fresh consumption is widely spread all over the world and also in Slovenia, but it has high temperature demands and thus additional heating is necessary. The Sustainable Process Index (SPI) was used for estimating ecological footprint, CO_2 emissions and Global warming potential (GWP) of different heating systems used by local producers. SPIonWeb® software was implemented for estimating the potential reduction of all impacts by introducing the alternative heating systems. For the production in the PE tunnel, fossil fuels might be successfully replaced by wooden chips and in the glasshouses by geothermal energy. For these reasons, the footprint might be reduced by 61.88% in PE production and up to 90 % in glasshouse.

Key words: *Tomato, heating systems, ecological footprint, Sustainable Process Index*

INTRODUCTION

Growing demand for fresh, out-of-season agricultural produce has driven an increase in greenhouse-based production in Europe since 1960s till nowadays.

However, greenhouse production is the most intensive method in agricultural production, owing to its high yield and high energy consumption per hectare (Khoshnevisan et al. 2013). Tomato is one of the most important greenhouse vegetable products in Europe, which can be grown in the greenhouse practically during the whole year. In 2014, annual tomato production for direct sale was about 8.9 mio tons, among which Italy (4.8 million tons), Spain (2.25 million tons) and Portugal (1.2 million tons) were the main production countries (WPTC 2015).

Table 1 Most important European tomato producers in 2014 (WPTC 2015)

	Glasshouse production (t)	Total production (t)
France	170.000	190.000
Greece	400.000	480.000
Nederland	700.000	700.000
Italy	1.100.000	4.800.000
Portugal	1.000.000	1.200.000
Spain	2.000.000	2.250.000
Total EU	5.370.000	9.620.000

Tomato belongs to the category of warm-season vegetables, which requires daytime temperatures between 27 ^{o}C and 30 ^{o}C, and the root temperature, not lower than 18 ^{o}C. Namely, because lower temperatures delay plant growth and fruit development (Dickerson 2011).

Because of the large number of processes that contribute to production and heating, the evaluation of the whole value chain becomes relevant to improving the energy and environmental performance of food products (Cellura et al, 2010).

Life-cycle assessment (LCA) is a method of evaluating the environmental effects (air, water, and land) associated with any given activity, beginning with the initial gathering of raw materials from the environment to the point at which all residuals are returned to the environment. Greater environmental awareness among consumers over the past decade has significantly increased the number of organizations conducting LCA studies (Romero-Gámez et al. 2012).

The Sustainable Process Index (SPI) is a member of the ecological footprint family. It was developed by Krotscheck and Narodoslawsky (1996) and customized for agriculture. The concept of calculating the footprint assumes that a sustainable economy might be built only on solar radiation as natural input, whereby the earth's intact surface acts as the resource for the conversion of solar radiation into products and services.

Since the global surface area is a limited resource, the area required to embed a certain process sustainably into the ecosphere is a convenient measure for ecological sustainability; the more area a process needs to fulfil a service, the more it "costs" from an ecological sustainability point of view Kettl (2013).

The main goal of our research was i) to compare the effect of conventional heating on ecological footprint, CO2 emissions and global warming potential (GWP) potential in two different greenhouse production of tomato in Slovenia; glasshouse and polyethylene (PE) tunnel, ii) to estimate the possible introduction of renewable heating systems (wooden chips, geothermal energy) in greenhouse production and on increasing the sustainability of tomato production.

METHODS

SPIonWeb tool

The SPIonWeb tool (http://spionweb.tugraz.at) is license free software for estimating the ecological footprint, CO_2 emissions and GWP developed at TU Graz. The ecological footprint of each transport system was estimated by including environmental impacts related to fossil-C, air, water, soil, non-renewable, renewable and area resources. The footprint of the SPI method calculates the actual surface needed for some specific process (Figure 1).

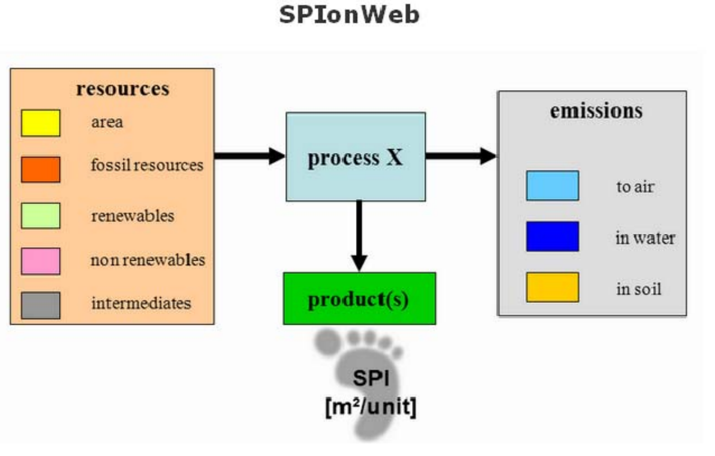

Figure 1 Ecological footprint scheme based on SPI (Kettl, 2013)

Calculation of fossil-C assumed sedimentation of carbon to ocean beds, which requires about 500 m² of sea ground per year to put 1 kg of carbon back into the long term (fossil) storage of the sea bed.

The footprint for emissions to water is based on a replenishment rate, which is based on the precipitation rate in a specific geographic region of the compartment and a natural concentration of the emitted substance. In the SPI concept, the concentrations found in ground water are the reference for each natural compartment. The footprint of a given emission flow is therefore the area that is necessary to provide so much pure water via the seepage rate that may dilute the emission to the reference concentration of the emitted substance in ground water.

The footprint for emissions to soil is similar to the footprint for emissions to water, and it is calculated based on the regeneration rate of the compartment soil calculated as compost generated from grassland and the natural concentrations of the emitted substances in the top soil.

The footprint for emissions to air does not have a natural replenishment rate as do the other compartments, but the natural emissions of gaseous substances by forests are taken as a reference. The footprint for emissions to air is calculated as the area of forest that emits the same amount as the emission in question

CO_2 (kg) emissions or releases are calculated from the "Area for fossil carbon", where the extracted fossil carbon and carbon based materials are assumed to be oxidized to CO_2 over the life cycle and finally to end up as CO_2 emission to the atmosphere.

GWP (global warming potentials) are calculated on the basis of GWP factors i. e. carbon dioxide equivalent (CO_2e), where exhausts gases components are converted to CO_2e by multiplying their amounts for instance (CH_4 has 25 and N_2O 298 higher GWP then CO_2 itself). The sum of CO_2 life-cycle-emissions equivalents of all input processes and other GWP relevant impacts is the total GWP measured in kg CO_2 equivalent Kettl (2013).

Input data

Data for this study was retrieved from interviews with tomato producers in eastern Slovenia, whereby two types of greenhouse production were compared.

First one represents a glasshouse with total area of 10.000 m^2 and production area of 9000 m^2 in which the tomato is hydroponically grown on coconut fibre wrapped in white PE 0.05 mm film.

Figure 2 PE tunnel (left) and glasshouse growing (right)

Second growing system represents a greenhouse (PE tunnel, EVA 200 μm, double layer inflated) with total area of 10.000 m^2 and production area of 8000 m^2 with additional heating, in which the plants are grown on natural soil according to GAP standard. The basic soil cultivation was performed by ploughing and harrowing.

The average lifespan of the glasshouse structure is assumed to be 20 years, while their foundations last for 30 years. The PE tunnel structure lasts for 10 years, and its EVA cover is replaced every 7 years. Polypropylene (PP) ropes for supporting the plants are used only for one year tie up the tomato plants.

The lifespan of the irrigation pipes made from High Density Polyethylene (HDPE) is 7 years in covered production. The soil protective white LDPE 0.05 mm is used in glasshouse to protect the environment against soil bacteria and increase the solar reflection from bottom upwards to the plants. In the tunnel production the black LDPE 0.05 mm is replaced every year and it is used for covering the soil directly beneath the plants to protect tomatoes against the mud particles.

In both systems grafted tomato seedlings were used as planted material, because the rootstock is selected for its ability to resist infection against certain soil-borne pathogens, or its ability to increase vigour and fruit yield. In the glasshouse a two stems growing technology is applied, while in the PE tunnel only one stem per plant is guided on the PP rope.

Seedlings were grown in separate glasshouse nursery for 12 weeks before being transplanted on the final location.

Heating system

Conventional heating of PE tunnel consists of two 100 kW extra light oil (ELO) boilers with a fan jet system for distributing warm air along the tunnel, which allows the heat to be spread more evenly into the lower part of the plants. With proper maintenance, the lifespan of a boiler was assumed to be 15 years, and that of the PE jet tube system on 7 years.

Alternative, renewable heating for PE tunnel represents wooden chips heating system consisted of 200 kW boilers, iron pipes and fan radiators, which lifespan was assumed to be 15 years.

Figure 3 Jet fan heating (left) and hot water heating with pipes (right)

Conventionally the glasshouse is heated with a two 250 kW natural gas boilers and iron pipes as radiators mounted under the plants, while renewable energy for glasshouse represents geothermal energy coming in the way of hot water (65 ^{o}C) from a 1500 m deep well through a heat exchanger system. The lifespan of the geothermal well depends on the water flow quantity and is assumed to be 30 years.

The tomato was planted in glasshouse end of January and its growing production lasted for 11 months, whereby the harvesting season was 9 months long. Contrary, the tunnel production started three months later at beginning of April and lasted to the end of November, with harvesting period of 6 months.

RESULTS AND DISCUSSION

Input processes in different production systems

Table 2 presents amounts of all the materials and machines used for production of tomato on 10.000 m^2 gross area in two production systems. The data were calculated per 1 kg of fresh tomato by using the information on annual yield (Table 3) and the facilities lifetime, which served as the basis for the estimation of the process impacts involved in the particular production. For installations and heating system lifespan was described in detail in previous chapter.

Greenhouse production uses modern technology, which is fully automatized and thus considerable electricity, heating, water and chemical input, is required. Electrical energy is mainly utilized by electro-drives for opening/closing the roof, pumps needed to run fertigation and for the automation process itself.

Table 2 Measures and inputs for different production systems of tomato

Measures	Input	Glasshouse	PE tunnel integrated	Units
Ploughing	50 kW tractor	/	2	(h, ***)
Basic fertilization (tractor)	50 kW tractor	/	1	(h, *)
	NPK (7:20:30)	/	500	(kg/ha)
	Stable manure	/	/	(kg/ha)
Fertigation	N-fertilizer (CaNO3)	11,000	500	(kg/ha)
	KNO3	6,600		(kg/ha)
	KCl	630		(kg/ha)
	MgSO4	4,600		(kg/ha)
	NPK (10:5:26)	/	1,800	(kg/ha)
	MnSO4	40		(kg/ha)
	CuSO4	5		(kg/ha)
Pesticides	Confidor SL 200 (Insec)	/	5.2	(l/ha)
	Calypso SC480			(1/ha)
	Ridomil gold pepite (Fung) combi	1	1	(1/ha)
	Switch® 62,5 WG (Insec)	0.12	0.12	(1/ha)
Water		22,270	10,500	m^3/anno/ha
Electricity		19,800	1,080	kWh/anno/ha
Heating		650,000	4,200	kWh/anno/ha
Plants		11,500	80,000	(pieces/ha)

Intensity of machinery use: * light, *** high

Yields

Annual yields of tomato varied significantly among two production systems, i.e. from 495.000 kg/ha in glasshouse to 275.000 kg/ha in PE tunnel structure (Table 3). The main reason lies in the energy and nutrition input, which in glasshouses enables the creation of optimal temperature conditions during 11-month growing season while under the tunnel tomato, can be grown for 8 months. However, the harvesting season is for two months shorter due to the growing time of tomatoes from blossom till ripening.

Table 3 Tomato yield under different production systems

Production system (PS)	Yield (kg/ha)	Plants	Growing (months)	Harvesting time (months)
Glasshouse	495,000	11,500	11	9
PE tunnel	275,000	60,000	8	6

Ecological footprint of different heating systems

The footprint, CO_2 release and GWP caused by conventional and alternative heating systems applied in glasshouse and PE tunnel are presented in detail in Table 4. In the first place, heating impacts are strongly dependent on the energy input required by a particular growing system, as well as the energy source used, whereby significantly lower values are calculated for renewable sources.

The biggest footprint is calculated when the gas is used for heating the glasshouse, because almost 0.125 m^3 of gas / kg fresh tomato is used in central European climate conditions for additional heating of a glasshouse to 25 ^oC. For those in available regions, a geothermal heating system would be the best solution, since it leaves the smallest ecological footprint (0.377 m^2a for 1 kg of tomatoes), even though the glasshouse 11-month growing cycle consumes the most heat.

Table 4 Additional footprint caused by heating in different tomato growing production systems

Production system	Footprint (m^2 a /kg)	CO_2 (kg)	GWP (CO_{2eq})
Glasshouse-geothermal	0.3770	0.0180	0.0250
Glasshouse- gas	78.450	0.5255	0.7334
PE tunnel-extra light oil	1.7490	0.0150	0.0144
PE tunnel-chips	0.6667	0.0025	0.0078

The PE tunnel production lasts only 8 months and the heating season is only 2 months, thus significantly lower energy input is required. For this reason, the ecological impact is much lower than those from the glasshouse, but again it depends very much on the energy used. Whenever heating with wooden chips is used the footprint amounts to 0.6667 m^2a/kg and it is significantly lower than the one from the ELO boiler heating (1.749 m^2a/kg).

Since CO_2 release is very important global warming gas, it is an integrated part of the SPIonWeb software. As seen from Table 4, heating glasshouse with natural gas causes almost 290 times more CO_2 release than the use of geothermal energy, despite the high energy demand for drilling. But the long lifespan and small annual energy inputs reduce the CO_2 release from 0.5255 kg on 0.018 kg per kg fresh tomato.

Again the CO_2 release is much smaller in the PE tunnel production by itself and it amounts to 0.0150 kg for ELO heating and 0.0025 kg for heating with wooden chips. The main reason lies again in a short heating season and the renewable energy source (wooden chips), which assumed the exhaust CO_2 not to contribute to green gas pool.

The use of wooden chips heating reduced the CO_2 release by 83.33 % in PE tunnel, which makes this renewable heating source very attractive for more sustainable tomato production even on smaller farms.

The biggest gas warming potential (GWP) is again caused by gas boiler heating in glasshouses and amounts to 0.7334 CO_{2eq} due to the high temperature deficit of tomato in the spring and autumn. GWP is for 29 times higher than the one from the geothermal heating, which is mainly assumed to cause the GWP only in processes of drilling of well and production of electricity needed for pumping the hot water across the heating system.

In both PE tunnel production systems, the GWP share was much lower than the one from glasshouse production, which might be explained by shorter heating season so GWP amounts to 0.0144 CO_{2eq} in ELO heating and only 0.0078 CO_{2eq} when heated with wooden chips. The main reason for six times lower GWP in the wooden heating represents the renewable material and the processes for manufacturing infrastructure for the wood pellet furnace.

Life Cycle impact breakdown for different production systems

LCA impact breakdown shows the share of most important impacts caused by all pre-processed needed for production of 1 kg of tomatoes.

In the following paragraphs we are presenting the life cycle impact (m^2a/kg) of two different heating systems for each production system (Figure 4). As seen, the biggest LCA impact is left in the glasshouse production and gas heating, which increase the Life Cycle impact significantly over the glasshouse geothermal heated production systems. Contrary, in PE tunnel production, the Life Cycle impact remains practically the same.

In glasshouse production the total impact amounts to 110.81 m^2 a /kg, whereas the use of gas heating creates the biggest share of 78.45 m^2 a/kg. It is calculated as a sum of all impacts involved in production and transportation of this conventional heating material and the quantity used, which is connected to the longest additional heating season. Consequently, this way of production exceeded the production with geothermal heating for 77.96 m^2 a /kg, whereas in the later one the share of heating is practically neglected.

In contrast, the total impact in PE tunnel production and ELO heating amounts to only 19.05 m^2a/ kg and 18.25 m^2a/kg whenever heated with renewable wooden chips, respectively. Again, in PE tunnel production, the use of ELO heating is not detectable in the impact because it is used for only a few days during vegetation; besides, the yield is very high, so this impact is practically negligible.

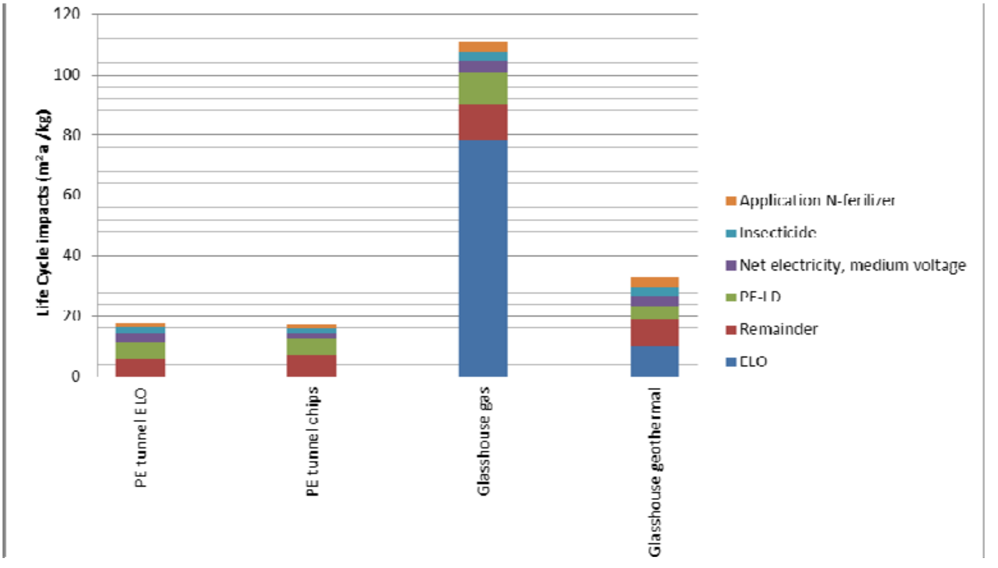

Figure 4 Life Cycle impact breakdown (m^2 a /kg) for different production systems and heating

SPI categories breakdown for different production systems

SPI categories represent the footprint breakdown (%) on six natural resources i.e. categories, which is left with all pre-processes needed for the production of 1 kg of tomatoes. As seen from Figure 5, in both productions system fossil-C is the most important SPI category, followed by the air and water. The maximal share of 52.3 % was calculated for PE tunnel production and 50.9 % for glasshouse production.

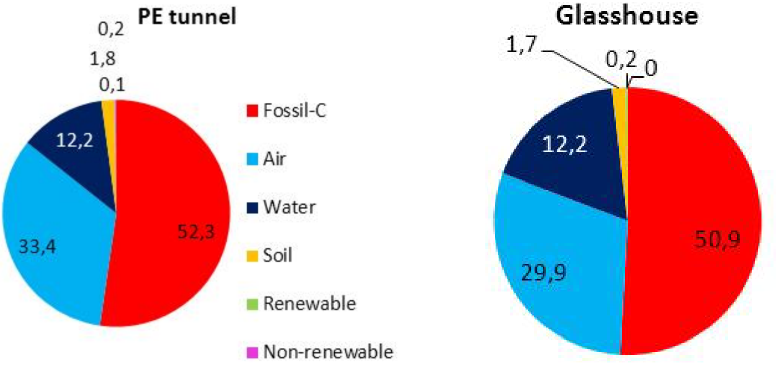

Figure 5 The share (%) of footprint SPI categories for different production systems.

The air share was reduced in glasshouse, where it went down from 33.4 to 29.9 %, while the water impact remains the same at 12.2 %.

CONCLUSIONS

The estimation of ecological footprint with SPIonweb software clearly indicated differences between various tomato production systems; gas heated glasshouse production leaves the highest ecological footprint 110.81 m^2a/kg, which is 5.8 times higher than in PE tunnel ELO heated production. However, the introduction of renewable energy sources significantly reduces the footprint in glasshouse on 78.45 m^2a/kg. On the other hand, the use of wooden chips in PE tunnel decreases the footprint only for 0.80 m^2a/kg due to the short heating season and small needs for additional heating.

ACKNOWLEDGEMENTS

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SMANJENJE EKOLOŠKOG OTISKA U STAKLENICIMA ZAMJENOM KONVENCIONALNIH GORIVA S OBNOVLJIVIM

SAŽETAK

Intenziviranje proizvodnje povrća u plastenicima dovelo je do aktivnosti koje duboko utječu na ekosustav, zbog čega je procjene utjecaja na okoliš vrlo značajna. Proizvodnja rajčica (Solanum lycopersicum L.) proizvodnja za svježu potrošnju široko je rasprostranjena po cijelom svijetu, a također u Sloveniji. Međutim rajčica ima potrebe po visokim temperatura pa time i dodatnom grijanju. Sustainable Process Index (SPI) koristi se za procjenu ekološkog otiska, emisija CO_2 te potencija toplogrednih plinova. U našem radu SPIonWeb® software implementiran je za procjenu, potencijalnog smanjenje ekološkog otiska, emisija CO_2 te potencija toplogrednih plinova radi uvođenja alternativnih sustave grijanja (geotermalna energija i drvena sječka). Za proizvodnju u PE tunelima fosilna goriva (loživo ulje) može biti uspješno zamijenjen drvenom sječkom te u stakleniku geotermalnom energijom. Analiza rezultata pokazala je kako se ekološki otisak proizvodnje rajčica u PE tunelima može smanjiti za 61.88% i do 90% kod proizvodnje u staklenicima.

Ključne riječi*: rajčica, sustavi grijanja, ekološki otisak, SPI (Sustainable Process Index)*

44. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

UDC 582.542:661.9:662.76
Stručni rad
Expert paper

OPTIMIZATION OF BIOGAS PRODUCTION BY THE ADDITION OF GREEN *MISCANTHUS X GIGANTEUS* IN ANAEROBIC DIGESTER

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SUMMARY

To increase biogas production resulted from anaerobic digestion of animal manure, worldwide it increased the interest to find some energetic crops that produce high methane yield per hectare with low environmental impact and that are economical for farmers. In the present paper, it was investigated the role of energy plant Miscanthus x giganteus (green leaves) in the anaerobic co-digestion process with fresh cattle manure. They were recorded daily production of biogas, and the components in its composition: the methane content, carbon dioxide and hydrogen sulfide. Other chemical features of substrat as folows: pH, total soluble solids (TTS), content of soluble proteins and sugar content were conducted. It has been shown that the addition of Miscanthus x giganteus (green leaves) in the anaerobic digester along with cattle manure, produced a good fermentation environment.

Key words: *energy crop, biogas production, optimisation, co-digestion*

INTRODUCTION

Anaerobic digestion process represents an attractive and effective treatment for the biodegradable fraction of agricultural wastes (animal manures and slurries, vegetable residues, energy crops), industrial sector (food industry, brewery industries, sludges from industrial processes, etc.), municipal residues and aquatic biomass (Al Seadi et al., 2013). The anaerobic digestion process is based on a microbial association between acid-producing bacteria, acid-degrading bacteria and methanogens. The methanogens bacteria convert the acetic acid, hydrogen and carbon dioxide into methane (Banks and Zhang, 2010).

The biogas produced from anaerobic digestion process is generally composed of about 48-65% methane (CH_4), 36-41% carbon dioxide (CO_2), up to 17% nitrogen (N), less than 1% oxygen (O_2), hydrogen sulphide between 32 – 169 ppm and traces of other gases (Rasi et al., 2007).

Animal manure is the most used substrate for biogas production. There are a lot of factors which contribute to the biogas yield of manure, such as: the animal species, feed, type of bedding and also the manure degradation during the storage. Moller *et al*. reported that the methane productivity is higher in pig (516 1 kg $^{-1}$ VS) and sow (530 1 kg $^{-1}$VS) manure than in cattle manure (469 1 kg $^{-1}$ VS) (Moller et al., 2004). It is well known that animal manures contain high concentrations of ammonia which are greater than that necessary for microbial growth and may be inhibitory to anaerobic digestion process (Chen et al., 2008). On the other hand, a high concentration of ammonia can be efficient when used with other feedstocks which have low nitrogen concentrations.

Biomass, including straws from wheat, rice, sorghum, unused stalks, maize silage and energy crops is also a promising feedstock for biogas production by anaerobic digestion process (Ward et al., 2008).

Co-digestion of animal manure with agricultural wastes can improve significantly the biogas production in anaerobic digesters. The most important reason for using co-digestion of animal manure and vegetal biomass is the adjustement of the carbon and nutrient balance (Parawira et al., 2004). According to data in the literature, for a good development of the anaerobic digestion process, the value of C/N ratio of the mixture must range between 20 – 30 (Puyuelo et al., 2011). Mata-Alvarez *et al.* (Mata-Alvarez et al., 2000) reported that digestion of more than one substrate in the same digester can establish positive synergism and the added nutrients can support microbial growth.

Even if biogas production from co-digestion of animal manure and maize is the most efficient option, it could result in serious competition between energy and food supplies. For that reason, it increased the interest in using as a substrate in biogas plants perennial crops mixed with animal manure (Klimiuk et al., 2010).

The optimization of anaerobic digestion consists in maximise the biogas yield for energy production. Optimisation represents the process conducted when exist a a number of parameters that can be controlled and a single variable that we want to maximise or minimise. In the case of anaerobic digestion process, it is desirable to obtain the highest possible biogas production from the smallest possible digester, or the maximum energy yield with the minimum operating costs (Banks and Heaven, 2013).

Amon *et al.* (Amon et al., 2007) studied the optimisation of methane production from agricultural crops and residues. Thus, they developed a methane energy system in order to estimate the biogas production from different crops and the impact of harvest time. They reported that maize should be harvest in the vegetation stage milk to wax ripeness and the methane production that can be achieved is about 7500–10200 m^3_N ha^{-1}.

Optimisation of environmental conditions within the digester such as operating temperature, pH, buffering capacity, fatty acid concentrations and mixing improves the biogas yield (Ward et al., 2008).

The main objective of this research was to evaluate and optimize the anaerobic co-digestion of energy plant *Miscanthus x giganteus* (green leaves) with fresh cattle manure.

To assess the suitability and profitability of used feedstock, laboratory tests consisted of determination of total soluble solids (TSS), content of soluble proteins and content of sugar were performed.

MATERIALS AND METHODS

Feedstock preparation

Miscanthus x giganteus plants used during experiment have been harvested during vegetation time from the culture of National Institute of Research – Development for Machines and Installations Designed to Agriculture and Food Industry, INMA Bucharest. In order to avoid the shortness of the anaerobic digestion process, because of the high cellulose content found in the stem, there have been used only the green leaves of the plant, chopped to a size between 2 up to 5 cm.

Fresh cow manure was collected in July 2015 from a farm in Teleorman county, Romania.

A quantity of 16.5 kg of cow manure was mixed with 3 kg of *Miscanthus x giganteus* leaves and 14 liters of water. C/N ratio of the tested substrate was determined according to the method proposed by Vintilă T. and Nikolic V. (Vintilă and Nikolic, 2009), having a value of 20.8.

In this experiment, the inoculum consisted of 5% of the fermented substrate used in previous experiment (Dinca et al., 2015).

Reactor design and experimental set-up

Figure 1 shows the anaerobic digester used for the experimental investigation. The vertical anaerobic digester has a working volume of 60 liters, is constructed from stainless steel with an inner diameter of 0.4 m and a height of 1.45 m, fitted with a top lid screwed. Also, it is insulated on the outside with a mineral wool and the content is heated by an electric boiler powered by photovoltaic panels. Water was used as heating fluid and was heated up to 70 ^{o}C in the 200 liters electric boiler.

The temperature and pH are automatically monitored by means of a temperature and pH sensor placed along the reactor and connected to the biogas plant. The experiment was carried out in the mesophilic range, and the temperature was gradually raised (in approximately 4 hours) from 23.5^{o}C to 37 ± 1.5^{o}C, this value being kept constant throughout the experiment.

The initial pH of the substrate was of 8.5 units, being displayed on the control panel. pH adjustment was carried out automatically using a solution of $CaCO_3$.

Reactor internal pressure is measured by a low pressure transducer, with measuring range of 0 – 3 bar, type HONEYWELL – MLH 010BGC14B. The substrate is mixed using a paddle stirrer driven by an electric motor, the stirred being set to start automatically at an interval of 30 minutes, with a time of mixing of 3 minutes. Retention time of the substrate in the anaerobic digester was of 22 days, until the production of biogas almost stopped.

The following parameters are continuously measured, controlled and recorded in the memory of the monitoring and control system fitted to the bioreactor: temperature along the reactor, pH and outlet gas pressure.

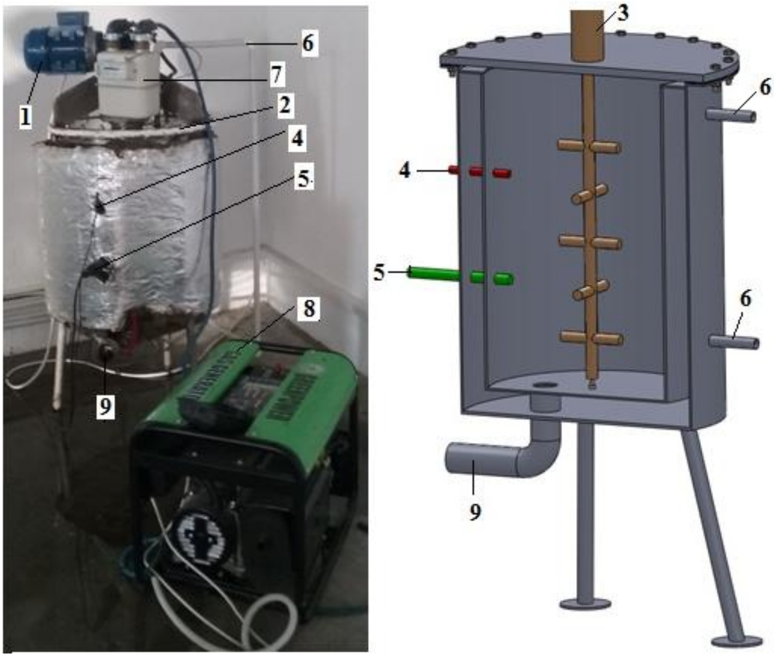

Fig. 1 Design of anaerobic digester used in the experiment; 1 – electric motor; 2 – lid with screws for sealing; 3 – paddle stirrer; 4 – temperature sensor; 5 - pH sensor; 6 – hot water circulation pipe; 7 – gas meter; 8 – power generator; 9 – sampling pipe

Methods of analysis

Evaluation of anaerobic digestion process was done by analyzing and interpreting the following parameters: total soluble solids (TSS), content of soluble proteins and content of sugar.

The content of TSS was determined with a thermobalance, after the centrifugation of initial samples at 5000 rpm followed by filtering through a membrane with pores of 0.45 μm.

The content of soluble proteins was determined according to the Lowry method (Waterborg, 2002) and the concentration of sugars was achieved by the method in which is used the 3.5-dinitrosalicylic acid (DNS) (Miller, 1959). In both cases, the absorbances were measured using a T92+ UV VIS spectrophotometer, PG Instruments.

The quantity of generated biogas was measured daily using a Sacofgas Milano gas meter, fitted with a pulse counter, 1 pulse = 0.01 m^3. The composition of the resulted biogas, (methane (CH_4% v/v), carbon dioxide (CO_2 % v/v) and hydrogen sulphide (H_2S % v/v) was measured using a portable Mentor/COMB/IR Series gas analyzer, fitted with sensors for methane, carbon dioxide and hydrogen sulphide.

RESULTS AND DISCUSSION

Determination of the total soluble solids, content of soluble proteins and sugars in the tested substrate can provide important information regarding the decomposition of feedstock and the production of biogas.

Table 1 shows the characterization of the tested substrate at different intervals of the anaerobic digestion process.

Table 1 Substrate characteristics during the anaerobic digestion process

	Day 1	Day 3	Day 8	Day 13	Day 18	Day 22
TSS (%)	1.7	1.3	1.1	0.97	0.75	0.4
pH	8.5	7.32	7.05	7.04	7.32	7.39
Protein content (mg/ml)	0.7	0.66	0.6	0.55	0.50	0.47
Sugar concentration (mg/ml)	4.8	4.4	4.0	3.4	3.0	2.6

The pH in the reactor never fell below 7.0, this demonstrates the good buffering capacity of the whole pilot plant.

Due to the multiplication of the bacterial cells and digestion produced by these, the substrate concentration decreased, this being recorded by a slightly decrease of sugar concentration and soluble protein.

A slight decrease of TSS content, from 1.7% to 0.4% was observed during the anaerobic digestion process, fact that can be attributed to the presence of easily degradable compounds within the soluble fraction.

Biogas production and composition were daily determined during the 22 days of anaerobic digestion. The recorded experimental data for the daily production of biogas and for the gases in its composition were fitted using Table Curve 2D program, which gave the analytical equations with coefficients values and the Pearson correlation coefficient (R^2).

Regarding biogas production curve (Figure 2), we observed a delayed start, this phenomenon being due to the absence of a specific inoculum, and the duration of adapting the microorganisms present in tested substrate at the bioreactor conditions. The maximum value of total biogas production during the 22 days of anaerobic digestion of animal manure and *Miscanthus x giganteus* was about 2.5 m^3/batch.

From the literature (Baba Shehu and Nasir, 2012), the cumulative biogas yield achieved from anaerobic digestion of cow dung at thermophillic temperature and 10 days hydraulic retention time, was 0.15 L/kgVS. Perenial plant *Miscanthus x giganteus*, was found to be the most promising alternative to maize in anaerobic anaerobic fermentation process. From their experiments, Mayer F. *et al.* (Mayer et al., 2014) reported that the production of biogas obtained from *Miscanthus x giganteus* green matter was of 5.5 ± 1x 10^3 m^3 ha^{-1}, as compared to 5.3 ± 1x 10^3 m^3 ha^{-1} for maize.

Variation of biogas production follows an exponential curve of the type $\ln y = a + bx^3 + c/x^{0.5}$.

The curve of experimental data with the equation displayed on the graphic shows a high correlation coefficient, R^2=0.977.

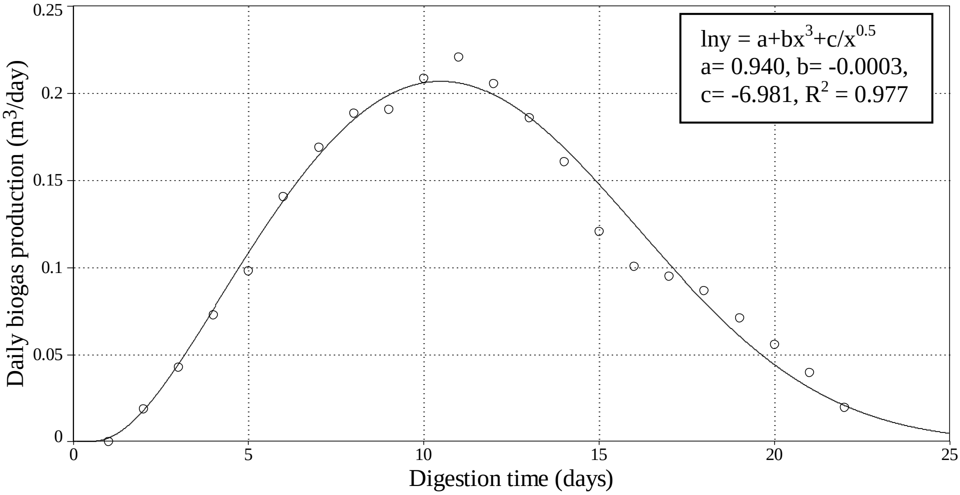

Fig. 2 Daily biogas production during the anaerobic digestion process

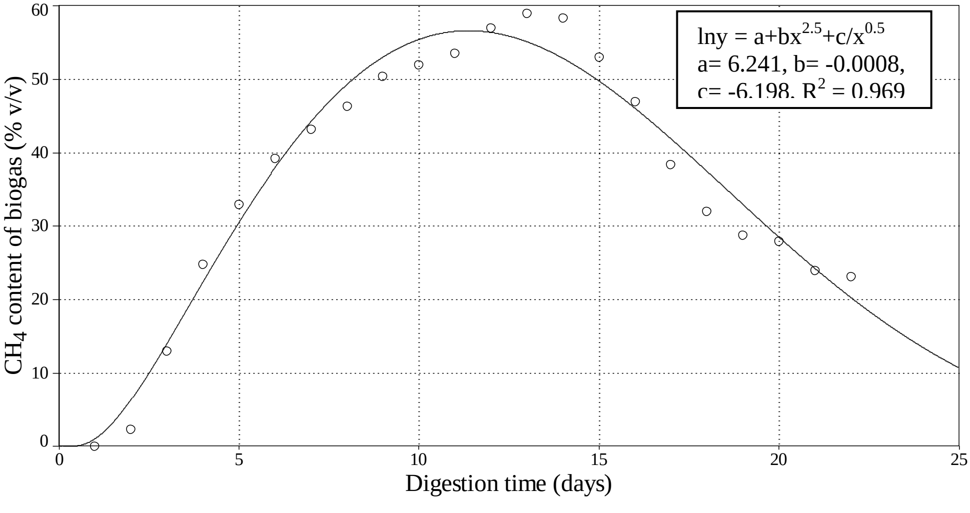

Fig. 3 Daily CH_4 content (% v/v) of the produced biogas

The most important component of biogas is methane (CH_4), because the biogas heating power depends on the methane percentage in biogas. The specific methane percentage in biogas is shown in Figure 3. It can be seen that the methane production on the first day of anaerobic digestion process was almost zero, this fact could be attributed to the small amount of methanogenic bacteria and also to their adjustment to the new digestion conditions. After the start-up period, the CH_4 content of the produced biogas was in the range of 50–60%, comparable to those in the literature. The highest daily methane percentage of 59% v/v was obtained on day 13.

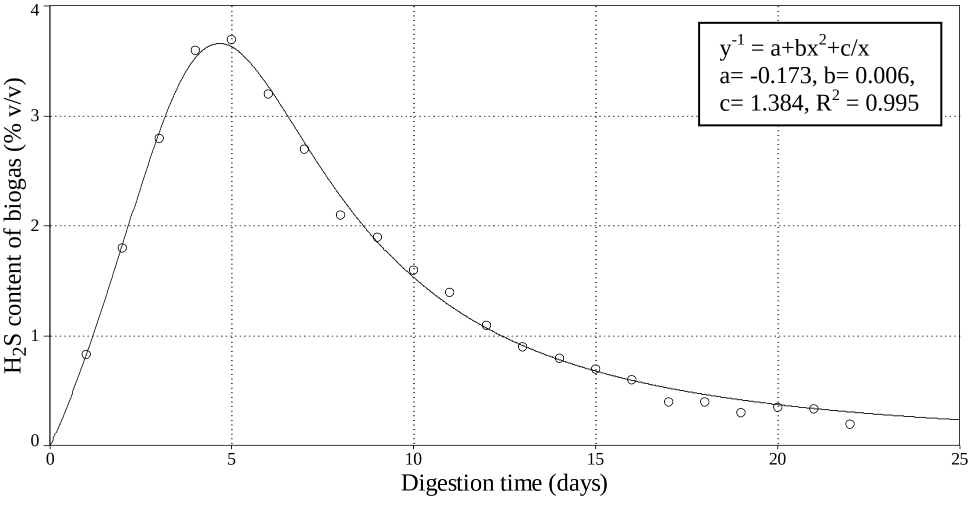

Fig. 4 Daily H_2S content (% v/v) of the produced biogas

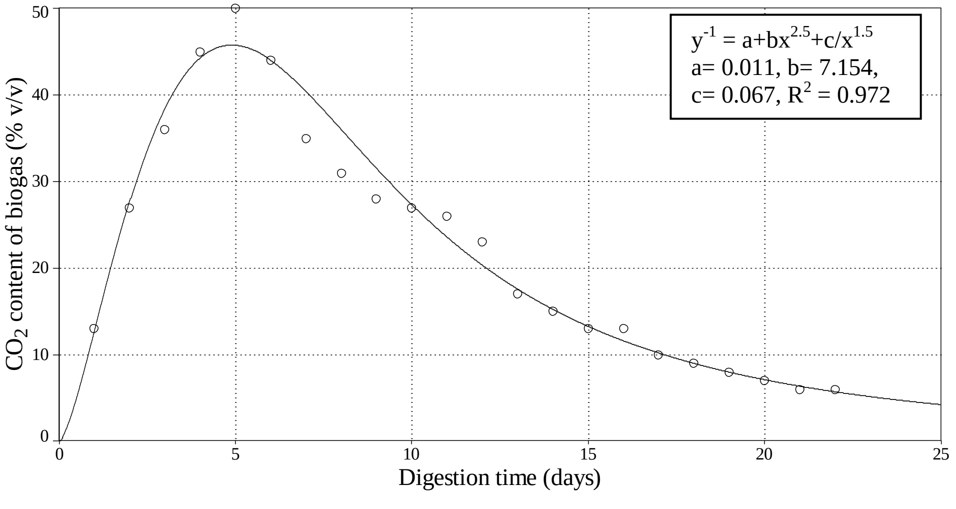

Fig. 5 Daily CO_2 content (% v/v) of the produced biogas

Hydrogen sulfide represents a hazardous component of biogas affecting the equipments used in energy generation technologies. As can be seen from Figure 4, the hydrogen sulfide percentages were about 0.836 to over 3.6% v/v, this fact suggested that the cow manure added in anaerobic digester determined a low H_2S concentration.

Carbon dioxide production was also monitored in this experiment to provide data on total biogas production. It can be seen from Figure 5 that this followed the same trend as that of hydrogen sulphide. The maximum value for CO_2 content was about 50% v/v in day 5 of incubation. High percent of CO_2 is an indicative of poor methane content (33% v/v in day 5) and therefore a lower energy value.

CONCLUSIONS

In this paper, the possibility of optimizing biogas production and methane yield from cow manure by adding *Miscanthus x giganteus* energy crop was investigated. There was evaluated the production of biogas and the variation in time of the characteristics of the tested substrate.

The small capacity biogas plant operated at 35 (±1) ^oC at neutral pH, intermitent mixing, with 22 days hydraulic retention time and a 60 l working volume.

The maximum yield of biogas, after 22 days of anaerobic digestion of animal manure and *Miscanthus x giganteus* was about 2.5 m^3/batch.

Based on the analysis of recorded data for a 22 days of incubation, the following conclusions can be made regarding the performance of anaerobic digestion process:

- the results presented in this paper show that the use of *Miscanthus x giganteus* mixed with cow manure for biogas production is a challenging process and that the substrate composition has a great influence on the anaerobic digestion process performance.
- in order to optimize the production of biogas and to obtain high methane percentage and low hydrogen sulphide percentage, different parameters should be monitored during the anaerobic digestion process, such as: temperature, pH, C/N ratio, pressure, retention time of the substrate in bioreactor, substrate type and total solids.
- The present results showed that the biogas production from cow manure can be optimized by adding *Miscanthus x giganteus* green leaves.

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44. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

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OGLJIČNI ODTIS SADJARSKE PRIDELAVE

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IZVLEČEK

Določen je ogljični odtis mehanizirane pridelave sadja v Sloveniji. Opravljena je analiza ogljičnega odtisa v primeru, konvencionalne, integrirane in ekološke sadjarske pridelave za tri velikosti kmetij (mala, srednja in velika) ter pet vrst sadja (jabolka, hruška, breskev, marelica in oljka). Pri vseh mehaniziranih delovnih operacijah se uporablja mineralno dizelsko gorivo za pogon traktorjev z agregatiranimi priključnimi stroji. V analizi so zajete ekvivalentne emisije CO_2 iz porabljenega mineralnega dizelskega goriva za pogon mehanizacije (direktna energija, ki se porabi v procesu sadjarske pridelave). Poleg ekvivalentnih emisij CO_2 iz mineralnega dizelskega goriva so zajete tudi emisije toplogrednih plinov, ki nastanejo zaradi uporabe organskih in mineralnih gnojil v pridelavi in preračunane na ekvivalent CO_2. V primeru konvencionalne pridelave je predvidena uporaba mineralnih gnojil, pri integrirani kombinacija mineralnega in organskega gnojila, pri ekološki pridelavi pa samo organskega gnojila. Seštevek ekvivalentnih emisij CO_2, ki nastanejo zaradi uporabe mineralnega dizelskega goriva in ekvivalentnih emisij CO_2 iz različnih vrst gnojil uporabljenih v procesu pridelave sadja, da skupno emisijo $CO_{2ekv.}$/t pridelka – sadja v pridelavi. Ugotovljeno je, da so emisije $CO_{2ekv.}$/t pridelka – sadja, najnižje pri integrirani, višje pri konvencionalni ter najvišje pri ekološki pridelavi sadja.

Ključne besede: *emisija CO_2, konvencionalna pridelava, ekološka pridelava, ogljični odtis*

UVOD

Uporaba velikih količin direktne in indirektne energije v kmetijstvu je prispevala značilnem povečanju pridelave hrane od šestdesetih let prejšnjega stoletja v svetu in pri nas.

Zaradi uporabe velikih količin direktne energije pa je sodobno kmetijstvo postalo tudi izredno odvisno od fosilnih goriv, kar velja tudi za sadjarsko pridelavo. Sodoben način pridelave hrane povzroča tudi velike emisije toplogrednih plinov ter odpadnih oziroma stranskih produktov. Toplogredni plini – TGP so plini, ki povzročajo učinek tople grede v Zemljinem ozračju. Glavnino toplogrednih plinov predstavljajo vodna para, ogljikov dioksid, metan dušikovi oksidi in ozon. Ugotovljeno je da so od začetka industrijske revolucije v koncu 18 stoletja koncentracija CO_2 v ozračju spreminjala od 280 ppm navzgor, v letu 2015 pa je že znašala 400 ppm in je trenutno najvišja v zadnjih 800000 let. Povišanje koncentracije je povzročila človeška dejavnost, predvsem sežiganje fosilnih goriv in krčenje gozdov. Zaskrbljujoče je da koncentracija CO_2 v ozračju narašča 2 ppm/leto, poleg tega naraščanje koncentracije celo pospešuje. Znanstveno razumevanje globalnega segrevanja narašča, IPCC je poročal leta 2014 da so znanstveniki prepričani z več kot 95 % verjetnostjo da je globalno segrevanje večinoma povzročeno zaradi naraščajočih koncentracij toplogrednih plinov in drugih antropogenih aktivnosti. Polovica ogljikovega dioksida, ki nastane z zgorevanjem fosilnih goriv pa ostaja v atmosferi in ni absorbirana z vegetacijo in oceani. Od škodljivih snovi, ki se izločijo v ozračje pri zgorevanju fosilnih goriv so okolju najbolj škodljivi ogljikov dioksid (CO_2), ogljikov monoksid (CO), dušikovi oksidi (NO_x), prašni delci itn. Pri zgorevanju mineralnega dizelskega goriva pri opravljanju različnih mehaniziranih delovnih operacij v sadjarstvu, s traktorji, ki so agregatirani s priključnimi stroji ali tudi drugimi stroji nastajajo emisije prej omenjenih škodljivih snovi (toplogrednih plinov) izražene z enoto kilogram ogljikovega dioksida - ekvivalent (kg CO_2 ekv.). V sadjarski pridelavi v Sloveniji v mehaniziranih delovnih operacijah prevladuje uporaba mineralnega dizelskega goriva zato so tudi emisije toplogrednih plinov iz tega vira najvišje. V prihodnosti pa bi večjo vlogo v kmetijski pridelavi morali odigrati alternativni viri energije in biogoriva nove generacije, s tem bi dosegali tudi zmanjšanje emisij toplogrednih plinov.

PREGLED LITERATURE

Uporaba energije (angl. kratica EU – Energy Use) je definirana, kot neto energija uporabljena za proizvodnjo kmetijskega pridelka dokler ni prodan in zapusti kmetijo oziroma je uporabljen, kot krma v živinoreji (Dalgaard in sodelavci 2001). Uporaba energije se lahko razčleni na direktno in indirektno energijo. Direktna energija ($EU_{direktna}$) predstavlja vnos energije v samo kmetijsko proizvodnjo. Ko se omenjeni vnos energije lahko direktno pretvori v energetske enote (porabljeno mineralno dizelsko gorivo, maziva, energija utekočinjenega naftnega plina ali zemeljskega plina za dosuševanje, električna energija za naknadno procesiranje pridelka itn.). Indirektna energija ($EU_{indirektna}$) je energija, ki je porabljena v proizvodnji vnosov uporabljenih v proizvodnji kmetijskega pridelka, ti vnosi pa ne morejo biti direktno pretvorjeni v energetske enote (stroji, gnojila, fito farmacevtska sredstva itn.).

V primeru mehanizirane sadjarske pridelave se uporablja za pogon traktorjev agregatiranih s priključnimi stroji in samovoznih kmetijskih strojev mineralno dizelsko gorivo, kar pomeni da je $EU_{direktna}$ posledica zgorevanja omenjenega goriva. Za celotne emisije CO_2 in drugih toplogrednih plinov, ki so nastali v procesu zgorevanja motorjev z notranjim zgorevanjem se da določiti ekvivalentna količina CO_2, ki je potrebna da povzroči efekt toplogrednega plina. Ta količina je izražena z enoto kilogram ogljikovega dioksida - ekvivalent (kgCO_2ekv.). Emisije mineralnega dizelskega goriva znašajo 3,18 kg $CO_{2ekv.}$/kg goriva oziroma 2,67 kg $CO_{2ekv.}$/l goriva (Guidelines to Defra/DECC's GHG Conversion Factors for Company Reporting, 2012). Različni avtorji poročajo, da je za porabo mineralnega dizelskega goriva za različne kmetijske operacije potrebno vzeti povprečne vrednosti, ker izmerjene vrednosti za porabo goriva, ki jih podajajo v l/ha ali kg/ha lahko zelo variirajo (Handler 2011; Dalgaard 2001; Jejčič in sodel. 2014). Ugotovljeno je da so emisije toplogrednih plinov $CO_{2ekv.}$/kg pridelka nižje pri konvencionalni in integrirani pridelavi v primerjavi z ekološko pridelavo sadja (Jejčič in sodelavci 2013, Al-Mansour in sodelavci 2015). Prej omenjeni avtorji tudi ugotavljajo da je pri ekološki proizvodnji sadja poraba energije nižja toda zaradi značilno nižjih pridelkov pri omenjeni proizvodnji so emisije $CO_{2ekv.}$/kg pridelka višje pri ekološki pridelavi v primerjavi s konvencionalno pridelavo. Do podobnih ugotovitev so prišli tudi nekateri drugi raziskovalci (Kumar 2012).

MATERIAL IN METODA DELA

V raziskavi so določeni ogljični odtisi za sadjarsko pridelavo v Sloveniji za pet vrst sadja (jabolka, hruška, breskev, marelica in oljka) za tri velikosti kmetije (mala, srednja in velika) ter tri vrsti pridelave (konvencionalna, integrirana in ekološka). Za določanje ogljičnega odtisa v sadjarski pridelavi (sadje za konzumno uporabo in predelavo v različne končne produkte, kot so sokovi, marmelade, žgane pijače itn.) je opravljena analiza konvencionalne, integrirane in ekološke pridelave glede porabe energije (v analizah se izhaja iz že vzpostavljenih sadovnjakov v polni rodni dobi). Za določanje porabe energije so narejeni modelni izračuni s podatki iz domačih in tujih znanstveno strokovnih baz, podatkov za porabo energije in emisije toplogrednih plinov v kmetijstvu ter z merjenjem porabe energije na vzorčnih kmetijah, zaradi dopolnitev podatkovne baze v primerih, kjer obstaja premajhna količina podatkov ali pa so podatki neuporabni za naše razmere zaradi specifičnosti sadjarske pridelave oziroma so nezanesljivi. Pri energetski analizi so razčlenjeni vnosi energije (direktna energija), ki je kompletno porabljena v obdobju pridelave sadja (eno leto). Vnosi energije skozi daljše časovno obdobje oziroma indirektna energija (za izdelavo traktorjev, priključnih strojev, opreme itn. ter energija za proizvodnjo mineralnih gnojili in zaščitnih sredstev) pa ni upoštevana v tej analizi. Za ugotavljanje porabe energije je izbrano nekaj vzorčnih kmetij. Poraba energije v mehanizirani sadjarski pridelavi je definirana, kot energija fosilnega goriva (mineralno dizelsko gorivo), ki se uporabi pri izvajanju različnih mehaniziranih delovnih operacij v enem letu. Celotna energija, ki se porabi za pridelavo sadja na površini enega hektarja, je ugotovljena s seštevanjem energetske porabe vsakega posameznega energetskega vnosa (1).

$$E_p = E_{ot} + E_g + E_n + E_v + E_p + E_t \tag{1}$$

E_p = Celotna energija porabljena v pridelavi sadja (MJ)

E_{ot} = energija za osnovno in dopolnilno obdelavo tal

E_g = energija za gnojenje

E_n = energija za nego

E_v = energija za varstvo

E_t = energija za interni transport pridelka

Poraba energije je ugotavljana pri opravljanju delovnih operacij s traktorskimi priključnimi stroji (agregat traktor + priključni stroj), ki so namenjeni za osnovno in dopolnilno obdelavo tal, gnojenje, nego, varstvo itn. Ugotovljena je količina mineralnega dizelskega goriva, ki se porabi pri izvajanju delovnih operacij s traktorji, ki so agregatirani z različnimi priključnimi stroji. Zajeta je tudi poraba goriva za interni transport pridelkov na sami kmetiji - transport s traktorji. Za merjenje porabe goriva je uporabljena volumetrična metoda. Pri ugotavljanju porabe energije v mehanizirani sadjarski pridelavi je ugotovljeno, da poraba goriva za enake delovne operacije lahko zelo variira, ker je odvisna npr. v primeru obdelave tal od samih pedofizikalnih lastnosti tal, načina obdelave tal, tehnike uporabe traktorskega agregata (traktor + priključni stroj), stanja stroja, usklajenosti moči trakorja glede velikosti priključnega stroja, števila prehodov traktorskih agregatov za posamezno delovno operacijo itn. Modelni izračuni so narejeni na osnovi povprečnih porab goriva za posamezne delovne operacije.

Vsi trije načini pridelave sadja imajo določene delovne operacije, ki so zelo podobne ali enake, kot so npr. gnojenje tal, nega nasadov, varstvo rastlin in pobiranje pridelka ter interni transport. Pri vseh omenjenih delovnih operacijah se uporablja energija mineralnega dizelskega goriva (pogon traktorjev z agregatiranimi priključnimi stroji). Večje razlike med načini pridelave so pri ostalih delovnih operacijah, npr. dopolnilna obdelava tal je predvidena v konvencionalni pridelavi v integrirani ali ekološki pa ne. V primeru dopolnilne obdelave tal (konvencionalna pridelava) je predvidena medvrstna obdelava tal z brananjem s krožno brano, oziroma možnost uporabe rotacijskih strojev za obdelavo tal (strojev, ki so gnani prek priključne gredi traktorja) in to vrtavkaste brane ali prekopalnika (freze). Pri rotacijskih strojih gnanih prek priključne gredi zadostuje za dopolnilno obdelavo tal večinoma en prehod prek obdelovalne površine za razliko od vlečenih izvedb traktorskih priključnih strojev npr. krožne brane, kjer sta potrebna dva ali celo trije prehodi. Za gnojenje je v primeru konvencionalne pridelave predvideno gnojenje s trosilnikom mineralnih gnojil. V primeru ekološke pridelave je predvideno gnojenje s trosilnikom hlevskega gnoja, v integrirani pridelavi pa uporaba trosilnika mineralnega gnoja in trosilnika hlevskega gnoja. V konvencionalni pridelavi v vinogradništvu se poleg varstva nasada s fitofarmacevtskimi sredstvi, uporablja še fitofarmacevtska sredstva - herbicide za zatiranje plevelov v vrstah v trajnih nasadih. V integrirani pridelavi se uporabljajo za varstvo nasadov samo določena fitofarmacevtska sredstva, za zatiranje plevelov v vrsti pa se uporabljajo mehanske metode oziroma mulčenje. Pri ekološki pridelavi se uporabljajo samo fitofarmacevtska sredstva, ki so dovoljena v tovrstni pridelavi, za vzdrževanje prostora v vrsti pa samo mehanske metode za zatiranje plevelov ali mulčenje. Za varstvo rastlin v konvencionalni in integrirani pridelavi je predvidena uporaba vinogradniških pršilnikov (z aksialno ali radialno izvedbo puhalnikov) za nanašanje fitofarmacevtskih sredstev. V integrirani pridelavi se uporabljajo fitofarmacevtska sredstva v manjših količinah, kar pomeni tudi manjše število prehodov traktorskih agregatov s pršilniki. Za nego je predvideno medvrstno vzdrževanje zatravljenih površin z mulčerji (kladivarji ali elisnimi), ki so namenjeni za mulčenje trave ter pri zimskem ali spomladanskem obrezovanju drobljenju ostankov obrezovanja. Pri ekološkem načinu pridelave je predvideno mehansko zatiranje plevelov v vrstah trajnih nasadov s traktorskimi priključnimi stroji.

Spravilo pridelka je ročno (prevladuje za spravilo grozdja v manjših vinogradih ter v večjih vinogradih za kakovostna in vrhunska vina) ali strojno s kombajni za grozdje (v večjih in velikih vinogradih, ki pridelujejo grozdje za namizna vina). Za interni transport so predvidene posebne izvedbe prikolic za boks palete in standardne traktorske prikolice.

Poraba energije v celotni pridelavi je tudi povezana z načinom gnojenja. Za gnojenje je predvidena uporaba mineralnega gnojila pri konvencionalni pridelavi, v integrirani je predvidena uporaba mineralnega gnojila in organskega gnoja (v razmerju 80 % mineralno in 20 % organsko gnojilo). Pri ekološki pridelavi pa je predvidena samo uporaba organskega gnoja (hlevski gnoj). Poraba gnojil je opredeljena na osnovi tehnoloških normativov. Količina gnojil je izražena v obliki čistih hranil (dušik, fosfor, kalij), količine gnojil pa so preračunane na količine pridelka. Za gnojenje je v primeru konvencionalne pridelave predvideno gnojenje s trosilnikom mineralnih gnojil. V primeru ekološke pridelave je predvideno gnojenje s trosilnikom hlevskega gnoja, v integrirani pa uporaba trosilnika mineralnega gnoja in trosilnika hlevskega gnoja. Določene so tudi porabe energije na enoto pridelka za posamezne delovne operacije. Poraba energije se razlikuje, ker se pri različnih načinih pridelave ne uporabljajo enake delovne operacije poleg tega so pridelki pri ekološkem načinu pridelave nižji v primerjavi s konvencionalno in integrirano pridelavo.

Za celotne emisije toplogrednih plinov, ki nastanejo v procesu zgorevanja goriva v motorjih traktorjev in različnih kmetijskih strojev se da določiti ekvivalentna količina CO_2, ki je potrebna da povzroči efekt toplogrednega plina. Toplogredni plini (TGP) so plini, ki povzročajo učinek tople grede v Zemljinem ozračju. Glavnino toplogrednih plinov predstavljajo vodna para, ogljikov dioksid, metan, amonijak in ozon. Količina toplogrednih plinov je izražena z enoto kilogram ogljikovega dioksida - ekvivalent (kg $CO_{2\ ekv.}$). Emisije toplogrednih plinov (CO_2, CH_4, in N_2O), ki nastanejo z zgorevanjem: mineralnega dizelskega goriva znašajo 2,67 kg $CO_{2\ ekv.}$/l goriva (IPCC 2012). Tudi emisije dušika (N) in drugih elementov iz organskih in mineralnih gnojil, so preračunane na ekvivalentne emisije CO_2 zaradi lažje primerjave vseh ekvivalentnih emisij CO_2 pri pridelavi. Celotne emisije toplogrednih plinov (TGP) iz energije, uporabljene v pridelovalnem procesu na enem hektarju sadovnjaka (t $CO_{2eq.}$ / ha), so izračunane, kot skupne emisije vsakega proizvodnega procesa, kot je prikazano v enačbi (2):

$$EMF_k = \sum_{j=1}^{m} \sum_{i=1}^{n} \left(\left(EF_i * \frac{X_i}{t_i} \right) * Ff_i \right)_j \qquad (2)$$

EMF_k: emisije TGP iz porabe energije za pridelavo produkta - sadja (k)

Ff_i: neposredni ali posredni emisijski faktor za fosilna goriva

EF: količina uporabljenih goriv ali druge vrste energije

X: število delovnih operacij na leto *(X= 0, 1, 2, 3….),*

t: povratna doba dejavnosti *(t=1,2,3…n),*

i: vrsta uporabljenih goriv ali energije,

j: vrsta delovne operacije (obdelava tal, gnojenje, varstvo rastlin, …),

k: vrsta sadja

Skupne emisije toplogrednih plinov (TGP) iz uporabljenih gnojil za en hektar (t $CO_{2\ ekv.}$ / ha) so prikazane v enačbi 3.

$$EMfr_k = \sum_{h=1}^{m}(QFr_{k,h} * EFr_h) \tag{3}$$

QFr: Količina porabljenega gnojila na en hektar (t / ha) za proizvod (k)

Ffr: TGP emisijski faktor za gnojila (kg $CO_{2\ eq}$. / kg)

h: elementi gnojil: dušik, fosfor, kalij, ...

Skupne emisije toplogrednih plinov $TEMF_k$ za en hektar sadovnjaka so enake seštevku emisij toplogrednih plinov od porabljene energije in uporabljenih gnojil

$$TEMF_k = EMF_k + EMfr_k \tag{4}$$

Ogljični odtis sadja $AgCF_k$ je izražen v rezultatih, kot razmerje med skupnimi emisijami toplogrednih plinov in celotnim pridelkom sadja, kar je prikazano v enačbi (5). Ogljični odtis je izražen v kg ekvivalenta CO_2 na tono pridelka - sadja [kg CO_2 ekv. / t].

$$\boldsymbol{AgCF_k = \frac{TEMF_k}{YF_k} 1000} \tag{5}$$

$AgCF_k$: ogljični odtis sadja [kg $CO_{2\ eq.}$/t],

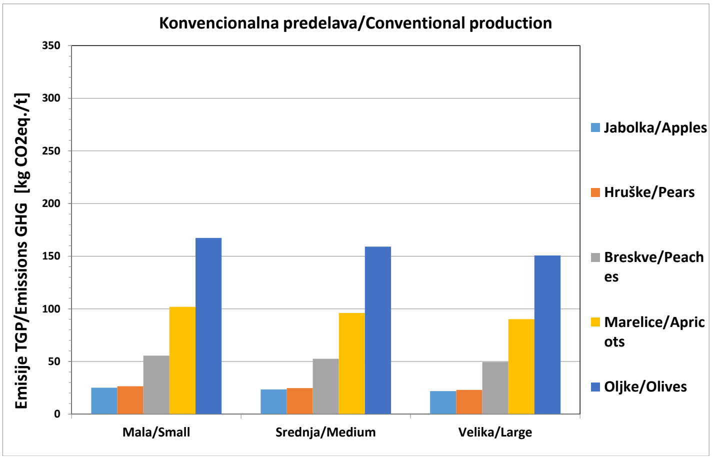
YF_k: pridelek sadja na en hektar [t/ha].

$TEMF_k$: Skupne emisije toplogrednih plinov od porabljene energije in gnojil za pridelavo na enem hektarju [kg CO_2/ha]

Emisije toplogrednih plinov so preračunane v kg ekvivalent CO_2 za pridelavo glede na način pridelave (konvencionalna, integrirana ali ekološka). Uporabljeni emisijski faktorji za izračun emisij toplogrednih plinov zaradi porabe fosilnih goriv so enaki emisijskim faktorjem, ki so uporabljeni v nacionalnih poročilih za mednarodne organizacije o emisijah toplogrednih plinov v Sloveniji (emisijski faktorji za CO_2, CH_4 in N_2O). Za varstvo rastlin so predvidena fitofarmacevtska sredstva, ki se uporabljajo pri konvencionalni in integrirani pridelavi (v prispevku je vrednotena samo direktna energija oziroma energija za pogon strojev za nanašanje fitofarmacevtskih sredstev). Za ekološko pridelavo pa so predvidena samo fitofarmacevtska sredstva, ki so dovoljena v ekološki pridelavi (ni uporabe konvencionalnih fitofarmacevtskih sredstev, dovoljena pa je uporaba bakrovih in nekaterih drugih preparatov), zamenjavo za herbicide pa predstavlja uporaba mehanskih metod za zatiranje plevelov (npr. traktorski priključni stroj, ki mehansko eliminira plevele v vrstah sadovnjaka, med vrstami pa se uporablja mulčenje). Pri izdelavi modela je predpostavljeno minimalno število nanašanja dovoljenih fitofarmacevtskih sredstev - bakrovi in nekateri drugi dovoljeni preparati. Za količine pridelkov so uporabljeni podatki KGZS in SURS (povprečje zadnjih deset let).

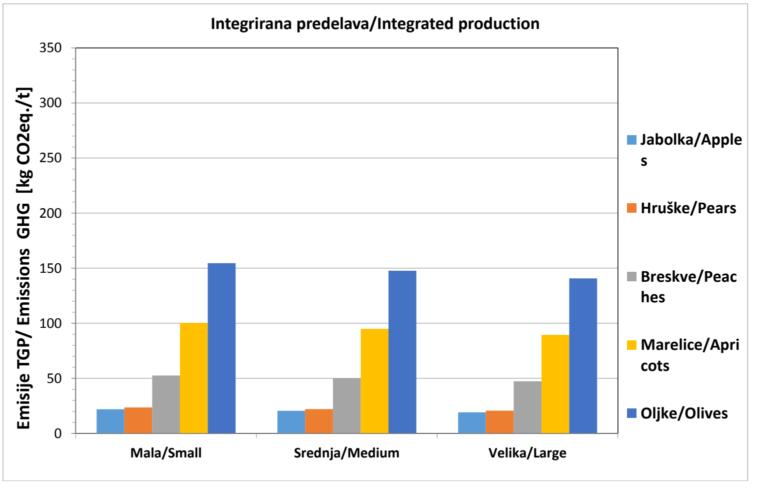
REZULTATI RAZISKAV

Ogljični odtisi za pridelke v sadjarstvu so določeni za: jabolke, hruške, breskve, marelice in oljke, za tri velikosti kmetije (mala do 5 ha, srednja od 5 do 10 ha in velika nad 10 ha) ter konvencionalno, integrirano in ekološko pridelavo. Emisije CO_2 nastanejo zaradi uporabe mineralnega dizelskega goriva pri vseh mehaniziranih opravilih v sadjarski pridelavi: osnovna in dopolnilna obdelava tal, gnojenje, varstvo, strojno pobiranje pridelka in interni transport pri pridelavi. Zaradi uporabe gnojil (anorganska in organska) nastanejo dodatne emisije toplogrednih plinov, ki so preračunane na ekvivalent CO_2. Seštevek emisij iz porabe mineralnega dizelskega goriva in gnojil (mineralnih in organskih) nam da končno emisijo CO_2. Ogljični odtisi v konvencionalni pridelavi sadja so določeni iz povprečne porabe mineralnega dizelskega goriva (poraba goriva izmerjena na kmetijah) za delovne operacije ter predvidenih količin gnojila (organskega in anorganskega) za določeni pridelek sadja. Emisije toplogrednih plinov v primeru male kmetije znašajo od 25,1 kg CO_2 ekv./t pridelka do 167,3 kg CO_2 ekv./t pridelka. V primeru srednje velikosti kmetije emisije znašajo od 23,4 kg CO_2 ekv./t do 159 kg CO_2 ekv./t pridelka. Za veliko kmetijo emisije znašajo od 21,8 kg CO_2 ekv./t do 150,6 kg CO_2 ekv./t pridelka. V primeru vseh treh tipov kmetij se najnižja vrednost emisij nanaša na jabolke, najvišja pa na oljke. Glede naraščanja višin emisij CO_2 ekv./t pridelka - sadja, jabolkam sledijo hruške, za tem pa breskve in marelice. Emisije CO_2 ekv./t pridelka – sadja, upadajo z velikostjo kmetije, najvišje so pri mali ter najnižje pri veliki kmetiji usmerjeni v sadjarsko pridelavo.



Slika 1 Emisije toplogrednih plinov kg CO_2 ekv. /t pridelka sadja (jabolke, hruške, breskve, marelice, oljke) za tri velikosti kmetij v primeru *konvencionalne sadjarske pridelave*
Fig. 1 Greenhouse gas emissions kg CO_2 eq. /t of fruits (apples, pears, peaches, apricots, olives) for the three farm sizes in the case of conventional fruit production

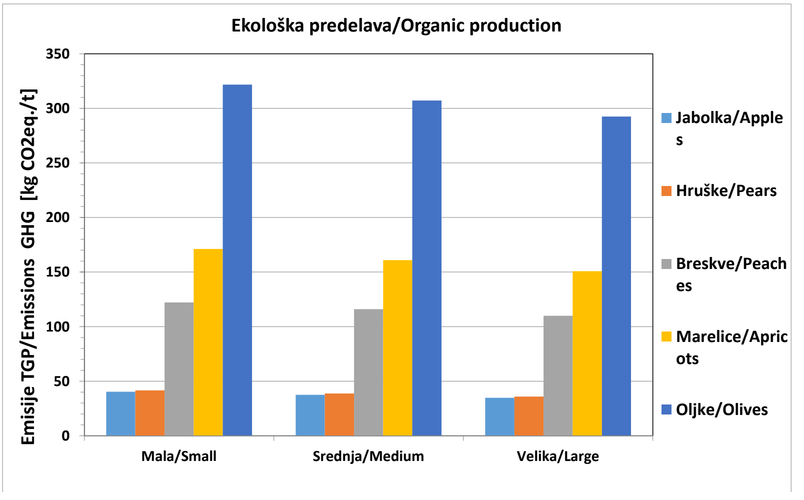
Ogljični odtisi v integrirani pridelavi sadja so določeni iz povprečne porabe mineralnega dizelskega goriva (poraba goriva izmerjena na kmetijah) za delovne operacije ter predvidenih količin gnojila (organskega in anorganskega) za določeni pridelek sadja. Emisije toplogrednih plinov v primeru male kmetije znašajo od 21,9 kg CO_2 ekv./t do 154,5 kg $CO_{2ekv.}$/t pridelka. V primeru srednje velikosti kmetije emisije znašajo od 20,6 kg CO_2 ekv./t do 147,6 kg CO_2 ekv./t pridelka. Za veliko kmetijo emisije znašajo od 19,2 kg CO_2 ekv./t do 140,7 kg CO_2 ekv. /t pridelka. V primeru vseh treh tipov kmetij se najnižja vrednost emisij nanaša na jabolke, najvišja pa na oljke. Glede naraščanja višin emisij CO_2 ekv./t pridelka - sadja, jabolkam sledijo hruške, za tem pa breskve in marelice. Emisije CO_2 ekv./t pridelka – sadja, upadajo z velikostjo kmetije, najvišje so pri mali ter najnižje pri veliki kmetiji usmerjeni v sadjarsko pridelavo. Emisije CO_2 ekv. /t pridelka – sadja upadajo z velikostjo kmetije, najvišje so pri mali ter najnižje pri veliki kmetiji usmerjeni v sadjarsko pridelavo.



Slika 2 Emisije toplogrednih plinov kg CO_2 ekv. /t pridelka sadja (jabolke, hruške, breskve, marelice, oljke) za tri velikosti kmetij (mala, srednja, velika) v primeru *integrirane sadjarske pridelave*

Fig. 2 Greenhouse gas emissions kg CO_2 eq. /t of fruits (apples, pears, peaches, apricots, olives) for the three farm sizes in the case of integrated fruit production

Emisije v ekološki pridelavi sadja so določene iz povprečne porabe mineralnega dizelskega goriva (poraba goriva izmerjena na kmetijah) za delovne operacije ter predvidenih količin gnojila (organskega in anorganskega) za določeni pridelek sadja. Emisije toplogrednih plinov v primeru male kmetije znašajo od 40,3 kg CO_2 ekv./t do 321,74 kg CO_2 ekv./t pridelka. V primeru srednje velikosti kmetije emisije znašajo od 37,6 kg CO_2 ekv./t do 307,11 kg CO_2 ekv./t pridelka. Za veliko kmetijo emisije znašajo od 34,8 kg CO_2 ekv./t do 292,4 kg CO_2 ekv./t pridelka. Vidna je tudi velika razlika v ogljičnem odtisu med pridelavo jabolk in oljk, npr. za malo kmetijo ogljični odtis je celo 7,9 krat višji v primeru oljk. V primeru vseh treh tipov kmetij se najnižja vrednost emisij nanaša na jabolke, najvišja pa na oljke. Glede naraščanja višin emisij $CO_{2ekv.}$/t pridelka - sadja, jabolkam sledijo hruške, za tem pa breskve in marelice. Emisije $CO_{2ekv.}$/t pridelka – sadja upadajo z velikostjo kmetije, najvišje so pri mali ter najnižje pri veliki kmetiji usmerjeni v sadjarsko pridelavo.



Slika 3 Emisije toplogrednih plinov kg CO_2 ekv. /t pridelka sadja (jabolke, hruške, breskve, marelice, oljke) določene za tri velikosti kmetij (mala, srednja, velika) v primeru *ekološke sadjarske pridelave*
Fig. 3 Greenhouse gas emissions kg CO_2 eq. /t of fruits (apples, pears, peaches, apricots, olives) for the three farm sizes in the case of organic fruit production

Integrirana in ekološka pridelava se glede mehaniziranih delovnih postopkov najbolj razlikujeta od konvencionalne pridelave. Iz tega izhajajo tudi razlike v porabi energije med posameznimi pridelavami. Tako se v konvencionalni sadjarski pridelavi lahko uporablja tudi dopolnilna obdelava tal, za vzdrževanje medvrstnega prostora v sadovnjaku pa se uporablja škropljenje s herbicidi za zatiranje plevelov in trave v vrsti. Poleg tega ima konvencionalna pridelava največje število škropljenj v primerjavi z integrirano in ekološko pridelavo. V integrirani pridelavi ni dopolnilne obdelave tal za vzdrževanje medvrstnega prostora v vinogradu (za vzdrževanje omenjenga prostora v sadovnjaku se uporablja mulčenje ter škropljenje plevelov s herbicidi v vrsti). Poleg tega je število škropljenj v tej pridelavi zmanjšano v primerjavi s konvencionalno pridelavo. V ekološki pridelavi se za vzdrževanje zatravljenega prostora v sadovnjaku uporablja med vrstno mulčenje in košnja tal v vrsti. Mulčenje se opravlja z elisnimi ali mulčerji kladivarji, poraba dovoljenih fitofarmacevtskih sredstev za varstvo sadnih dreves je zmanjašana, tako da je število škropljenj še nižje v primerjavi z integrirano pridelavo. Razlika je tudi pri porabi energije za gnojenje, pri konvencionalni pridelavi se uporablja gnojenje z mineralnimi gnojili. V primeru integrirane pridelave je predvidena uporaba mineralnega in hlevskega gnoja, za ekološko pridelavo pa je predvideno, da se uporablja hlevski gnoj. V ekološki pridelavi se uporabljajo organska gnojila (gnoj), ki imajo nižje emisije toplogrednih plinov v primerjavi z anorganskimi gnojili (mineralna gnojila). Poleg tega se v ekološki pridelavi lahko tudi uporablja kombinacija organskih gnojil v kombinaciji s počasi topnimi mineralnimi gnojili. *Za vse tri načine sadjarske pridelave (konvencionalna, integrirana, ekološka) ter tri velikostne razrede kmetij je značilno da najmanjši ogljični odtis ima pridelava jabolk, sledi pa pridelava hrušk, breskev, marelic in oljk.*

ZAKLJUČEK

Ugotovljeno je da so emisije toplogrednih plinov v sadjarski pridelavi izražene v CO_2 ekv./t sadja najnižje pri integrirani pridelavi, višje pri konvencionalni ter najvišje pri ekološki pridelavi sadja. V primeru vseh treh tipov kmetij se najnižja vrednost emisij nanaša na jabolke, najvišja pa na oljke. Glede naraščanja višin emisij CO_2 ekv./t pridelka, jabolkam sledijo hruške, za tem pa breskve in marelice. Emisije CO_2 ekv./t pridelka, upadajo z velikostjo kmetije, najvišje so pri mali ter najnižje pri veliki kmetiji usmerjeni v sadjarsko pridelavo. Emisije TGP so najvišje pri oljkah zaradi nižjega hektarskega pridelka v primerjavi z ostalim sadnimi vrstami in velikih potreb po gnojilu (velike količine dušika). Emisije so pri mali kmetiji višje tudi zaradi uporabe traktorskih agregatov manjše moči, ki so energetsko manj učinkoviti v primerjavi s traktorskimi agregati večje moči, poleg tega je več praznih hodov pri strojnih opravilih na majhnih delovnih površinah. Razlika je tudi pri porabi energije za gnojenje, pri konvencionalni pridelavi se uporablja gnojenje z mineralnimi gnojili, v primeru integrirane pridelave je predvidena uporaba mineralnega in hlevskega gnoja, za ekološko pridelavo pa je predvideno, da se uporablja samo hlevski gnoj. V ekološki pridelavi se uporabljajo organska gnojila (gnoj), ki imajo nižje emisije toplogrednih plinov v primerjavi z mineralnimi gnojili. Poleg tega se v ekološki pridelavi lahko tudi uporablja kombinacija organskih gnojil v kombinaciji s počasi topnimi mineralnimi gnojili.

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CARBON FOOTPRINT OF FRUIT PRODUCTION

ABSTRACT

Carbon footprint of mechanized orchard production in Slovenia was determined. An analysis of the carbon footprint in the case of conventional, integrated and organic fruit production for the three sizes of orchard farms (small, medium and large) and five fruit productions (apple, pear, peach, apricot and olive) was made. In all mechanized working operations in fruit production, energy of mineral diesel fuel is used to power tractors aggregated with implements. The analysis covered the equivalent CO_2 emissions from the consumption of mineral diesel fuel to power tractors aggregated with implements (direct energy consumed in the process of orchard production). In addition to the CO_2 emissions from the mineral diesel fuel used in the fruit production, also were covered greenhouse gas emissions resulting from the use of organic and mineral fertilizers in the production and converted to equivalent CO_2. In the case of conventional production in orchards, provided is use of mineral fertilizers, in integrated orchard production combination of mineral and organic fertilizers and in organic orchard production only usage of organic fertilizers. The sum of equivalent CO_2 emissions resulting from using mineral diesel fuel for mechanized working operations and CO_2 equivalent emissions from fertilizers used in the orchard production process, results in the total emissions of $CO_{2equ.}$/t of fruit produced. It has been found that emissions of $CO_{2equ.}$ /t of fruit, are the lowest in integrated, higher in conventional and highest in the organic fruit production.

Key words: *CO_2 emissions, conventional production, organic production, carbon footprint*

44. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

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Stručni rad
Expert paper

OGLJIČNI ODTIS PRIREJE MLEKA

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IZVLEČEK

Določen je ogljični odtis konvencionalne in ekološke prireje mleka za tri velikost kmetij. Analiza emisij toplogrednih plinov je pokazala, da prireja mleka (emisije od začetka procesa v hlevu do konca procesa v hlevu) ustvari od 0,71 kg $CO_{2ekv.}$/kg mleka do 0,74 kg $CO_{2ekv.}$/kg mleka (odvisno od velikosti črede in tehnologije reje) pri strojni molži ter 0,75 kg $CO_{2ekv.}$/kg mleka pri robotizirani molži v konvencionalnem načinu kmetovanja. Za ekološki način prireje mleka je analiza emisij toplogrednih plinov pokazala, da prireja mleka (emisije od začetka procesa v hlevu do konca procesa v hlevu) ustvari od 1,02 kg $CO_{2ekv.}$/kg mleka do 1,06 kg $CO_{2ekv.}$/kg mleka (odvisno od velikosti črede in tehnologije reje) pri strojni molži ter 1,06 kg $CO_{2ekv.}$/kg mleka pri robotizirani molži. Določeni so tudi ogljični odtisi mleka v embalaži in nekaterih drugih mlečnih izdelkov. Emisijam toplogrednih plinov iz prireje mleka so prištete emisije toplogrednih plinov, ki nastanejo v samem procesiranju mleka (pasteriziranje, steriliziranje, homogeniziranje, proizvodnja sirov itn.) v mlečne izdelke. Pri konvencionalnem načinu prireje mleka - za tri velikosti kmetij (strojna molža in robotizirana molža), celotne emisije toplogrednih plinov (prireja + procesiranje mleka) znašajo: pri pasteriziranem mleku v embalaži od 0,8 kg do 0,83 kg $CO_{2ekv.}$/kg izdelka, pri mleku v embalaži obdelanem z UVT metodo od 0,86 do 0,89 kg $CO_{2ekv.}$/kg izdelka, pri mleku v prahu od 1,13 do 1,15 kg $CO_{2ekv.}$/kg izdelka ter pri siru od 1,07 do 1,10 kg $CO_{2ekv.}$/kg izdelka. Pri ekološkem načinu prireje mleka za tri velikosti kmetij (strojna molža in robotizirana molža), celotne emisije (prireja + procesiranje mleka) toplogrednih plinov znašajo: pri pasteriziranem mleku v embalaži od 1,10 kg do 1,15 kg $CO_{2ekv.}$/kg izdelka, pri mleku v embalaži obdelanem z UVT metodo od 1,16 do 1,21 kg $CO_{2ekv.}$/kg izdelka, pri mleku v prahu od 1,43 do 1,48 kg $CO_{2ekv.}$/kg izdelka ter pri siru od 1,37 do 1,41 kg $CO_{2ekv.}$/kg izdelka.

Ključne besede: *emisije toplogrednih plinov, električna energija, dizelsko gorivo*

UVOD

Kmetijstvo samo prispeva znaten delež emisij toplogrednih plinov, zato bo v prihodnosti soočeno tudi s precejšnjimi zahtevami za zmanjševanje njihovih emisij. Za kmetijstvo prihodnosti bo največji izziv ustvariti pravilno ravnotežje med zagotavljanjem zadostnih količin hrane in drugih surovin za prebivalstvo in emisijami toplogrednih plinov, ki nastajajo v življenskem ciklu različnih kmetijskih produktov (od pridelave do predelave v končni pridukt ter njegovega konca). Najpomembnejši toplogredni plini so ogljikov dioksid, metan in dušikovi oksidi. Toplogredni plini se v kmetijstvu sproščajo v vseh fazah življenskega cikla nekega produkta zaradi rabe energije za pogon kmetijskih strojev, uporabe mineralnih in organskih gnojil, predelavi v končne produkte, skladiščenju itn. Gospodarna in ekološko naravnana kmetijska pridelava, ki je vse bolj v ospredju kmetijske pridelave pa postavlja zahteve po zmanjševanju porabe energije ter posledično emisij toplogrednih plinov. V sodobni kmetijski pridelavi ter živinoreji del toplogrednih plinov nastane, kot posledica uporabe različne kmetijske mehanizacije oziroma procesne opreme. Zaradi skrbi za življensko okolje so zasnovane metode, ki ugotavljajo vpliv določenih produktov na okolje. Najbolj uporabljena in uveljavljena je metoda analize življenjskega cikla (angl. Life cycle analysis, kratica LCA), ki analizira vpliv nekega izdelka na okolje v vseh življenjskih fazah: proizvodnji, uporabi in odstranitvi. LCA je računski sistem, ki opisuje in kvantificira indikatorje okoljske sprejemljivosti in merljivosti, v zadnjem obdobju pa se uporablja tudi v kmetijstvu. V primeru kmetijstva se analiza življenskega cikla nanaša na: pridelavo, predelavo ter konec kmetijskega produkta. V vseh fazah življenskega cikla se porablja energija, ki poleg nekaterih drugih procesov prispeva emisijam toplogrednih plinov (kratica TGP). Ogljični odtis je izraz za skupek ogljikovega dioksida ter drugih toplogrednih plinov, ki jih v okolje neposredno ali posredno spusti določen objekt, naprava, izdelek, proces ali telo. Ogljični odtis je mogoče izračunati in ovrednotiti. Zaradi poenostavljenega razumevanja so emisije toplogrednih plinov preračunane na ekvivalent ogljikovega dioksida, ki je med toplogrednimi plini, najbolj prepoznaven.

PREGLED LITERATURE

Energija, ki je porabljena v kmetijstvu se lahko razčleni na direktno in indirektno energijo. Direktna energija ($EU_{direktna}$) predstavlja vnos energije v kmetijsko proizvodnjo, ki se lahko direktno pretvori v energetske enote (porabljeno mineralno dizelsko gorivo, maziva, energija utekočinejnega naftnega plina – UNP ali zemeljskega plina za gretje, električna energija za različne procese, predelavo končnega produkta itn.). Indirektna energija ($EU_{indirektna}$) je energija, ki je porabljena v proizvodnji različnih inputov (vnosov), ki so uporabljenih v proizvodnji kmetijskega pridelka ali končnega produkta, omenjeni vnosi pa ne morejo biti direktno pretvorjeni v energetske enote (stroji, gnojila, fito farmacevtska sredstva, objekti na kmetiji itn). Celotna energija (Dalgaard in sodelavci 2001) se lahko predstavi s pomočjo enačbe (1).

$$EU_{celotna} = EU_{direktna} + EU_{indirektna}\,(\mathrm{MJ}) \qquad (1)$$

Predstavljena enačba se lahko uporabi v primeru različnih kmetijskih pridelav. V našem primeru smo jo uporabili za analizo porabe energije v procesu reje živali – krav molznic.

Direktno energijo, ki je porabljena v procesu reje živali se lahko dodatno razčleni na vse oblike energije porabljene v procesu reje živali (Jejčič in sodelavci 2013, 2014).

$$EU_{direktna} = (EU_{električna} + EU_{dizel} + EU_{ostala})\ (\mathrm{MJ}) \tag{2}$$

$EU_{električna}$ = električna energija porabljena v procesu reje

EU_{dizel} = energija iz mineralnega dizelskega goriva porabljenega v procesu reje živali

EU_{ostala} = ostala energija porabljena v porcesu reje živali (iz drugih virov ali alternativnih energetskih virov).

Toplogredni plini – TGP so plini, ki povzročajo učinek tople grede v Zemljinem ozračju. Glavnino toplogrednih plinov predstavljajo vodna para, ogljikov dioksid, metan, amonijak in ozon. Izračun emisij toplogrednih plinov iz posameznega procesa v sklopu reje krav molznic je rezultat emisij zaradi porabe energije iz uporabljenega mineralnega dizelskega goriva in električne energije. Uporabljeni emisijski faktorji za izračun emisij toplogrednih plinov zaradi porabe goriva ali električne energije energije so enaki emisijskim faktorjem, ki so uporabljeni v nacionalnih poročilih za mednarodne organizacije o emisijah toplogrednih plinov v Sloveniji (emisijski faktorji za CO_2, CH_4 in N_2O). Emisije toplogrednih plinov so preračunane v kg ekvivalent CO_2 za prirejo mleka glede na način reje krav molznic - konvencionalna ali ekološka prireja mleka (Jejčič in sodelavci 2013).

Sodobno kmetijstvo je izredno odvisno od virov fosilnih goriv. Tudi v govedoreji se rabijo fosilna goriva, npr. v primeru mehanizirane pridelave krme, transporta gnoja in gnojevke itn., se uporablja za pogon traktorjev s priključnimi stroji oziroma samovoznih kmetijskih strojev, mineralno dizelsko gorivo. Porabljena energija, $EU_{direktna}$ iz mineralnega dizelskega goriva je posledica zgorevanja omenjenega goriva v motorjih traktorjev in samovoznih kmetijskih strojev. Pri popolnem zgorevanju goriv, ki vsebujejo ogljikovodike, teoretično nastajata samo ogljikov dioksid (CO_2) in vodna para (H_2O). Poleg tega vsebujejo produkti zgorevanja tudi odvečni kisik (O_2) in dušik (N_2). Ker pa zgorevanje ni nikoli popolno, je v izpušnih plinih še veliko drugih produktov (Gruden 2011). Za celotne emisije toplogrednih plinov (CO_2, CH_4, in N_2O), ki nastanejo v procesu zgorevanja goriva v motorjih traktorjev in drugih kmetijskih strojev se da določiti ekvivalentna količina CO_2, ki je potrebna da povzroči efekt toplogrednega plina. Omenjena količina je izražena z enoto kilogram ogljikovega dioksida - ekvivalent (kg CO_{2ekv}). Emisije toplogrednih plinov (CO_2, CH_4, in N_2O), ki nastanejo z zgorevanjem: mineralnega dizelskega goriva znašajo 2,67 kg CO_{2ekv}/l goriva (podatki IPCC 2012). Električna energija lahko izhaja iz različnih virov (hidro elektrarne, termo elektrarne, jedrske elektrarne, obnovljivi viri energije) zato je pri izračunih uporabljen podatek o mešanici emisij TGP v kg CO_{2ekv} /kWh za njo. Za emisije kg CO_{2ekv}/kWh iz proizvodnje električne energije v R. Sloveniji je vzet podatek 0,516 kg CO_{2ekv}/kWh (Jejčič in sodelavci 2013)

MATERIAL IN METODA DELA

Živinorejske ali mešane kmetije, ki se ukvarjajo s prirejo mleka smo za potrebe določanja porabe energije razdelili glede števila živali na kmetije z malo čredo 5 – 10 GVŽ, srednje veliko čredo 11 – 60 GVŽ ter veliko čredo 61 do 120 GVŽ. Tehnologije, ki se uporabljajo na mlečnih farmah se razlikujejo glede načina reje (vezana, prosta, globoki nastilj), velikosti črede in glede tega ali je prireja mleka na konvencionalen ali ekološki način prireje. Zaradi lažjega in bolj organiziranega dela ter večje produktivnosti se v reji krav molznic uporabljajo različni mehanizirani sistemi: za krmljenje, odstranjevanje gnoja, zračenje, molžo, ohlajanje mleka in razsvetljavo. Vsak od sistemov ima lahko več podsistemov oziroma se znotraj vsakega sistema uporablja različna strojna oprema oziroma stroji. Za delovanje omenjenih sistemov je potrebna energija (v analizi je upoštevano opravljanje delovnih operacij, kjer se uporablja energija iz različnih virov, ročne delovne operacije niso upoštevane). Za ugotavljanje porabe energije na kmetijah usmerjenih v prirejo mleka smo opravili analizo porabe celotne energije, ki je potrebna v procesu prireje mleka (v analizi prireje mleka v konvencionalni in ekološki reji je upoštevano da se uporablja električna energija in mineralno dizelsko gorivo).

V prireji mleka so pri mehaniziranih delovnih operacijah, kjer se uporabljajo električni stroji in oprema zajeti, stroji za molžo, hlajenje mleka, čiščenje gnoja, prezračevanje objektov ter električna razsvetljava. Pri malih čredah se uporablja molža v vrč povezan z vakuumsko črpalko, pri srednje velikih in velikih čredah pa molža s sistemom mlekovoda in vakuumsko črpalko. Pri velikih čredah obstaja še možnost uporabe robota za molžo (sistem se trenutno uporablja na majhnem številu kmetij). Za krmljenje se uporabljajo različni sistemi, pri majhnih čredah in ekološkem načinu reje, je še vedno prisotno veliko ročnega dela. V primeru, da se uporabljajo krmilno mešalni vozovi (traktorski priključki), je predvideno, da se omenjeni sistemi uporabljajo na kmetijah s srednje veliko in veliko čredo. V primeru velike črede, kjer se uporablja robot za molžo smo dodatno predvideli tudi uporabo samovoznih krmilno mešalnih vozov (izvedba z lastnim pogonskim motorjem). Za transport krme v hlev in krmljenje se uporabljajo krmilno mešalne prikolice, ki v traktorskem agregatu za delovanje rabijo mineralno dizelsko gorivo. Poleg odvzema silaže iz koritastih silosov, krmilno mešalne prikolice omogočajo tudi pripravo celotnih obrokov – mešanice voluminozne krme, silaže, koncentratov in dodatkov v sami prikolici. Tako pripravljena krmna mešanica se zatem razdeli v jasli. Za odstranjevanje gnoja, v primeru reje na rešetkah se gnojevka zbira v zbiralniku gnojevke, kjer jo je potrebno premešati, črpati in razvažati s cisternami za gnojevko na kmetijske površine. Za mešanje, črpanje in razvoz gnojevke se uporabljajo traktorski agregati, ki uporabljajo mineralno dizelsko gorivo. Za hlajenje mleka se uporabljajo sistemi za hlajenje s hladilnimi bazeni za mleko, kjer se rabi električna energija, za prezračevanje se uporabljajo električni ventilatorji, za razsvetljavo pa različne izvedbe električnih svetil. Za vzdrževanje higiene v hlevu pa se uporabljajo visokotlačne naprave za pranje z električnim pogonom. Celotna energija porabljena v prireji mleka predstavlja seštevek porabljene električne energije in porabljenega mineralnega dizelskega goriva. Indirektna energija ni posebno razčlenjena, ker je v primeru naših izračunov nismo upoštevali (težko jo je natančno definirati, avtorji, ki jo uporabljajo vzamejo splošne podatke za porabo energije v proizvodnji strojev industriji ali avtomobilski industriji, omenjeni podatki pa ne ustrezajo realni porabi energije za proizvodnjo traktorjev in kmetijske mehanizacije). V primeru pa da prištejemo še indirektno energijo je poraba energije v procesu reje živali – krav molznic višja, kar pomeni tudi višje emisije toplogrednih plinov oziroma $CO_{2ekv.}$, ter višji končni ogljični odtis končnega produkta – mleka.

Za ugotavljanje porabe električne energije smo razvili in izdelali prenosne električne merilnike, ki smo jih povezali s posameznimi stroji ali celotno električno instalacijo hleva.

Zaradi zanesljivosti meritev smo meritve vseh električnih strojev opravljali skozi daljše časovno obdobje tako da smo posamezni električni stroj spremljali več dni, tednov in celo mesecev. Na ta način so zajete na električnih strojih tudi porabe električne energije, ki jih v krajšem časovnem intervalu ne bi uspešno zajeli. Npr. pri robot molži je zelo pomembno opravljati meritve porabe električne energije skozi daljše časovno obdobje, zaradi specifičnosti same tehnologije in načina uporabe (omenjeni stroj je v stanju pripravljenosti skozi cel dan, krave molznice pa hodijo na prehranjevanje in molžo tudi po večkrat na dan). Iz števila delovnih ur, ki jih opravijo električni stroji se določa kumulativna poraba električne energije.

Slika 1 Prenosni merilnik porabe električne energije, ki se povezuje s posameznimi stroji ali s celotno električno instalacijo v hlevu; merilnik beleži trenutno, maksimalno, kumulativno itn. porabo električne energije priključenih strojev
Fig. 1 Portable device for measuring electric energy consumption, connected with electrical machines, devices or the entire electrical installation in the barn; device records the current, maximum, cumulatively etc. electrical energy consumption of connected electrical machines and devices

Za porabo energije traktorjev s priključnimi stroji, ki se uporabljajo v prireji mleka smo opravili meritve porabe mineralnega dizelskega goriva (volumetrična metoda) pri opravljanju različnih delovnih operacij. Npr. merjenje porabe energije za mehanizirano krmljenje živali smo opravili na strojih za odvzem silaže iz koritastih silosov in krmilno mešalnih prikolicah. Poraba mineralnega dizelskega goriva je izražena v l/ha.

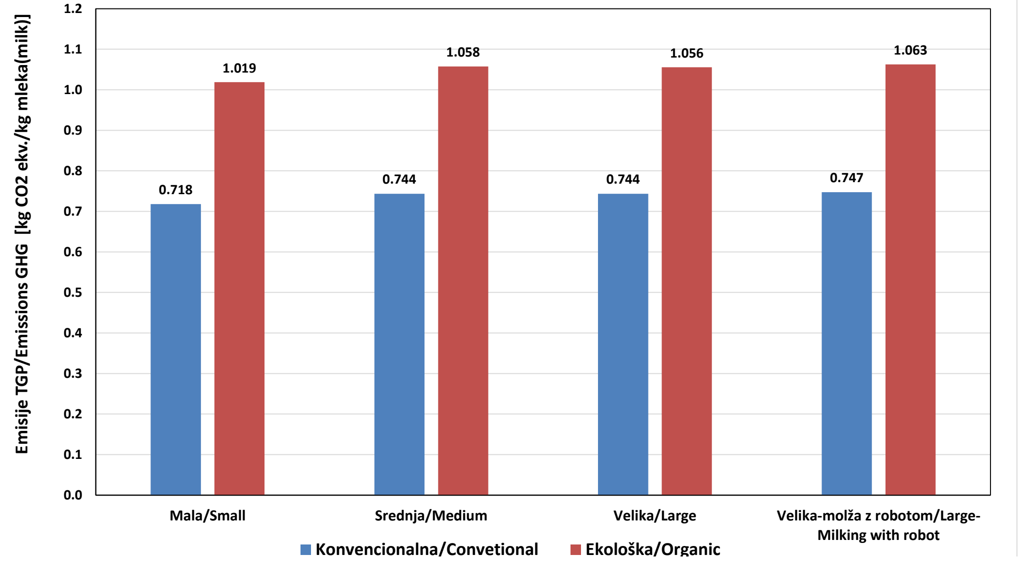
REZULTATI RAZISKAV

Ugotovljeno je da se poraba celotne energije na eno kravo molznico (seštevek porabljene energije iz mineralnega dizelskega goriva in porabljene električne energije) glede velikosti črede giblje od 418,43 kWh/žival leto do maksimalno 829,28 kWh/žival leto pri konvencionalnem načinu reje krav molznic ter strojni molži. Poraba energije narašča s številom živali v reji ter intenzivnostjo uporabe mehanizirnih postopkov. V porabi celotne energije za konvencionalno rejo odpade 56,3 % na električno energijo in 43,7 % na energijo iz mineralnega dizelskega goriva. Ugotovljeno je, da se od celotno porabljene energije 56,3 % nanaša na električno energijo v prireji mleka (hlajenje mleka, molzne naprave, razsvetljavo objekta z živalmi, gretje vode za procesne potrebe, itn.) ter 43,7 % na energijo mineralnega dizelskega goriva (za pogon krmilno mešalnega voza). Pri električni energiji so največji porabniki hlajenje z 38,1 %, molža z 28,5 % in razsvetljava z 23,4 % (90 % odpade na naštete porabnike). Pri robotski molži je poraba električne energije višja v primerjavi s konvencionalno molžo. V primeru ekološke pridelave se poraba celotne energije nekoliko zmanjša zaradi paše. V tem primeru se zmanjša tudi poraba energije mineralnega dizelskega goriva za krmljenje (krmilno mešalni voz), ker se krave določeni del leta pasejo, poleg tega pa se zmanjšajo tudi potrebe po električni energiji za zračenje, razsvetljavo itn. Poraba energije za molžo in hlajenje pa ostane enaka, ker molža in hlajenje mleka v večini primerov poteka na enak način. V primeru ekološke reje se poraba energije giblje od 249,16 kWh/žival leto do maksimalno 584,73 kWh/žival leto, pri robot molži pa se poveča in doseže maksimalno 646,42 kWh/žival leto. Za ekološko rejo v porabi celotne energije odpade 70,3 % na električno energijo in 29,7 % na energijo iz mineralnega dizelskega goriva (pogon krmilno mešalnega voza). Pri ekološki reji je manjša uporaba krmilno mešalnega voza in posledično manjša poraba mineralnega dizelskega goriva.

Opravljene meritve porabe energije so pokazale, da je največji porabnik energije krmljenje, kjer se uporablja krmilno mešalni voz - traktorski priključek (za pogon traktorja se rabi mineralno dizelsko gorivo, traktor pa zaradi energetskih izgub pri dizelskem motorju in transmisiji traktorja prenese manjši del energije, ki je vsebovana, kot kemična energija v gorivu na stroj, ki je priključen na traktor, v tem primeru krmilno mešalni voz).

Na osnovi porabe energije se da določiti ogljični odtis prireje mleka. Določeni so ogljični odtisi za prirejo mleka glede velikosti kmetije (mala, srednja, velika) ter dva načina reje živali (konvencionalna in ekološka). Analiza emisij toplogrednih plinov v proizvodnji mleka je pokazala, da prireja mleka (emisije od začetka procesa v hlevu do konca procesa v hlevu) ustvari od 0,718 kg CO_{2ekv}./kg mleka do 0,74 kg CO_2 ekv./kg mleka (odvisno od velikosti črede in tehnologije reje) pri strojni molži ter 0,75 kg CO_{2ekv}./kg mleka pri robotizirani molži v konvencionalnem načinu kmetovanja. Za ekološki način reje je analiza emisij toplogrednih plinov v proizvodnji mleka pokazala, da prireja mleka (emisije od začetka procesa v hlevu do konca procesa v hlevu) ustvari od 1,02 kg CO_2 ekv./kg mleka do 1,06 kg CO_{2ekv}./kg mleka (odvisno od velikosti črede in tehnologije reje) pri strojni molži ter 1,06 kg CO_{2ekv}./kg mleka pri robotizirani molži.

Mleko se predela v različne mlečne izdelke, ki so glede porabe energije za procesiranje različno zahtevni. Za procesiranje mleka v različne mlečne izdelke se uporabljajo različne metode, prevladujejo pa termične metode, ki so energetsko tudi najbolj potratne. Najbolj razširjena je pasterizacija, ki predstavlja termalno uničevanje mikroorganizmov s temperaturami do 100 °C, sterilizacija s temperaturami 115 – 120 °C (20 – 45 min) ter UVT postopek s temperaturami 140 – 165 °C za nekaj sekund. UVT proces se uporablja za pred obdelavo mleka in proizvodnjo steriliziranega UVT mleka, sterilizacija pa se uporablja za mleko, ki mora biti dalj obstojno. Pasterizacija danes porabi manjši del energije (ponovna uporaba toplotne energije je med 90 – 94 %). UVT postopek in sterilizacija sta energijsko bolj potratna kot pasterizacija. Pri sterilizaciji je temperatura precej višja in na splošno temperaturna razlika med virom toplote in mlekom, ki ga je potrebno sterilizirati precej višja, kot pri pasterizaciji. Tendenca večje proizvodnje mleka, ki je obdelano z UVT postopkom v primerjavi s pasteriziranim mlekom, vpliva na porabo večjih količin energije za procesiranje določene enote mleka.



Slika 2 Ogljični odtisi prireje mleka pri konvencionalni in ekološki prireji mleka za tri velikosti kmetij, v primeru velike kmetije je dodatno podana tudi molža z robotom
Fig. 2 The carbon footprint of milk production in conventional and organic milk production for the three sizes of farms, in the case of large farm additionally is given also milking robot

Določeni so tudi ogljični odtisi mleka v embalaži in nekaterih mlečnih izdelkov glede velikosti kmetije za prirejo mleka (mala, srednja, velika) in načina prireje mleka (konvencionalna, ekološka). Ogljični odtisi zajemajo emisije toplogrednih plinov, ki nastajajo pri prireji mleka (na sami kmetiji) ter nadaljnji predelavi oziroma procesiranju mleka (toplotna obdelava, pakiranje, izdelava jogurtov, sirov, itn.) v mlečne izdelke. Emisijam toplogrednih plinov iz prireje mleka (izražene v $CO_{2ekv.}$/kg mleka) so prištete emisije toplogrednih plinov (izražene v $CO_{2ekv.}$/kg mleka) za samo procesiranje mleka (zajete so emisije toplogrednih plinov, ki nastanejo pri različnih postopkih procesiranja mleka, kot so: pasteriziranje, steriliziranje, homogeniziranje, proizvodnja sirov itn.) v mlečne izdelke. Ugotovili smo, da pri konvencionalnem načinu prireje mleka za tri velikosti kmetij (strojna molža in robotizirana molža), celotne emisije (prireja mleka + procesiranje mleka) toplogrednih plinov znašajo: pri pasteriziranem mleku v embalaži od 0,8 kg do 0,83 kg $CO_{2ekv.}$/kg izdelka, pri mleku v embalaži obdelanem z UVT metodo od 0,86 do 0,89 kg $CO_{2ekv.}$/kg izdelka, pri mleku v prahu od 1,13 do 1,15 kg $CO_{2ekv.}$/kg izdelka ter pri sirih od 1,07 do 1,10 kg $CO_{2ekv.}$/kg izdelka. Pri ekološkem načinu pridelave mleka za tri velikosti kmetij (strojna molža in robotizirana molža), celotne emisije toplogrednih plinov (prireja mleka + procesiranje mleka) znašajo: pri pasteriziranem mleku v embalaži od 1,10 kg do 1,15 kg $CO_{2ekv.}$/kg izdelka, pri mleku v embalaži obdelanem z UVT metodo od 1,16 do 1,21 kg $CO_{2ekv.}$/kg izdelka, pri mleku v prahu od 1,43 do 1,48 kg $CO_{2ekv.}$/kg izdelka ter pri sirih od 1,37 do 1,41 kg $CO_{2ekv.}$/kg izdelka. V vseh omenjenih primerih se najvišje vrednosti emisij toplogrednih plinov nanašajo na robot molžo, poleg tega je vidno da je tudi razlika v emisijah toplogrednih plinov med strojno in robot molžo minimalna. Emisije toplogrednih plinov iz procesiranja mleka so tudi višje pri ekološki prireji v primerjavi s konvencionalno prirejo mleka. Pri predelavi mleka je energetsko najbolj potratna proizvodnja mleka v prahu ter proizvodnja koncentriranega mleka, ki lahko poteka s postopkom evaporacije ali membranske koncentracije. Če bi emisijam iz prireje mleka in procesiranja mleka prišteli še vrednosti emisij za transport mleka so celotne emisije toplogrednih plinov ustrezno višje.

ZAKLJUČEK

Ugotovljeno je da so emisije toplogrednih plinov v prireji mleka izražene v $CO_{2ekv.}$/kg mleka pri konvencionalni prireji mleka nižje v primerjavi z ekološko prirejo mleka. Pri ekološki prireji je proizvodnja mleka nižja v primerjavi s konvencionalno prirejo mleka, kar vpliva na končne emisije $CO_{2ekv.}$/kg mleka. Ugotovljeno je tudi da je razlika v emisijah toplogrednih plinov med strojno in robot molžo minimalna. Emisije toplogrednih plinov iz procesiranja mleka v različne mlečne izdelke (izražene v $CO_{2ekv.}$/kg mleka) so višje pri ekološki prireji mleka v primerjavi s konvencionalno prirejo mleka. Pri predelavi mleka v mlečne izdelke so emisije toplogrednih plinov izražene v $CO_{2ekv.}$/kg izdelka najmanjše v proizvodnji pasteriziranega mleka v embalaži, sledi mleko v embalaži (UVT metoda). Najvišje emisije toplogrednih plinov izražene v $CO_{2ekv.}$/kg izdelka so v proizvodnji mleka v prahu ter proizvodnji koncentriranega mleka.

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CARBON FOOTPRINT OF MILK PRODUCTION

ABSTRACT

Carbon footprint of conventional and organic milk production for the three farm sizes was determined. Analysis of greenhouse gas emissions showed that milk production (emissions since the beginning of the process in the barn until the end of the process in the barn) generated from 0.718 kg CO_{2equ}/kg of milk to 0.74 kg CO_{2equ}/kg of milk (depending on the size of the herd and rearing technologies) for machine milking and 0.75 kg CO_{2equ}/kg milk in robotic milking in the conventional milk production. For organic milk production an analysis of greenhouse gas emissions showed that milk production (emissions since the beginning of the process in the barn until the end of the process in the barn) generates from 1.02 kg CO_{2equ}/kg milk to 1.06 kg CO_{2equ}/kg of milk (depending on the size of the herd and rearing technologies) in conventional machine milking and 1.06 kg CO_{2equ}/kg of milk in robotic milking. Also carbon footprint of packed milks and some other dairy products was determined. Greenhouse gas emissions from milk production are added to the emissions of greenhouse gases from processing of milk (pasteurizing, sterilizing, homogenizing, production of cheeses, etc.). In the conventional milk production for the three sizes of farms (milking machines and robotic milking), total emissions of greenhouse gases (milk production + processing of milk in different milk products) are: for packed pasteurized milk from 0.8 kg to 0.83 CO_{2equ}/kg of product, for packed milk treated with the UHT method from 0.86 to 0.89 kg CO_{2equ}/kg of product, for the milk powder from 1.13 to 1.15 CO_{2equ}/kg of product and for chees from 1, 07 to 1.10 kg CO_{2equ}/kg of product. In the organic milk production for the three sizes of farms (milking machine and robotic milking), total emissions (milking machines and robotic milking) of greenhouse gases are: for packed pasteurized milk from 1.10 kg to 1.15 kg CO_{2equ}/kg of product, for packed milk treated with the UHT method from 1.16 to 1.21 kg CO_{2equ}/kg of product, for the milk powder from 1.43 to 1.48 kg CO_{2equ}/kg of product and for cheese from 1, 37 to 1.41 kg CO_{2equ}/kg of product.

Key words: *greenhouse gases emission, electric energy, diesel fuel*

44. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

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Prethodno priopćenje
Preliminary communication

SPECTRO-RADIOMETRICAL ANALYSIS OF PLASTIC NETS FOR GREENHOUSE SHADING UNDER ARID CONDITIONS

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SUMMARY

The use of plastic nets in agriculture is now a consolidated reality all over the World. Plastic nets are used to protect orchards, flowers and vegetables thanks to the direct effect of crop protection against atmospheric agents (hail, wind, snow, heavy rain), birds and insects, as well as sand and saltiness, avoiding damages and/or dirtiness of the crop. Plastic nets perform indirect effects as well, when they are employed to close greenhouses and tunnels: due to their influence on the values of the main microclimatic parameters (temperature, relative humidity, carbon dioxide concentration, solar radiation, etc.), they could play a fundamental role on creating more favourable microclimatic conditions during the crop growth. The considerable success that plastic nets have registered in mild climate countries, as those located within the Mediterranean area, is currently pushing towards similar interesting application even in areas characterized by different climates - like the arid conditions usually found in Northern Africa and the Middle East - where greenhouse shading is essential in summer to reduce the solar radiation load.

In the present paper, the spectro-radiometrical properties of some different nets - white, black and thermal-screen - employed in Saudi Arabia to shade the roof and side-walls of a polycarbonate ventilated greenhouse, were measured in laboratory in the solar/PAR range and in the thermal Infra-Red wavelength. From the obtained results, it is clear that the absorbance of the black plastic net is very high, both in the solar (nearly 70%) and in the IR (over 75%), so their use inside the greenhouse should be avoided. On the other hand, the level of transmittance of the white plastic net (over 60%), joined to its significant reflectance – that generates mutual progressive reflections with the greenhouse cladding sheet, if it is installed inside the greenhouse – confirms once more that shading nets should be employed only outside the greenhouse, in order to fully *express their potential of shading the incoming solar radiation. Finally, the thermal screen seems very effective in blocking the IR radiation. This characteristic, joined with a high reflectance in the solar wavelength, makes this material very powerful for an effective contribution to an improvement in the energy balance of a greenhouse.*

***Key words**: plastic net; radiometrical characteristics; shading; greenhouse; arid climate.*

INTRODUCTION

Plastic nets are widely used all over the World for agricultural application [Briassoulis et al., 2007]. Protection from heavy meteorological actions (*i.e.*, hail, wind, snow, or strong rainfall) in fruit-farming and ornamentals, as well as shading the solar radiation in greenhouse or modifying its micro-environment through the realization of a confined airspace with better microclimatic conditions, is the most common case. Besides protecting plants against excessive heat load, shading also significantly reduces the crop water consumption in arid regions [Al-Helal & Abdel-Ghany, 2011; Abdel-Ghany et al., 2015]. Plastic nets are also used as standalone cover, or in connection with structures for growing arboreal cultivation, for the protection against virus-vector insects and birds [Picuno P., 2014]. Despite their widespread use, however, neither growers nor net producers have clear ideas about the relationship between the net typology optimization for a specific application and the construction parameters of the net. The choice often depends on empirical or economic criteria, and not on scientific considerations [Castellano et al., 2008/a].

In a large number of agricultural applications, the radiometric characteristics of the net are the most important parameter, which have to be taken into account by the growers. The radiometric properties of the permeable membrane influence the quality of the agricultural production and the aesthetic characteristics of the netting system. If the transmittance could be considered one of the main parameters involved in the choice of agronomic requirements of the netting system, the reflectance of the net is strictly involved in the aesthetic assessment of the net-house in the rural landscape, since the colour of the material and the light reflection - especially on the wavelengths visible for the human eye (*i.e.*, VIS = 380-760 nm) - determine the aesthetic value of the net structure and its environmental impact. Then, nets with lower values of reflectance should be chosen in order to reduce the visual impact of the building.

Nets with an expected shading factor should have a high transmission for diffuse light. Insect nets and anti-hail nets should have as high as possible light transmission. The colour of a net influences the spectral distribution of the radiation passing through the net absorbing their complementary colours, consequently the choice of the colour of the net combined with the radiation requirements of the plant could be strategic to optimize the production and, more generally, the performance required [Castellano et al. 2008/b]. According with these Authors, more research is needed to quantify the radiometric properties of nets and develop models to predict the light intensity and quality on crop level.

Spectro-radiometrical characteristics of greenhouse shading plastic nets

Shading the roof of a greenhouse is usually performed by various conventional methods such as: whitening by spraying the exterior cover surface with an aqueous solution of hydrated Calcium oxide [$Ca(OH)_2$], external shade cloths, deploying movable refractive screens or curtains and plastic nets of various types and colours [Kittas et al., 2009]. Whitening the roof is nearly inexpensive; it can be used for reducing the heat load during summer. However, it reduces the average greenhouse transmittance to solar radiation by about 50%; it is washed away if rains falling over the greenhouse, and its shading density cannot be changed once applied [Baille et al., 2001]. However, no scientific contribution was proposed so far within the international relevant literature for the quantification of the shading effect of roof whitening with hydrated Calcium oxide.

An external or internal shade can be obtained by using movable plastic nets, curtains or refractive screens applied above or below the roof of the greenhouse. Some previous studies [Briassoulis et al., 2007; Kittas et al., 2009] evaluated shading nets either independently, or investigated their influences on greenhouse macroclimate (*e.g.*, air temperature, relative humidity and solar radiation). All shading methods are aimed to regulate the amount of solar energy entering the greenhouse and reduce the heating load in summer. Thermal screens are used inside the greenhouses in order to limit both convective and thermal radiative heat losses, especially during cold winter nights. Usually this kind of application requires aluminium colour nets to increase the reflection of heat radiation emitted from inside the greenhouse.

Nets are, unlike other covering materials, three-dimensional structures: the whole construction parameters of the net, combined with the shape of the structure, the position of the sun and the sky conditions affect the radiometric performance of the permeable structure [Castellano et al., 2008/a]. The colour of a net influences the spectral distribution of the radiation passing through the net, absorbing its complementary colours, consequently the choice of the colour of the net combined with the radiation requirements of the plant could be strategic to optimize the production and, more generally, the performance required to the net.

Previous experimental studies [Sica & Picuno, 2008; Schettini et al., 2011] have showed that, as expected, the transmittance of nets decreases when the mesh net becomes more close. Even so, the definition of a relationship between porosity and transmittance of a net appears hard to obtain. Porosity is not a parameter sufficient to quantify the shading effect, that is influenced by many other factors (polymer, thickness, colour, distance between the net and the plan receiving the radiation, additives, shape and diameter of the thread, *etc.*). Anyway, it's a matter of fact that, at present, only the global shading factor is usually reported by the industries as a technical information on the leaflet that accompanies the material, while the information about the transmittance value of the net in the principal wavelength ranges (solar: 200-2.500 nm; Phosynthetically Active Radiation (PAR): 400-700 nm; Thermal Infra Red: 7,5-25,0 μm) seems very meaningful, taking into account the different effects on the crops and on the protected environment. Transmittance coefficients at the different wavelength ranges appear therefore as an indispensable tool, able to classify the covering material in relation with the micro-climatic parameters of the protected environment, the quality of the radiation, the temperature and the air flow. First spectro-radiometrical tests have shown that the nets determine effective qualitative changes in the incoming solar spectrum, that is the variation of the distribution of the radiant energy at different wavelengths. Unfortunately at present there is a lack of a specific Standard defining the spectro-radiometrical characteristics that agricultural nets should demonstrate, in order to adequately perform the application for which they are designed [Sica & Picuno, 2008].

Also the durability on time of a plastic net is strongly connected to its spectro-radiometrical properties. UV stabilizers increase the resistance to commercial nets against solar radiation up to 400 – 800 kLy [Castellano et al., 2008/b], which corresponds to a durability of the polymer of 5 to 6 years in mild climates - such as the Mediterranean basin (100-120 kLy/year) - or 3 to 4 years in arid areas (140-160 kLy/year). In this view, the formulation, through a set of specific experimental tests, of a mathematical algorithm able to predict the useful lifetime of a plastic material depending on the main climatological and environmental characteristics of the location where it will be used, in order to govern the chemical formulation of the basic polymer and/or quantity and quality of its additives, still appears an interesting option [Picuno P., 2014].

MATERIALS AND METHODS

In order to analyse the radiometric characteristics of some of the most diffused plastic nets in arid regions, three different plastic nets - that were employed in Saudi Arabia to shade the roof and side-walls of a polycarbonate ventilated greenhouse [Abdel-Ghany et al., 2015] - were analysed in the Laboratory of Material Tests of the SAFE School of the University of Basilicata (Italy). The spectro-radiometrical characteristics of these three nets were determined through a Jasco V-570 spectro-radiometer in the UV-VIS-NIR wavelength, and a Jasco FT/IR-430 spectro-radiometer in the LWIR wavelength.

Figure 1 The three analysed plastic nets: white net (left), black net (centre), aluminized thermal screen (right).

The following three nets (fig. 1) were analysed:

- white plastic net - 185 µm thickness, 50% porosity, 30% shading factor, (Saudi Yarn & Knitted Technology Factory-SYNTECH);
- black plastic net - 250 µm thickness, 30% porosity, 50% shading factor, (Saudi Yarn & Knitted Technology Factory-SYNTECH);
- plastic aluminized thermal screen - 183 µm thickness, 15% porosity, 70% shading factor, (Ludvig Svensson, China).

RESULTS AND DISCUSSION

The results of the spectro-radiometrical analysis over the tested materials are reported in Tables 1, 2 and 3, in terms of the main characteristics measured in the solar/PAR range, as well as in the Thermal Infra-Red wavelength.

Table 1 Results of the spectro-radiometrical analysis on the white plastic net

Range	Wavelength [nm]	Transmittance [%]			Reflectance
		Total	Direct	Diffuse	[%]
Solar	200 – 2.500	61,0	43,4	17,7	24,1
PAR	400 – 700	62,6	42,0	20,6	24,0
Solar IR	700 – 2.500	62,1	46,1	15,9	24,6
UV	280 – 380	8,0	5,6	2,4	12,7
UVA	320 – 380	8,2	5,7	2,5	12,6
UVB	280 – 320	0,5	0,3	0,3	14,8
Thermal IR	7.500 - 12.500	7,9			2,8

Table 2 Results of the spectro-radiometrical analysis on the black plastic net

Range	Wavelength [nm]	Transmittance [%]			Reflectance
		Total	Direct	Diffuse	[%]
Solar	200 – 2.500	27,9	26,1	1,9	3,5
PAR	400 – 700	27,5	26,6	0,9	3,7
Solar IR	700 – 2.500	28,3	25,6	2,7	3,3
UV	280 – 380	27,7	27,0	0,7	4,1
UVA	320 – 380	27,7	27,1	0,6	4,1
UVB	280 – 320	27,8	27,1	0,7	4,1
Thermal IR	7.500 - 12.500	23,2			0,9

Table 3 Results of the spectro-radiometrical analysis on the thermal screen

Range	Wavelength [nm]	Transmittance [%]			Reflectance
		Total	Direct	Diffuse	[%]
Solar	200 – 2.500	26,1	13,4	12,7	55,2
PAR	400 – 700	26,3	12,8	13,6	55,4
Solar IR	700 – 2.500	27,0	14,4	12,5	55,4
UV	280 – 380	3,7	2,1	1,7	46,0
UVA	320 – 380	3,8	2,1	1,7	45,8
UVB	280 – 320	0,4	0,2	0,2	53,6
Thermal IR	7.500 - 12.500	4,7			87,0

In the case of the white plastic net, its level of transmittance (over 60% - Table 1), joined to its significant reflectance – that generates mutual progressive reflections with the greenhouse cladding sheet inside the greenhouse – confirms once more that shading nets should be employed only outside the greenhouse, in order to fully express their potential of shading the incoming solar radiation.

On the other hand, from the reported results it is clear that the absorbance of the black plastic net (Table 2) – equal to the part complementary to 100% of transmittance + reflectance - is very high, both in the solar (nearly 70%) and in the IR (over 75%), so their use inside the greenhouse should be avoided.

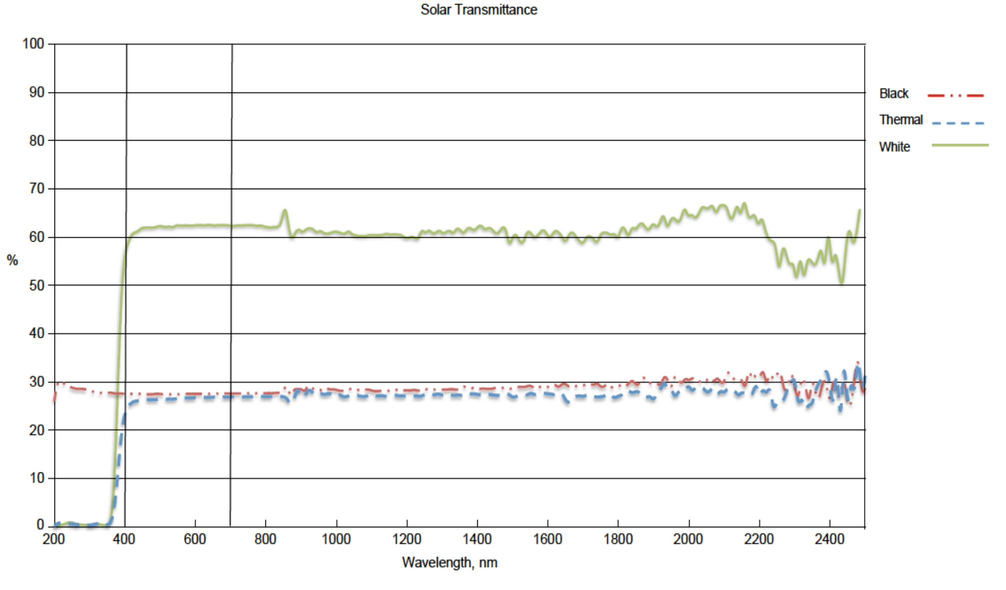

Figure 2 Transmittance of the three nets in the UV-VIS-NIR wavelength

Finally, the thermal screen (Table 3) seems very effective in blocking the IR radiation. This characteristic, joined with an high reflectance in the solar wavelength, makes this material very useful for an effective contribution to the improvement in the energy balance of a greehouse.

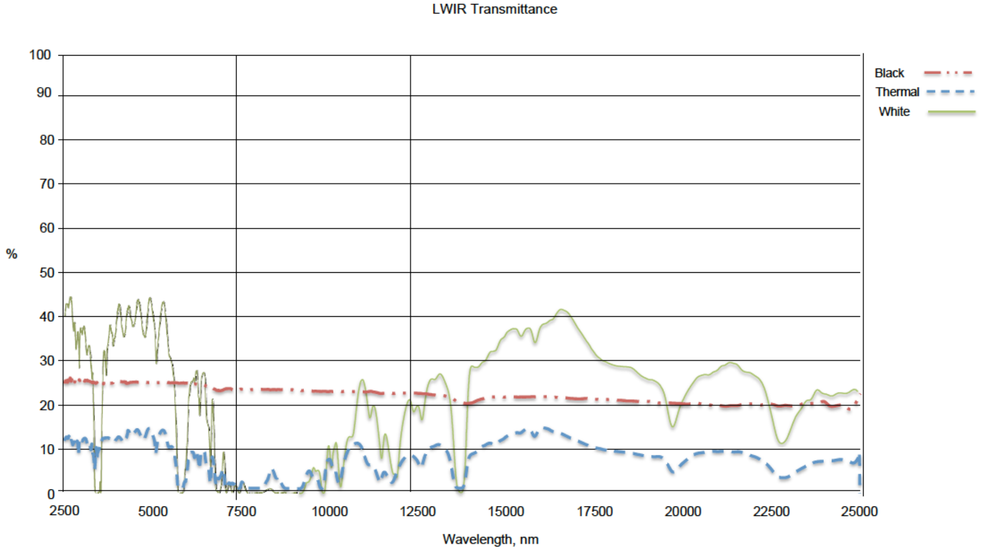

Figure 3 Transmittance of the three nets in the LWIR wavelength

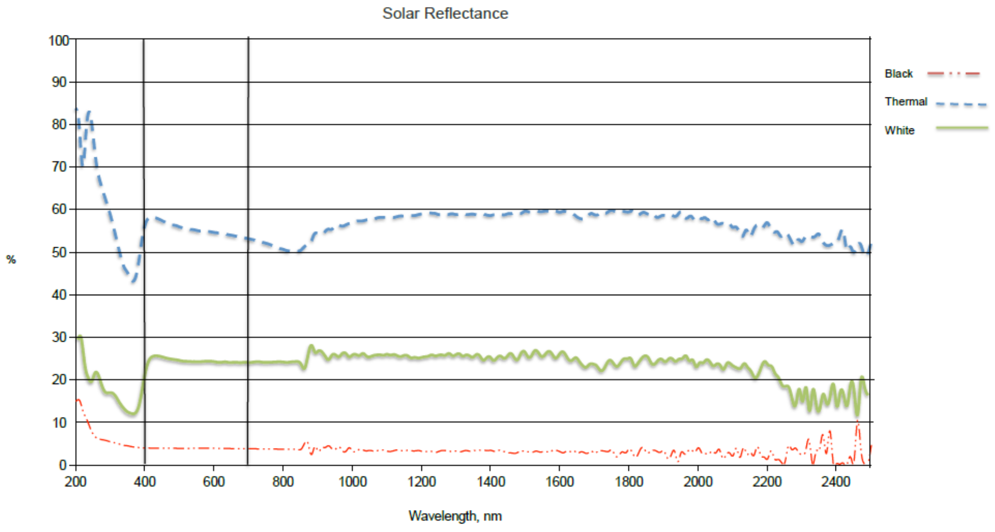

Figure 4 Reflectance of the three nets in the UV-VIS-NIR wavelength

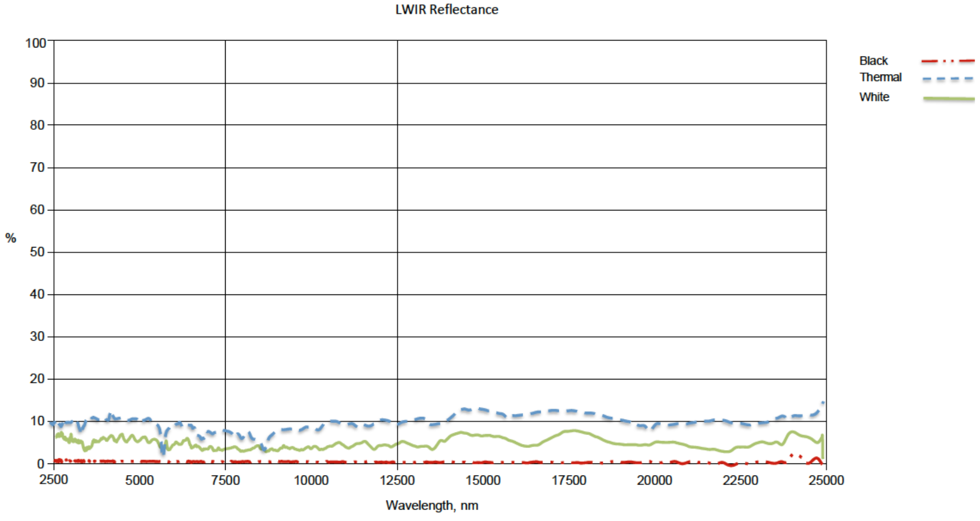

Figure 5 Reflectance of the three nets in the LWIR wavelength

In figures n. 2 and 3 the diagrams of transmittance of the three nets are reported, respectively in the UV-VIS-NIR wavelength and in the LWIR wavelength, while the corresponding diagrams of reflectance are reported in figures 4 and 5.

CONCLUSIONS

In the last years an extensive use of agricultural plastic nets in protected agriculture was recorded thanks to their beneficial effects on the crop. However, their use sets some technical problems connected with their spectro-radiometrical characteristics and the consequent microclimatic performance. Nets are often employed as greenhouse elements without any engineering design, only basing on the knowledge of some technical characteristics that, in some cases, are determined through laboratory test conducted on the basis of Standards applicable to different materials (*e.g.*, glass, or transparent film). Suitable criteria for an objective comparison, comprehensible and usable by the farmers, are therefore still impossible to define.

More research is therefore needed to characterize different types of nets for specific purposes, as well as to quantify the effects of the net colour on the greenhouse internal climate and crop response. Also the duration of a plastic net, depending on the site and condition of application still needs further analysis.

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43. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

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Izvorni znanstveni rad
Original scientific paper

IR INVESTIGATION REGARDING THE DEGRADATION OF NATIVE STARCH BASED FILMS

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SUMMARY

Worldwide, the volume of plastic film used in agriculture has increased greatly in the last 10 years, only in Europe being consumed 75,000 t / year films for direct covering on rows and more than 130,000 t / year of mulching films.

Using these plastic films have some big disadvantages: they are manufactured from petroleum based raw materials which is not a renewable resource; produce a large amount of waste with decomposition in very long time and require very high costs (approximately EUR 700-800 / ha), in recovery, storage and recycling or disposal at the end of cultivation.

A viable alternative solution and of great interest to the agricultural polyethylene films is the development and use of biodegradable plastics due to contribution to the conservation of petroleum resources, reduce waste quantities due to biodegradability and ensure environmental protection by reducing carbon dioxide emissions [3].

The use of starch as raw material in order to obtain degradable bioplastic is of great interest due to its hydrophilic nature, which plays an important role in initiating biodegradation process [2,5].

This paper presents preliminary results of natural degradation under the action of climatic factors, water absorption and IR spectroscopy investigations for mulch film obtained by thermoplastic extrusion and rolling, of native starch (with amylose content of 21%), subjected to natural degradation by water absorption. Changes of the IR spectra before and after the hydration-drying confirm its degradability.

***Key words**: starch based film, degradation, IR spectroscopy,*

INTRODUCTION

Worldwide, the volume of films for use in agriculture has greatly increased in the last 10 years. The latest data shows that agriculture and horticulture are responsible for approximately 1.5 million t consumption of annual production of polymers in Europe. Currently, the market is still dominated by the agricultural films made from low density polyethylene (PE). These films have two major disadvantages: they are manufactured from petroleum based raw materials and produce a large amount of waste that needs to be removed from the field and destroyed. An alternative solution to agricultural polyethylene film is the development and use of biodegradable plastics, from renewable agricultural resources which decompose completely at the end of the production cycle due to the action of climatic factors (humidity, solar radiation, etc.) and microorganisms found in the soil. In this way we may solve two problems of great importance for the environment: saves fossil resources and reduce emissions of greenhouse gases (GHG).

Research and development activities conducted worldwide to identify alternative raw materials that can be use to ensure an environmentally –friendly nature of plastics materials revealed starch based biopolymers as a possible solution to the environmental problem concerning the plastic waste disposal and reducing of oil resources [4]. The target of recent investigations in the field of bioplastics is to obtain packaging material from pure starch and to exclude synthetic polymers from the formulation [3].

An important role in initiating biodegradation process of starch is played by its hydrophilic nature [2, 5].

A number of non-destructive techniques can be used to obtain informations about the degradation mechanism of biopolymer, like: Fourier transform infrared spectroscopy (FTIR), differential scanning colorimetry (DSC), nuclear magnetic resonance spectroscopy (NMR), water uptake, rheological measurements, X-ray Diffraction (XRD).

This paper presents some preliminary results of natural decompose due to the action of climatic factors (rain, humidity, solar radiation), degradation after absorption of distillate water, and Fourier transform infrared spectroscopy (FTIR), investigations for a starch based film obtained by thermoplastic extrusion and rolling, of native starch, (with an amylase content of 21%).

METHODS

The formulation used to obtain the film contains normal corn starch from SC Amylon SA Sibiu, Romania, glycerol and water. The initial water content of starch on wet basis (wt.b) was 10.76% and the density was 0.561 g/cm^3. The amylase content was 21%. The glycerol was purchased from SC Nordic Invest SRL Cluj Napoca and had a concentration of 99.5% and a density of 1.262 g/cm^3. The water used was from the water supply system.

To prepare the mixture of plasticizers, fed with the dosing pump, was used a water / glycerol ratio of 1/3. The rate of starch was 3.5 kg / h and the volume of the dosing pump 1 l / hour. Given the density (1 g / ml for water and 1.26 g / ml glycerol), resulting proportions of plasticizers, based on the solids, are 7.14% water and 27% glycerol.

Renewable laminated film was made on an installation whose elements are shown in Fig. 1.

To observe the obtained film degradation a sample sized 150 x 400 mm was cut and placed directly on the soil and was exposed to climatic factors during Mai-September 2015. The mean temperatures and average precipitation are presented in Fig. 2 and Fig. 3.

To track degradation of the film under climatic factors action, pictures were made at the end of each month.

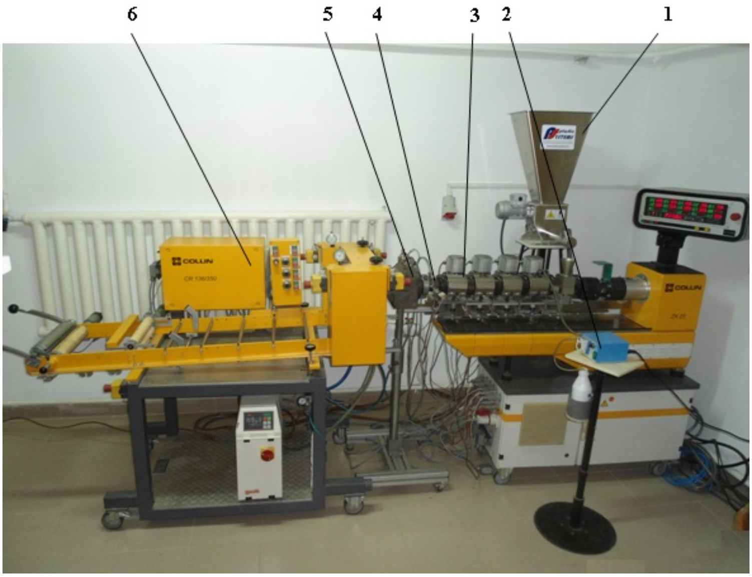

Figure 1 Extrusion and rolling equipment- assembly
1-dispenser for powdered materials, 2- liquid pump, 3- extruder, 4-adapter, 5- widening die, 6- rolling equipment

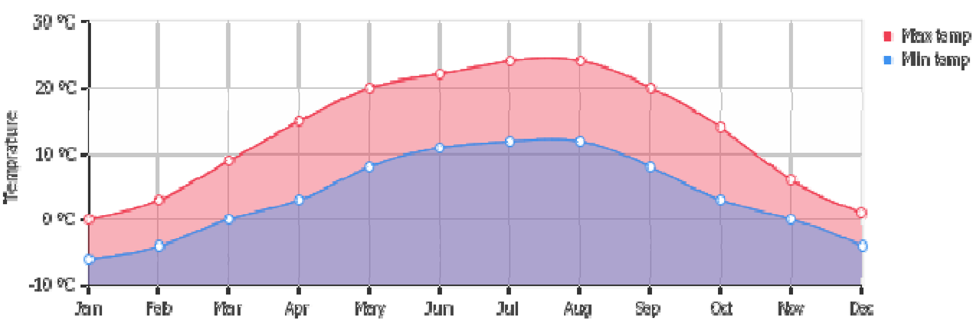

Figure 2 Average min and max temperatures in Cluj-Napoca, Romania [6]

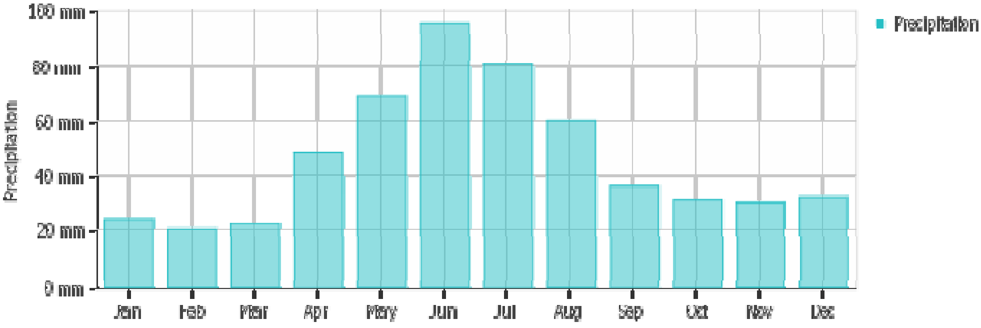

Figure 3 Average precipitations in Cluj-Napoca, Romania [6]

In order to determine the amount of water absorbed we cut a sample of rectangular shape with dimensions of 20 x 30 mm, the length after rolling direction, and immersed it in 4 ml of distilled water. It was noted that the sample absorbs water at high speed reaching saturation after about 1 hour.

The quantity of absorbed water was determined as follows. First we measured the mass of samples in dried state, after that the samples were immersed in distilled water and kept 5 minutes. Then the samples were removed from water and the excess water was removed by placing the sample on absorbent paper for 2 minutes and the water uptake was measured using a Partner WLC 0.6/B1 analytical balance with a precision of 0.1 g. After each measurement we refill the water until we reach the initial weight of recipient+sample+water and we repeated this measurement until we obtained more than 5 equal values for the uptake water.

To highlight the IR spectra changes due to hydration-drying processes we use an FT-IR spectrometer Jasco 4100. Samples were prepared as strips of 3x10 mm in size and samples as pressed pill of 0.2 g KBr + 0.003 g sample. Spectra were obtained for films in original condition, after hydration for 24 h and 48 h drying and after 3 months of degradation under the action of climatic factors.

RESULTS AND DISCUSSION

In Figure 4 are presented the images taken at the end of each month of climatic factors action. At the end of the survey period the starch based film obtained is decomposed, but we observed that decomposing process of the film starts too soon and it is accelerating in periods with frequent rains, comparing with periods of sunny days. The formula used to obtain this film must be improved so that the film keeps its integrity a longer time to ensure the crop protection during a complete production cycle

Figure 5 present the sample mass with uptake water absorbed during 1 hour. The sample absorbed a high quantity of water (~ 200% of sample`s mass in 1 hour) with high velocity and looses its integrity after 5 days. The water absorption capabilities were estimated from water uptake, and from this point of view the starch based film has a reduced time of degradation swallowed in water.

Figure 4 Degradation of starch based film under climatic factors action, may-september 2015

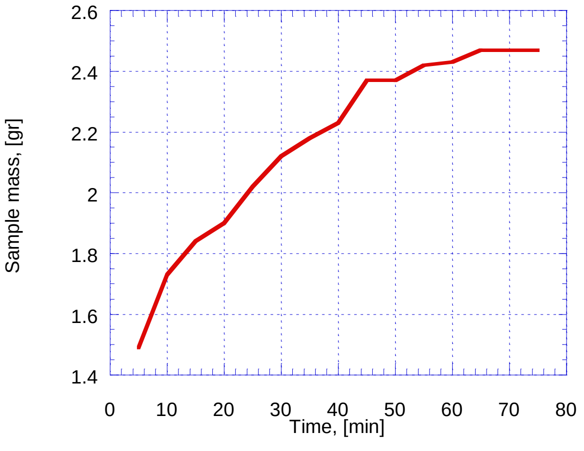

Figure 5 Mass uptake for the starch based film sample

By IR measurements can be revealed the effects of the structural modifications induced by the composition and synthesis process of the samples, on the vibrations of the molecular bonds. We compared the spectra of film samples at different stages: initial film, film after a process of hydration- drying, and film after exposure at climatic factors for 5 months.

The IR spectra of the film samples at different stages, contains many vibration bands of each component (starch, water, glycerol), some of them appearing at the same wave numbers as in the spectrum of water, starch (fig.7). For instance, the band 1632 cm^{-1} of water appears distinctively and a bit shifted (1634 cm^{-1}) in the spectrum of the films in each stage. It is evident the diminution of the peak centered at 1634 cm^{-1} due to decrease of water content.

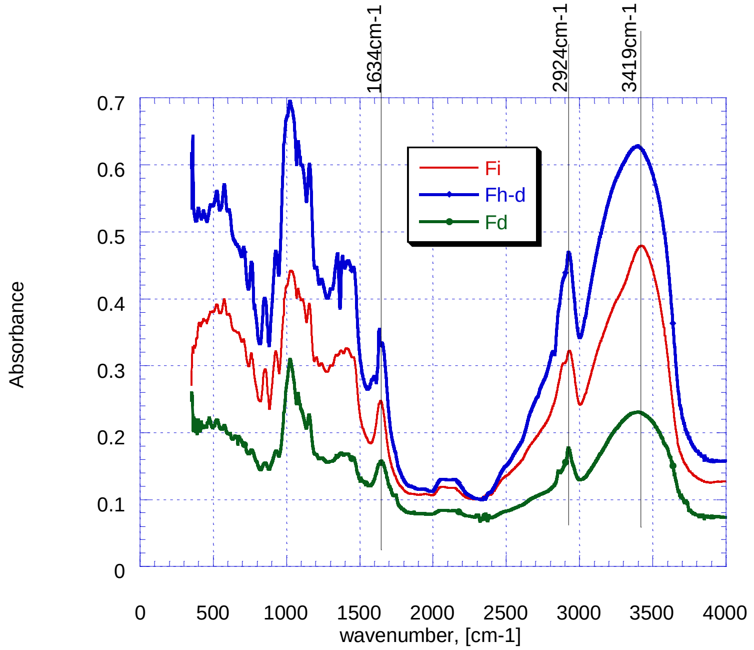

Figure 6 IR spectra of the film samples at 3 stages: initial-Fi; after hydration- drying-Fh-d; decompose after exposure at climatic factors-Fd

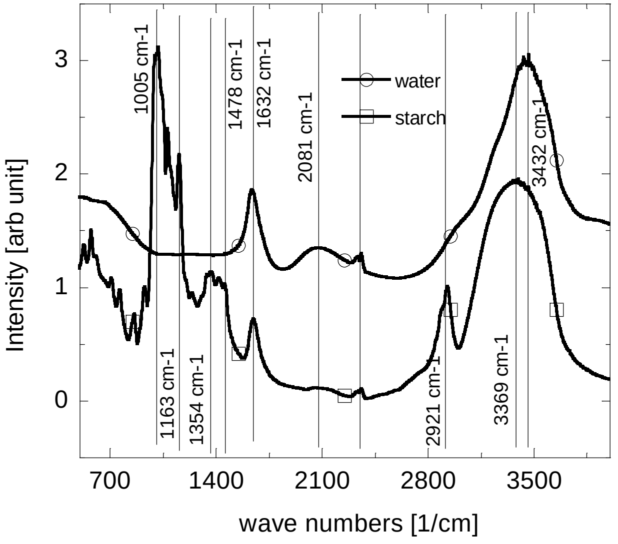

Figure 7 The IR spectra of pure water and pure starch

The well defined band appeared at 2924 cm^{-1} corresponding to starch component. A similar band was observed at 2930 cm^{-1} for other kind of starch of fresh tortilla by other authors and was assigned to vibrations of CH_2, [1].

The most evident difference among the IR spectra of the film samples in different stages is the diminution of peaks which correspond to the stretching vibrations of each component of the formula. Regarding the spectra is evident that the sample placed on the ground under the influence of climatic factors has the lowest amplitude corresponding to the peaks of each component, supported by morphological observations regarding film disintegration into small particles.

CONCLUSIONS

The native starch based film was obtained by extrusion and rolling from a mixture of starch, glycerol and water. The proportion of plasticizers, based on the solids, are 7.14% water and 27% glycerol.

The film samples were tested in order to observe their degradation while swallowed water and under climatic factors action.

The water absorption capabilities were estimated from water uptake, and from this point of view the starch based film has a reduced time of degradation swallowed in water. The samples immersed in water looses its integrity after 5 days. Also the decomposing process of the film, under climatic factors action, is accelerate and it is required to improved the formula to ensure integrity of the film throughout a complete production cycle.

Sample degradation is highlighted in the IR spectrum by decreasing the amplitude of vibrational bands corresponding components: starch (2924cm-1 and 3419cm-1), water (1634 cm-1). The lowest amplitude was obtained for the sample placed on the soil and subject to the climatic factors, this is the sample with the highest degree of degradation.

ACKNOWLEDGMENTS

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EXPERIMENTAL MODELS OF UNDERGROUND TEMPERATURE FOR DECISION MAKING IN WINE CELLAR DESIGN

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SUMMARY

Buildings for wine storage and aging should assure constant performances of stability of indoor thermo-hygrometric conditions. Solutions characterized by low energy consumption can be achieved through the construction of underground wine cellars. They can benefit from the ground potential of temperature peaks dampening and thermal wave phase shifting. The design of such buildings requires a deep knowledge of underground temperature distributions in the surface and shallow layers. This implies a proper investigation of temperature profiles at various distances beside the cellar walls and below its floor. The objective of the study is to identify the spatial distributions and time trends of temperature in the ground layers involved in the interaction with underground buildings for wine production. Furthermore the study aims at providing analytical models for the underground temperature wave in surface layers, for the underground temperature wave below a building, and for the air temperature wave inside an underground wine cellar. The research has been developed by means of an experimental monitoring system which has been specially designed and installed in an Italian farm winery assumed as a pilot case. The analytical models proposed have been calibrated and validated against the experimental data of a three-year monitoring. The models allow to predict the temperature behaviour of underground cellar in different geographic locations, depending on soil characteristics. Beside the application of the models for the study case, two further scenarios of geographic location and four ones of soil features have been analysed and compared. Underground composed by lithotypes with high *insulation potential and heat storage capacity appear to be the most appropriate for buried wine cellars.*

***Key words**: temperature distribution, geothermal monitoring, wine cellar, underground building*

INTRODUCTION

Wine production represents a fundamental branch of the food industry, and involves the farm sector not only for grapevine growing, but also concerning the winemaking process. The production processes in farm wineries must comply with strict requirements of environmental control, in order to assure the proper development of fermentation, refinement, and aging of wine. Temperature in particular has to be kept within predefined ranges, which depend on the specific oenological techniques adopted, with special attention to avoid temperature rising above the upper threshold (Fuller et al., 2004), which is identified by many author with 20°C (Tinti et al., 2014). Buildings for wine storage and aging should assure constant performances of stability of indoor thermo-hygrometric conditions (Ruiz De Adana et al., 2005), in order to achieve an appropriate environment for wine (Christaki and Tzia, 2002). In the last decades winery buildings have been built in many cases aboveground (Torreggiani et al., 2014, 2011), relying on air-conditioning systems. This solution on the one hand allows to reduce the construction costs, but on the other hand entails higher GHG emissions and energy demands that may result in management costs depending on energy market trends. Moreover, in case of failure of the cooling system, the wine quality may be compromised. For these reasons, building solutions characterized by low energy consumption have been preferred in recent years (Benni et al., 2013), with a consequent new interest for the construction of underground wine cellars. In fact, they can benefit from the ground potential of temperature peaks dampening and thermal wave phase shifting, besides favouring adequate moisture levels for wine storage and aging (De Rosis et al., 2014). The design of such buildings requires a deep knowledge of underground temperature distributions in the surface and shallow layers. Moreover, the temperature gradient in the soil around the cellar has to be defined, in order to correctly model the ground–building interactions. This implies a proper investigation of temperature profiles at various distances beside the cellar walls and below its floor. Several studies have been published about the temperature variation assessment in undisturbed underground, based on time and depth (Baggs, 1983). The issue of thermal interaction between buildings and underground has been addressed in literature as well (Chow et al., 2011; Mihalakakou, 2002; van Manen and Wallin, 2012), but results require validation, which is strongly affected by site characteristics and buildings features. In particular the definition of underground thermal behaviour in the shallow layer (with depth between 2 m and 15 m) and in the surface zone (above the depth of 2 m) in different climatic and geological contexts represents a research development necessary to identify the most appropriate design solution for underground buildings with requirements of indoor temperature control.

In this context, the objective of the study is to identify the time variations of temperature distributions related to the ground layers involved in the interaction with the underground wine cellar in a significant study case, and to provide an analytical model for temperature behaviour in shallow and surface layers.

METHODS

The research has been developed by means of an experimental monitoring system, specially designed and installed in an Italian farm winery assumed as a pilot case within a significant Italian wine production region (Tassinari et al., 2011). The study case concerns the Emilia-Romagna Region wine sector, with particular reference to the eastern portion of Bologna Province (Tassinari et al., 2010) where over 130 family-run wine farms have been surveyed, identifying an average yearly production capacity of 1500 hl and an economic vitality that allows them to compete on the global market. The selected farm, beside various buildings hosting the wine-making functions, includes a masonry building with two aboveground storeys and an underground cellar for wine ageing. The plan dimensions of such underground space are 6 m × 10.50 m, with the floor located 2.90 m below the ground. As for geological aspects, the study area belongs to a lithostratigraphic unit characterized by valley deposits from alluvial plain. At depth of the layers under study, the underground is composed prominently by clay and silty clay. There are not consistent shallow aquifers, so that the presence of groundwater is scarce and variable across the year, depending exclusively on weather conditions.

The experimental apparatus consists in a set of sensors, able to measure and register temperature within the cellar and in the underground at different depths. Climatic sensors data-logger type PCE-HT71 have been used. Sensors have resolution of 0.1°C and accuracy of ±0.5°C, which represent acceptable values for the type of research developed (Barbaresi et al., 2014). Lab verifications on the sensors demonstrated a higher accuracy than that declared by the manufacturer. Three sensor were placed inside the cellar at three different heights above the floor equally spaced (at 0.80 m; 1.60 m 2.40 m), based on an experimental temperature test carried out in the same study case. A weather station type PCE-FWS20 was installed in the proximity of the buildings to monitor the environmental conditions. This station records temperature, moisture, pressure, wind velocity and direction, with a frequency of 30 min. These data are expected to be correlated to underground temperature, considering that the thermal behaviour of the surface layer is influenced by daily variation, while that of the shallow one is affected by seasonal changes.

Two vertical drillings have been prepared in order to acquire temperature data required for thermal characterization of the surface and shallow layers of the soil around the underground cellar (Tinti et al., 2014). In particular, one borehole (named *I*) has been performed on the west side of the building (WGS84 coordinates 44°24′45.89″ N, 11°39′17.11″ E), in an area without trees or artefacts which could affect the temperatures of the layers concerned. The distance of borehole *I* from underground building is 4 times greater than the depth of underground space; therefore, the area can be referred to as undisturbed ground. The second borehole (*II*) has been realized on the northern side of the building (WGS84 coordinates 44°24′46.20″ N, 11°39′17.77″ E), in a position where solar radiation is influenced by shading made by the building itself. The distance from the building side is around a half of the height of the underground building. Therefore, the ground cannot be considered undisturbed, due to the proximity of the underground building and the presence of shading. Vertical boreholes (*I* and *II*) are 6 m deep, with a diameter of 0.18 m. Helical drilling has been performed and no casing has been used. Inside these holes three PE pipes have been inserted, with an external diameter of 63 mm and a thickness of 5.8 mm. Pipes lengths are respectively 2, 4 and 6 m. Inside each PE pipe, a sensor has been allocated. In each hole, therefore, three sensors are inserted, each one at a defined depth. A third inclined drilling (borehole *III*) has been realized, reaching the ground below the building. Due to the site conditions and operational constraints, the inclination of a drilling suitable to achieve this aim resulted in a 10° angle below the horizontal. Borehole *III* has a diameter of 0.18 m with no casing and is 17 m long. Inside the hole, three PE pipes (external diameter of 63 mm and thickness of 5.8 mm) have been inserted. Pipes lengths are respectively 7 m, 11 m and 17 m. Inside each PE pipe, a sensor has been allocated. Therefore, in the hole three sensors have been inserted, each one at a defined depth, respectively1.8 m, 2.6 m, 3.7 m. In boreholes *I*, *II*, and *III*, a cement-bentonite mixture guarantees the thermal contact between pipes and ground. At the top of each hole, a manhole was installed in order to close it and protect sensors and cables from external conditions. Sensors have been inserted in proper metal boxes, and then lowered inside the holes at different depths, with water-proof cables. Further sensors have been positioned to register the temperature behaviour in the surface layer at 0.10 m, 0.65 m, and 1.20 m depth (Tinti et al., 2015).Following a first check of data monitoring, a registration frequency of one hour has been adopted for temperature records, as it represents the maximum time span within which maximum variations registered are always smaller than instrument accuracy. Data have been collected since June 2012 inside the cellar and March 2013 in the underground.

RESULTS AND DISCUSSION

The results of a monitoring campaign carried out for almost three years were used to verify the standard model of underground temperature distribution for the surface and shallow zones. This model is the standard underground temperature equation (Baggs, 1983), together with all its derivations, appropriate for very surface underground and thermal interaction with underground building (Mihalakakou et al., 1995; Popiel et al., 2001; Mazarron and Canas, 2008; van Manen et al., 2012).

The space-time model represents the ambient temperature wave, which deepens into the ground, altered by the presence of buildings, foundations and other artefacts. Below the surface, the ambient wave is damped and shifted, according to the underground thermal inertia and insulation potential, and, mostly in very shallow layers, can even be affected by natural time-dependent phenomena, such as snow melting, rainfall or soil irradiation and shading. The presence of artefacts warps the phenomena; this is particularly significant in underground spaces, where the convection phenomena given by air flow must be taken into account. Through a multi-parametric non-linear regression technique, applied on the experimental temperature waves for one year of monitoring, it has been possible to estimate all the unknown parameters (underground thermal diffusivity α, shading and vegetation coefficient h, specific cellar insulation parameters k, η and τ). All other involved parameters are related to site ambient condition (annual temperature T and amplitude A, day of minimum temperature t_0, geometry of site r and s). In order to find the coefficients of the non-linear regression, the technique used the derivatives of the model, calculated on the parameters of interest, and the problem was solved by using the plug-in Xlstat® of Microsoft Excel®. The models applied are expressed by equations 1-4, respectively providing the standard underground temperature wave model (1), the underground temperature wave model specific for surface layers (2), the underground temperature wave model below the building (3), and the air temperature wave model inside the underground cellar (4).

$$T(x,t)=T_m-A\cdot e^{-x\cdot\sqrt{\pi/(365\alpha)}}\cos\left[\frac{2\cdot\pi}{365}\left(t-t_0-\frac{x}{2}\sqrt{\frac{365}{\pi\cdot\alpha}}\right)\right] \tag{1}$$

$$T(x,t)=T_m-1{,}07\cdot h\cdot A\cdot e^{-x\sqrt{\pi/(365\alpha)}}\cos\left[\frac{2\cdot\pi}{365}\left(t-t_0-\frac{x}{2}\sqrt{\frac{365}{\pi\cdot\alpha}}\right)\right] \tag{2}$$

$$T(x,t)=T_m+k-\eta\cdot A\cdot e^{-x\cdot\sqrt{\pi/(365\alpha)}}\cos\left[\frac{2\cdot\pi}{365}\left(t-t_0-\tau-\frac{x}{2}\sqrt{\frac{365}{\pi\cdot\alpha}}\right)\right] \tag{3}$$

$$\bar{T}=(T_m+k)+\frac{A}{(s-r)\cdot 2\cdot\sqrt{\pi/(365\cdot\alpha)}}\cdot e^{-x\cdot\sqrt{\pi/(365\alpha)}}\cdot\left[\sin\left(\frac{2\cdot\pi}{365}\left(t-t_0'(x)-\frac{x}{2}\sqrt{\frac{365}{\pi\cdot\alpha}}\right)\right)+\cos\left(\frac{2\cdot\pi}{365}\left(t-t_0'(x)-\frac{x}{2}\sqrt{\frac{365}{\pi\cdot\alpha}}\right)\right)\right]\Bigg|_s^r \tag{4}$$

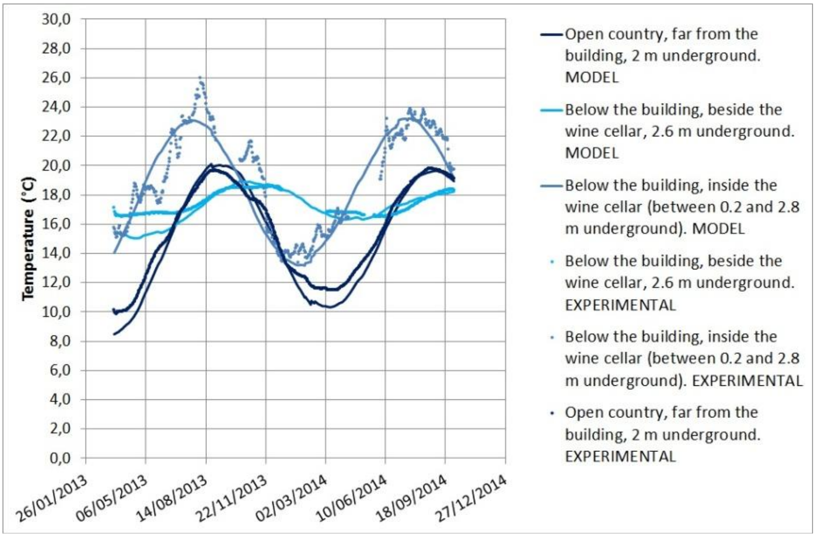

Figure 1 Comparison between experimental and model data for the Toscanella (BO) case study

Underground temperature wave model is based on ambient parameters (T and A), mediated on a year of measurements. Although this choice can lead to satisfactory results for a monitoring campaign with a maximum period of one year, it is no more applicable for longer campaigns, because of climate variations in time. A more robust statistical tool taking into account these changes must be applied. For the purpose of the present work, a moving average method, focused on the measurement point, was chosen. A comparison between experimental data and models for the underground wine cellar case study has been carried out on in three different measurement points: 1) open country, far from the building, 2 m underground; 2) below the building, besides the wine cellar, 2.6 m underground; 3) inside the wine cellar, between 0.2 and to 2.8 m underground. Measurements collected in the remaining positions surveyed were used for the model calibration and are reported in papers by Tinti et al. (2014; 2015).

The presence of air inside the wine cellar homogenises the temperature, due to convective motion. The third model, in first approximation, can therefore represent the average air temperature of the cellar. This can be useful for wine cellar designers, because the air temperature control is one of the most important issues of wine storage application.

Experimental and model data for the case study are shown in Fig. 1.

Table 1 Data of the three sites considered for the analysis

			Toscanella (BO)	Bevagna (PG)	Marsala (TP)
Coordinates	Latitude (°, ', ")		44° 23' 03.79" N	42° 56' 14.23" N	37° 47' 52.96" N
	Longitude (°, ', ")		11° 38' 04.64" E	12°36' 33.37" E	12° 26' 13.26" E
	Altitude (m)		68	218	12
Climatic parameters	*2012*	T_m (°C)	14.7	15.7	18.5
		A (°C)	19.0	17.0	13.5
		t_0 (d)	37	35	45
	2013	T_m (°C)	14.1	15.1	18.0
		A (°C)	16.5	15.0	10.5
		t_0 (d)	53	40	41
	2014	T_m (°C)	15.2	15.8	18.5
		A (°C)	14.5	15.0	13.0
		t_0 (d)	365	365	365
Underground tipology			Clay	Silty clay	Calcarenite
Underground parameter		α (m^2/d)	0.0288	0.0648	0.1068
		C (MJ/m^3 K)	1.50	2.40	2.23
		λ (W/m K)	0.50	1.80	2.75
Vegetation and shading parameter		h (-)	0.63	0.63	0.63
Cellar geometric parameters		z_{top} (m)	0.2	0.2	0.2
		z_{bot} (m)	2.8	2.8	2.8
Building parameters		k (°C)	2.5	2.5	2.5
		τ (d)	30	30	30
		η (-)	0.32	0.32	0.32

The results of comparison of standard underground thermal behaviours are shown in Fig. 2; those concerning the comparison of underground thermal behaviours below the building are shown in Fig. 3; and the comparison of air thermal behaviours inside the underground cellar is given in Fig. 4.

Both climate and underground parameters strongly influence the capacity of an underground cellar to correctly store wine. In order to evaluate the influence of sole underground thermal parameters on wine storage potential, the air temperature changes inside the cellar has been finally simulated, by varying the underground lithotype and characteristics, with the climatic data of the northern Italy site. Table 2 reports the different lithotypes used for the investigation, together with their average thermal values, while Fig. 5 shows the simulation results.

The air temperature inside the cellar increases (and moves away from the upper temperature threshold) together with the increase of thermal conductivity λ and diffusivity α of underground layers. This is due to the fact that surface and shallow underground layers are basically influenced by ambient air temperature, while the geothermal gradient is almost negligible. In fact, high values of conductivity and diffusivity lead to higher and faster heat exchange between ambient and underground, which is then transmitted to the wine cellar, whose temperature rises up. On the contrary, high values of specific heat C would increase the underground heat storage, which therefore would release less heat, more slowly, to the wine cellar.

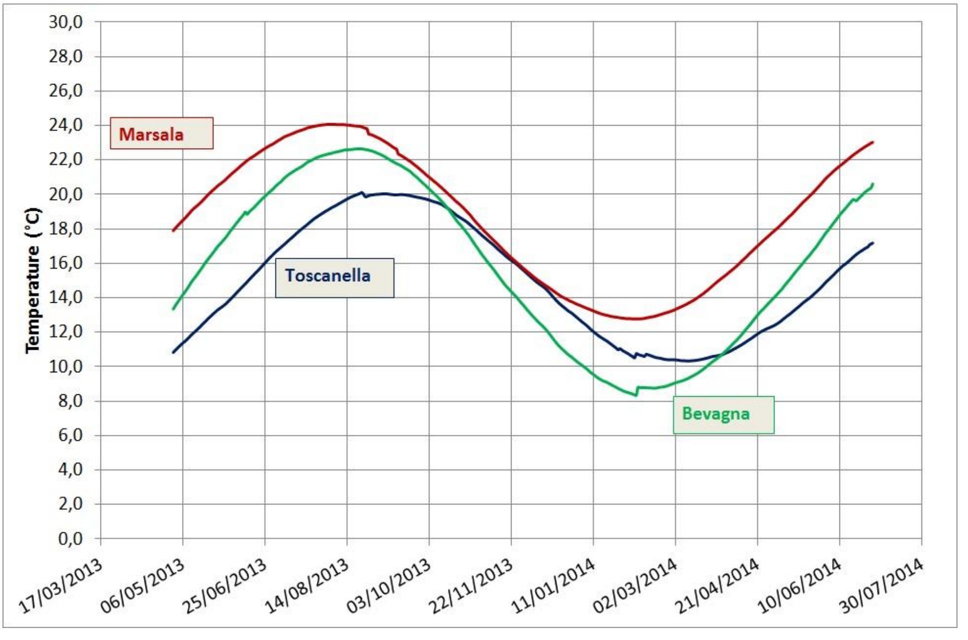

Figure 2 Comparison of standard underground thermal behaviour among the three sites considered: Toscanella (BO), Bevagna (PG) and Marsala (TP)

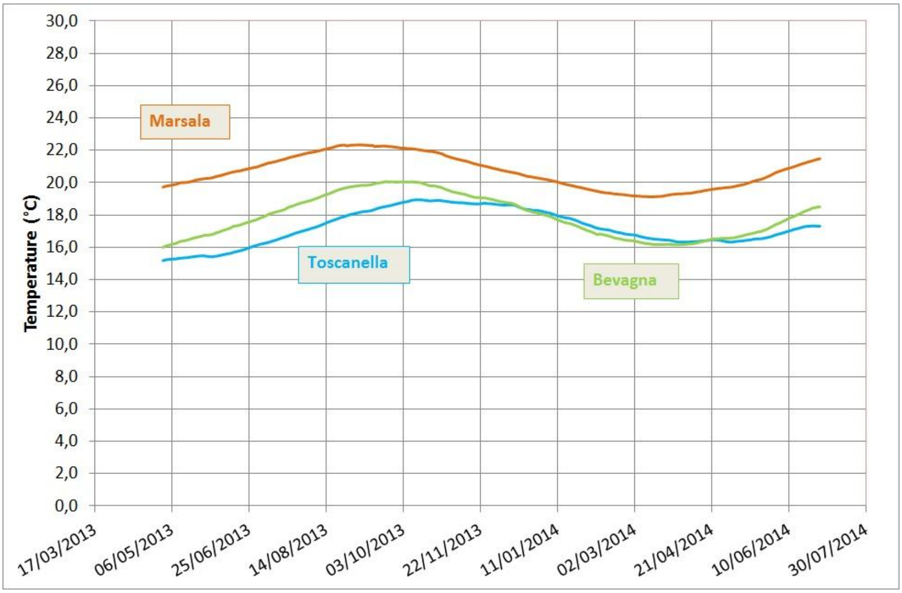

Figure 3 Comparison of underground thermal behaviour below the building among the three sites considered: Toscanella (BO), Bevagna (PG) and Marsala (TP)

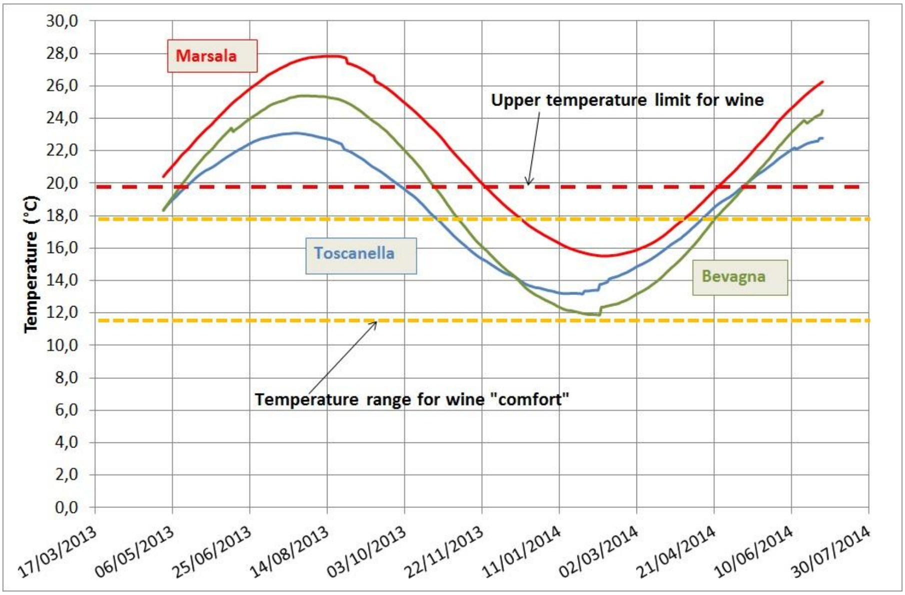

Figure 4 Comparison of underground air thermal behaviour inside the underground cellar among the three sites considered: Toscanella (BO), Bevagna (PG) and Marsala (TP)

Table 2 Average values of thermal parameters of most common rock and soil types in the shallow underground

	Clay	Sandstone	Moist silty clay	Dry gravel	Moist sand
C (MJ/(m^3 K))	1.5	2.2	2.4	1.4	2.5
λ (W/m K)	0.5	2.8	2.8	0.4	2.4
α (m^2/d)	0.0288	0.1100	0.0648	0.0247	0.0829

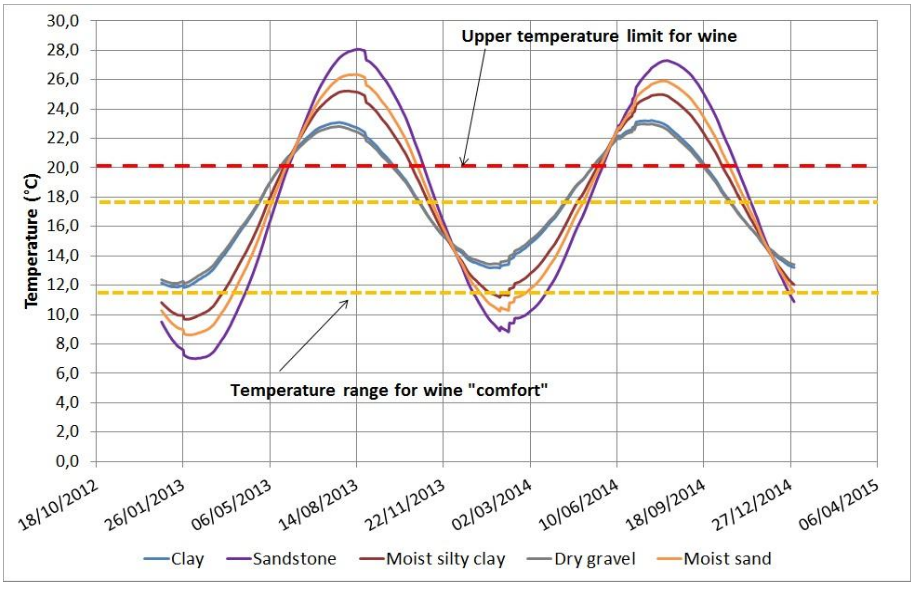

Figure 5 Comparison of air thermal behaviour inside the underground cellar for different rock and soil types in Toscanella climate (BO)

CONCLUSIONS

Multi-year trends of underground temperature at different depths and with various levels of interaction with a buried cellar have been provided and analysed. On the basis of known equations reported in scientific literature, new formulae were defined to model heat transfer in the considered dominion. The expressions developed proved suitable to reproduce the phenomena surveyed of temperature distribution in surface layers and their thermal interaction with underground buildings. Mathematical models of temperature distribution in the surface and shallow layers and within underground buildings have thus been developed, tested, refined and validated with reference to the study case. These models allow to predict the temperature behaviour of underground cellar in different geographic locations, depending on soil characteristics. They can be applied in the design of an underground cellar, in particular to define the optimal characteristics of insulation of the buried walls, based on the geometric and technical features of the construction under study, and data of underground and indoor temperatures, which can easily be collected in the preliminary site analysis phases or in analogous underground artefacts already existing. The results have showed that underground thermal properties can be optimally used in order to reduce energy needs for cellar temperature control: lithotypes with high insulation potential and heat storage capacity appear to be the most appropriate for wine cellar location.

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44. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

UDC 502/504
Stručni rad
Expert paper

DATABASES AS SUPPORT FOR ENVIRONMENTAL MANAGEMENT AND PROTECTION

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SUMMARY

The support of life development on Earth is the environment. This paper presents the implementation of a structure of environmental legislation database and GIS (Geographic Information System) database into web platform. The databases was designed as support for environmental and management protection. Improve of public awareness is an important part of activity regarding environmental management.

The internet user will find in databases the structured knowledge and information regarding to environmental legislation and about the processes, phenomena and actions with negative effects or potential impact on the environment.

The structures of databases will be to assure easy access to legislation and their requirements and also to phenomena with environmental impact.

The classical features for access to environmental database have been implemented: search, query through the reports, viewing, and also specific facilities for database administrator: update, adding records, structure management, etc.

In addition, database will be structured on legislation requirements of main normative act separately. It will allow an analysis of the requirements of each law especially in terms of public awareness on environmental protection and management.

GIS database will be available online and allows online access to locations with environmental impact and problems. The main structure contains layers with geographical information. The interaction and administration of the databases will by assured by web interfaces. In terms of structural, conceptual and application level, the methodology of the databases achievement can also be applied in other domain to provide structured information of interest to it.

Key words: *database, GIS, environmental legislation, environmental management and protection, awareness, internet.*

INTRODUCTION

Beginning with 19th century, human civilization is passing a period of great scientific discoveries that led and lead to great changes on life on Earth, with beneficial effects and sometimes with negative effects on short, medium and long term.

Until the beginning of this period, the global natural resources were sufficient for life on Earth and especially for its population.

The support of life development on Earth is the environment, which is mainly the result of the interaction between human activity and its natural components: air, water, soil, subsoil, biosphere, atmosphere, etc. This interaction influences the existential conditions and possibilities for future development of human society.

With the appearance of industry, the interaction of human with the environment has changed. On the one hand, the wellbeing and the quality of life increased for human populations and on the other hand, this wealth has led to greater consumption of natural resources and energy. Thus arose the problem of limited natural resources and the pollution problem.

Pollution and other negative effects on the environment have caused and is still causing climate change, representing one of the biggest problems of today's world.

To limit the negative effects on the environment and reducing pollution sources are required several actions, among which we mention:

- preventing and combating of environmental damage caused by various factors;
- the extensive research regarding the quality of the environment and the methods and techniques for limiting of its degradation
- adopting of medium and long-term strategies for sustainable development in harmony with the environment and life on Earth.

According to those above, one of the actions to reduce environmental degradation is prevention, which is done by the human being. This action is based on improving the public awareness on environmental protection and management

Improving public awareness on environmental management and protection can be done through several ways:

a) the use of mass media;
b) awareness campaigns or other similar actions;
c) environmental education at various levels: preschool, primary, secondary, high school, university and general public;
d) public participation in environmental activities;
e) knowledge of rights, responsibilities and obligations regarding environmental legislation, as well as, the consequences of breach thereof;

f) other [1].

To these we can add:

g) knowledge and information about the processes, phenomena and actions with negative effects on the environment, as well as, those with potential environmental impact from a local or global area.

The last ways above e) and g) can also be achieved with the help of a legislation databases, on-line interactive with the environmental legislation and with a GIS (Geographic Information System) database with environmental impact and problems into a geographic determined area.

MATERIAL AND METHOD

A database is a collection of pieces of information that is organized and used on a computer [2]. Environmental database was developed by MySQL Database Management System [3].

GIS database is a collection of spatial or geographic information and was developed by OpenLayers tools [4].

Identifying the areas affected and the degree of their deterioration and elimination of the causes and the effects are priorities in environmental protection actions. Meanwhile, the prevention and awareness activities can contribute decisively to avoid causes and phenomena with possible impact on the environment.

Regarding the ways to protect the environment from institutional point of view, several problems should be solved:

- creation of a legislative and institutional system appropriate and effective to ensure compliance with the laws in force that includes a legislation environmental system adequate to actual requirements [5];
- development of programs and policies on the medium and long term to protect the environment, in order to ensure sustainable development, in accordance with the EU strategy and the international context;
- identification of funding sources for activities and actions of environmental protection and management.

At the level of European Union there is a well-tuned environmental legislative system that has been implemented and harmonized in each Member State, including in Romania.

Environmental legislation database

The information in the database are structured in files with legislation documents at national and European level, tables with information about these laws and tables with legislation requirements relating to environmental protection and management.

Environmental European Union legislation includes: regulations, directives and decision. Romanian legislation or legislation from an European country can includes laws and government decisions.

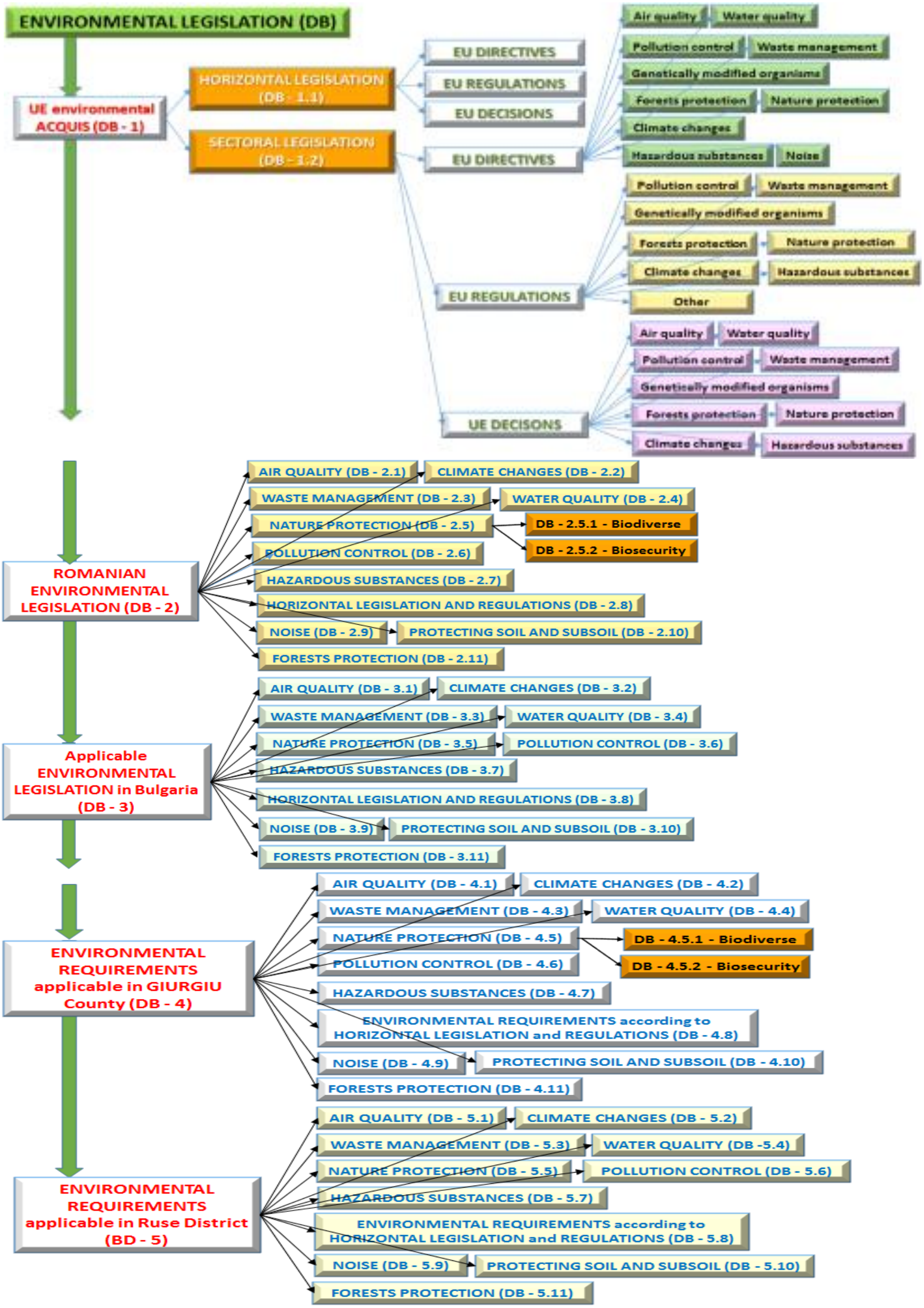

Fig. 1 Arborescent structure of legislation database

The database structure was designed in arborescent way [6]. It is formed at macro level from a structure of folders, which is identical with the structure of the main menu of the web platform database.

This structure allows Internet users to navigate easily in the database (DB) as shown in Fig. 1.

In the same time, classical facilities for access to database have been implemented: search (Fig. 2), query through the reports, viewing, as well as those specific for database administrator: update, adding records, structure management, etc. [7].

Search

The search terms can be input in the specified field. To search an exact phrase must use double quotes (example: "water pollution").

It is possible to search inside the database itself, inside the legislation files or both (Fig. 3). After the report is generated, it is possible to print only the records found in the database. The files can be opened and printed individually.

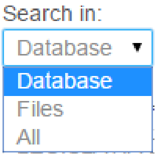

Fig. 2 “Search in” menu – image capture

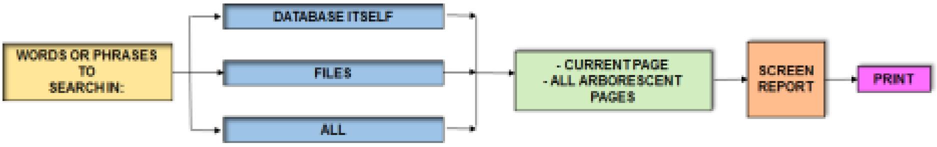

Fig. 3 The ways to search information in database

The client-server architecture is implemented for related informatic system (Fig. 4).

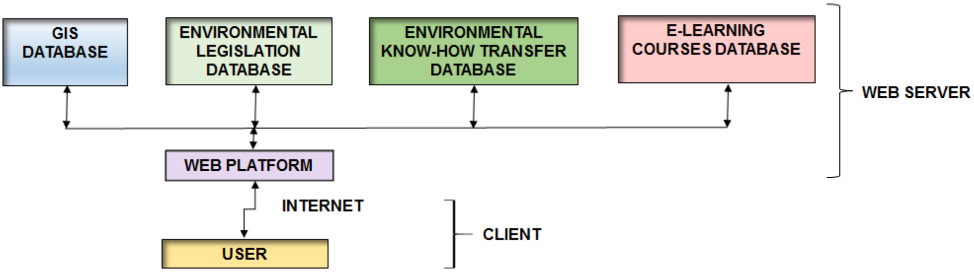

Fig. 4 Client - server architecture of databases to improve the public awareness on environmental management and protection

The search can be performed in a section of the database (and/or associated legislation files). The report will show only the records and/or files corresponding to this section and all its subsections like in Fig. 1.

Report

The "**Report**" option allows to perform an advanced search in the environmental legislation database and/or inside files containing laws.

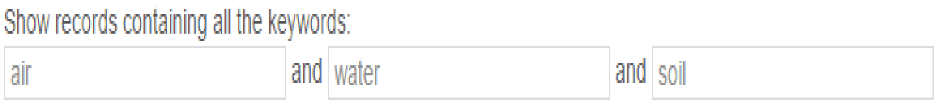

Fig. 5 Fields to input search terms

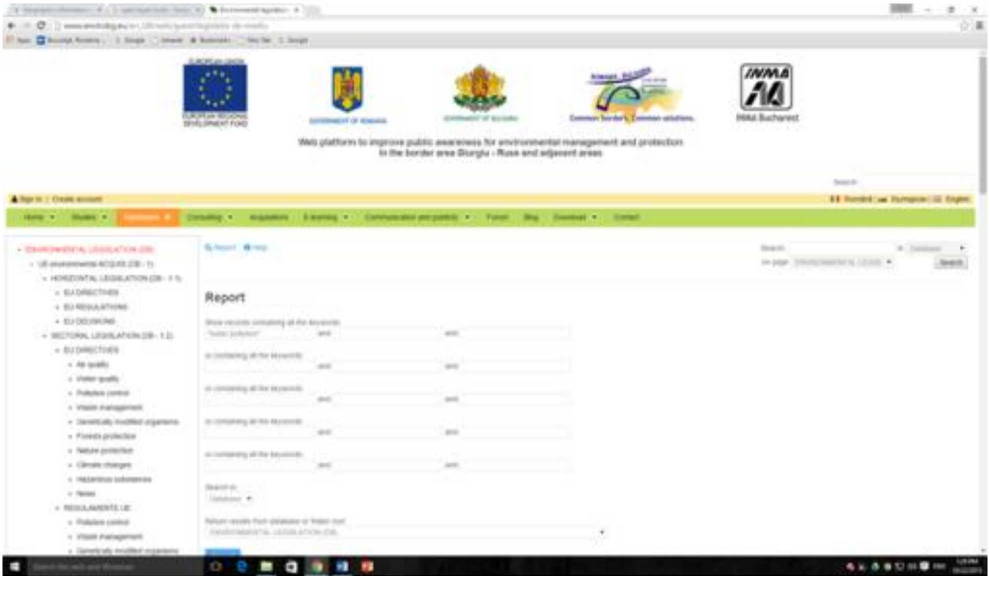

Fig. 6 Search exact phrase

There are 5 lines of fields where you can enter search terms. The report will perform 5 different searches (one for each line of terms) and it will join the results: it will display the records containing all the terms specified on the first row, then the records containing all the terms specified on the second row and so on:

- it is possible to input search terms on each field or all the terms in the same fields (separated by space). The following examples will return the same results (Fig. 5).
- to search an exact phrase use double quotes (example: "water pollution"). In a single field you can enter only one exact phrase. If the field contains an exact phrase then it

cannot contain other search terms (use the other fields on the same row to specify other terms or other exact phrases to search) (Fig. 6);

- each search term must contain minimum 2 characters;
- it is not necessary to enter text in all the fields, empty fields will be ignored.

GIS database

The environment is a multidimensional reality in continuous transformation because of human action and natural factors. The human society is beneficiary of the environment, which through its activity and creation can produce harmful or beneficial effects on it.

Geographical components of the Earth (lakes, ponds, rivers, forests, plains, etc.) make up ecosystems that maintain their equilibrium, as long as, the human not disturb them. Besides disturbing natural factors, the man can become a factor of imbalance.

The imbalances occur when factors and processes with negative environmental impact occur.

Identification of these factors in a geographical area and informing the general public regarding to their presence can contribute significantly to their removal or to prevent the occurance in other locations. An effective way to do this is to develop a GIS database. It can be integrated in a web platform for broader access to information through the Internet.

The information structure from database will be organized into layers. Each layer will contain relevant information on environmental impact, geospatial information on the size and the position of the area with environmental impact.

The used layers can be: forests, lakes, rivers, desertification, erosion,Romania, Bulgaria, etc.

RESULTS AND DISCUSSION

Within the web platform www.envirobg.eu was achieved an on-line GIS database with environmental impact sources for Giurgiu- Ruse area and an on-line environmental legislation databases within "*Network and web platform to improve the public awareness on environmental management and protection in the cross - border area Giurgiu - Rousse and adjacent cross - border areas*" project.

The main facilities of the environmental legislation database implemented are: search, reporting, viewing, printing, as are shown in the following figure (Fig. 7):

GIS database allows the web platform users to obtain information on the sources of environmental impact in the Giurgiu-Ruse area, in order to improve the public awareness on environmental management and protection in the border area Giurgiu-Ruse.

In order to achieve this was used OpenLayers web mapping library [4], for a variant. For the second variant were used Google Earth software and Google Earth API (application programming interface) [8], free version

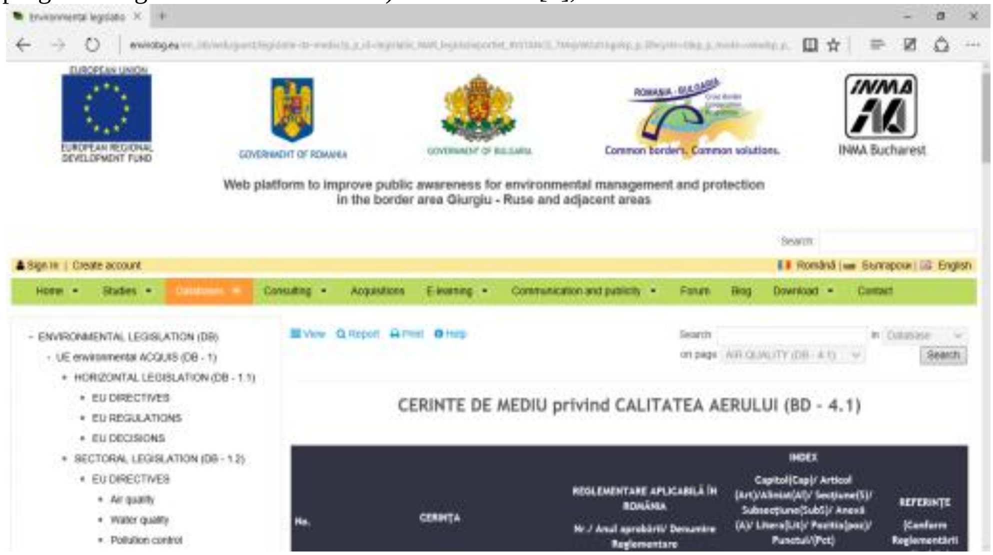

Fig. 7 Searching into environmental legislation database

Aspects during on-line use of the GIS database are presented in (Fig. 8) and (Fig. 9).

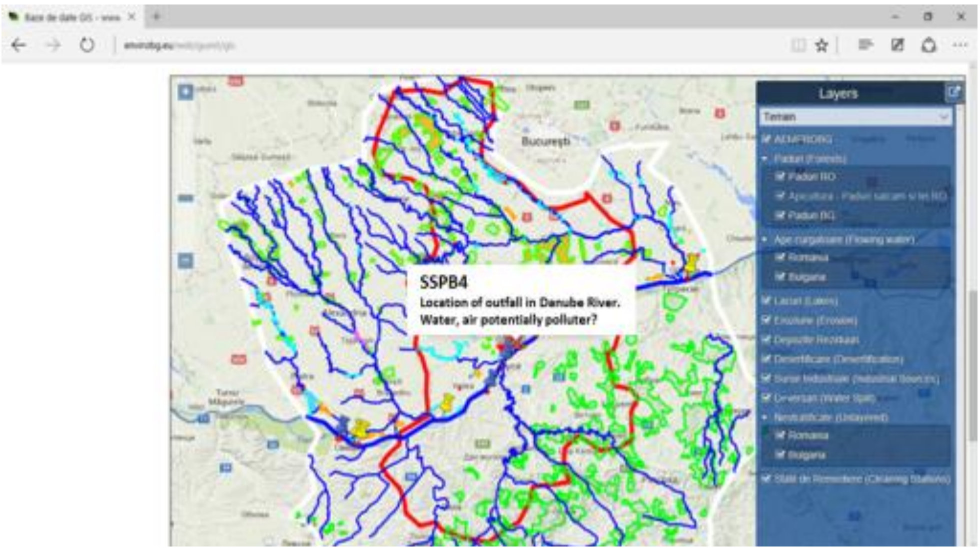

Fig. 8 Screen capture with GIS database (OpenLayers)

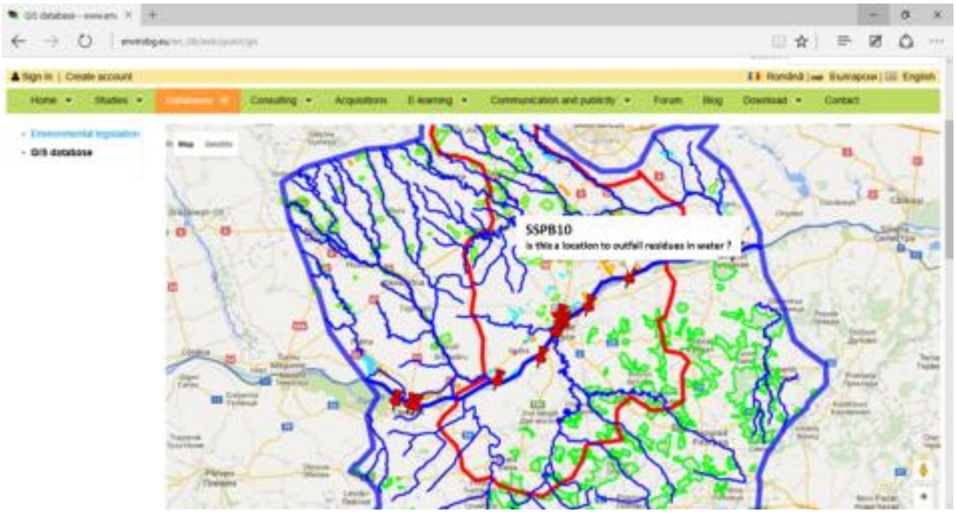

Fig. 9 Screen capture with GIS database (Google Earth)

CONCLUSIONS

The legislation and GIS databases, as well as, databases generally, represent elements that can provide useful information in environmental management and protection activities.

Databases presented in this paper have been designed and achieved in order to be placed in WWW(World Wide Web) space and to be used on-line through Internet. Thus, they can be embedded in web pages.

The databases contribute to improve the public awareness on environmental management and protection by providing:

- Structured knowledge and information about environmental legislation, as well as, the rights and the obligations arising therefrom;
- Knowledge and information about the processes, phenomena and actions with negative effects on the environment, as well as, those with potential environmental impact from a local or global area.

The methodology of the databases achievement can also be applied in other domain to provide structured information of interest to it.

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44. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

UDC 001.9:378.663
Prethodno priopćenje
Preliminary communication

BUILDING CAPACITY OF SERBIAN AGRICULTURAL EDUCATION TO LINK WITH SOCIETY

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SUMMARY

Knowledge transfer in agricultural sciences is rather limited after students' graduation from the Faculty of Agriculture. There is a lack of courses for professional development of teachers from agricultural middle schools, as well as a need of permanent improvement and upgrading of courses and trainings created for advisors in agricultural extension services. The CaSA project objective is to contribute to the improvement of agricultural education to meet the needs of Serbian society. CaSA foresees: upgrading quality and availability of vocational agricultural education by strengthening professional and pedagogical competences of educators (University teachers, secondary school teachers, advisors) and creation of the repository for courses and additional contents important for agricultural education. Improvement of agricultural education will be achieved by introducing trainings in active teaching learning (ATL), communication skills, e-learning, together with newest knowledge emerging from research activities incorporated in vocational courses. Creation of the National Repository for Agricultural Education (NaRA), will enable networking of all stakeholders in agricultural education and assure sustainability. In addition, among 13 project partners, the Ministry of education is a compulsory partner for Structural Measures TEMPUS projects. This is important for recognition of the National repository by relevant state authorities. Online courses and teaching material, live stream trainings, results from the research projects, and different data bases will be available in NaRA after project life-time.

***Key words**: agricultural knowledge transfer, innovation, NaRA.*

INTRODUCTION

This is a presentation of the CaSA project and the role it plays in linking research and innovation with knowledge improvement in agriculture. CaSA is a national project, coordinated by The University of Belgrade, Faculty of Agriculture.

It belongs to the TEMPUS sub-program Structural measures and the Action Higher education and society. These two benchmarks point out what are the main objectives of the project: to improve quality and availability of vocational agricultural education; to strengthen competences of educators; to create a National Repository for Agricultural Education (NaRA).

Basic course is strengthening links between higher education (HE) and society by building capacity of Serbian:

- University teachers from Faculties of Agriculture (FA)
- Agricultural secondary school (AMS) teachers
- Experts in Extension services (ES)

to improve teachers' competences in pedagogic skills and provide in-service vocational training courses.

Specific objectives of the project are:

- SO1 - Improvement of quality and availability of vocational agricultural education
- SO2 - Strengthening of professional and pedagogical competences of educators
- SO3 - Creation of the "open source" repository for educators in the area of agricultural education

Creation of a National Repository for Agricultural Education (NaRA) - a repository for online courses and teaching resources to ensure project sustainability and networking of all stakeholders in agricultural education.

There are 13 partners contributing to the project, 10 Serbian and 3 EU partner institutions. Serbian partners are 5 agricultural faculties from Belgrade, Novi Sad, Kragujevac, Novi Pazar and Sremska Kamenica, as well as Association of Agricultural Middle School in the area of agriculture, food processing and food production, Institute for Science Application in Agriculture responsible for in-service training of agricultural advisors, 2 NGO training organization (Education Forum and Balkan Security Network) and the Ministry of Education, Science and Technological Development of the Republic of Serbia. EU partners are universities from Timisoara (Romania), Maribor (Slovenia) and Foggia (Italy)

All project activities are grouped into 11 work packages.

The project lasts for 3 years (01/12/2013 - 30/11/2016) and aims to build the capacity of main holders of Serbian agricultural education: university teachers, teachers in agricultural middle schools and agricultural advisors working in extension services.

The CaSA project's main achievement will be the creation of a NaRA, available as an electronic platform that should enable the sustainability of the project and connection of stakeholders involved in all levels of agricultural education and training in Serbia. This repository will include: information necessary for teaching traditional courses as well as online courses for professional development of Agricultural Middle Schools and experts in extension services; databases of results obtained by research; selected and recorded classes of interactive teaching; selected parts of courses realized and/or developed within the project, prepared in the form of online video tutorials and posted together with additional teaching contents; and other relevant contents added to the repository based on authorized decisions of the NaRA Advisory Board.

All project participants have agreed and signed the Constituent agreement on project implementation and NaRA management.

STATE AND STRUCTURE OF AGRICULTURAL EDUCATION IN SERBIA

Most of the jobs in modern agricultural production permanently need acquiring additional knowledge regardless of the period passed from graduation. Besides research carried out in scientific institutions (universities, research institutes) occupations that need constant knowledge update are primarily teaching and advising. University teachers, together with teachers in middle agricultural schools and advisors employed in extension (advisory) services are the fundament of agricultural education in all areas of Serbian agriculture, including animal sciences. Knowledge upgrade is compulsory for all the three pillars of Serbian agricultural education: university teachers, secondary school teachers, and advisors. They are thus part of the lifelong learning (LLL) process.

Continuous professional development of agricultural middle school (AMS) teachers is defined by the "Law on basis of education system", article 129 (*Official Gazette of the Republic of Serbia, no. 55/2013*). According to the law, continuous professional education of teachers is compulsory. It can be provided by different organizations: NGOs, schools, faculties, registered agencies, and Centers for professional development established by local authorities; financed by the Ministry of Education and/or projects funded by EU or other international organization (*Popovic,* 2013). However, the choice of programs for continuous professional development is made rather inconsistently than according to the established education policy; it is based on the offer of courses, not on the need analysis (*Pesikan et al*. 2010a). In addition, there is discrepancy between programs and practices in a sense of huge differences between courses in: training type, trainers' competences, training duration, content, and evaluation, as well as monitoring of training effects in classes (*Pesikan et al*. 2010b).

Knowledge upgrade in advisory service seems better organized: agricultural Farm Advisory System (FAS) in Serbia is entrusted to the Institute for Science Application in Agriculture, Belgrade. The Institute is a coordinating institution in charge of Education of advisors. The legal basis for advisory system is "Law on performing advisory and expert operations in agriculture" (*Official Gazette of Republic of Serbia No. 30/10 from 7.5.2010*). The Ministry of Agriculture, Forestry and Water Management (MAFWM) issue a Decree on Determining Annual Program on Advisory work Development in Agriculture, for the current year and announces a Competition for the 31 centers (funded by the Government) and 3 private advisory services to apply for the funds provided by the Ministry. According to law provisions MAFWM is in charge for FAS organization, work and performance.

Table 1 represents an overview of accredited courses for AMS teachers since 2006/07. In the newly published Catalogue for 2014/2015 and 2015/2016 courses offered to teachers of middle agricultural schools are extremely rare: only 3 courses, out of 868 accredited courses could be connected with agricultural practice. In the earlier catalogues from the total number of 1002 courses accredited for professional development of teachers only 12 courses offered were somehow linked to agriculture (7/12 for AMS teachers), while not a single one was devoted to zootechnics, except “Animal welfare and us” a course given by an NGO for animal protection. Among these courses that could be taken by agricultural middle school professors, only 1/12 is offered by the Faculty of Agriculture University of Novi Sad (http://katalog.zuov.rs/).

This actual situation clearly indicates that courses for teachers of secondary school level are an absolute necessity and that animal science professionals must urgently find a way to support people working outside the University, educated by the University, to ensure LLL possibilities to our colleagues responsible for the education of agricultural animal producers and teachers in secondary education level.

When it comes to advisors, in Serbia, from 2010, every year all advisors have education in three areas: knowledge widening, knowledge upgrade, and knowledge application. In addition, specific workshops are organized in all areas of agriculture during the Annual seminar.

Table 1 Accredited courses for teachers of AMS from 2006/07 to 2014/16

School year	Number of courses available to AMS teachers	Accredited courses offered by faculties of Agriculture
2006/07	0	0
2007/08	0	0
2008/09	15	0
2009/10	4	1
2010/11	7	1
2011/12	6	1
2012/14	7	1
2014/16	3	0

The aim of this contribution is to describe the obtained TEMPUS project and its role in reinforcing knowledge transfers in agricultural, including animal sciences.

NEEDS OF SERBIAN SOCIETY - THE IDEA OF THE TEMPUS PROJECT

Starting from the idea that 3 basic pillars of agricultural education: Universities, secondary agricultural schools and advisory services, need mechanisms of LLL implemented, and that such mechanisms are not fully established in Serbia, the Faculty of

Agriculture University of Belgrade and the Faculty of Agriculture University of Novi Sad have decided to prepare a TEMPUS project, in the frame of the TEMPUS action HE and society.

These two faculties together were participants in a number of previous TEMPUS projects; first was a project that facilitated the reform process according to the principles of Bologna declaration, and their common efforts contributed to reformed agricultural curricula (*Poleksic et al*, 2004; *Poleksic et al*, 2006).

During project preparations following challenges for the Serbian agricultural education were identified: a lack of pedagogical education for students of faculties of agriculture during their graduate courses students that continue their carrier in education, as teachers in secondary schools or university teachers, lack any formal pedagogical education; there is also a need for young university teachers to learn academic skills such as writing project proposals, preparing project budget, presenting project results, writing scientific papers, etc; secondary school teachers and agronomy experts from advisory services need in-service training.

In addition, advisors working directly with farmers need some skills development such as modern means of communication and preparing project proposals to be able to apply for funds available for Serbian producers and companies. In conclusion, all the mentioned holders of agricultural education have an obligation to upgrade their professional knowledge, but they also need development of skills their profession requires.

The project idea originated from a general need of the Serbian Society to reinforce agricultural practice, to apply newly generated scientific knowledge, and modern production and processing practices. In addition, agricultural education has to inform and educate the public including raising public awareness about agricultural development, issues such as ecological agriculture, organic production, GMO, and other important issues. The project proposal fits into the Strategy for Education Development of the Republic of Serbia until 2020 (*Strategy of Education Development in Serbia to 2020+, 2012*). Teachers' education and teachers as key factor of education development are particularly addressed in the Strategy. These should be achieved by: development of in-service teachers training to improve teachers' competences for encouraging students' creativity, innovation and entrepreneurship; training of all teachers to use ICT in teaching; and implementation of methods of ATL.

Areas of specific interest: development of LLL in the society at large, cooperation with other education levels and development of human resources are national priorities defined that the CaSA project proposal intended to deal with.

The proposal was successful, and a project "Building capacity of Serbian Agricultural Education to link with Society, CaSA" 544072-TEMPUS-1-2013-1-RS-TEMPUS-SMHES officially started in January 2014.

PROJECT SUMMARY

The project, coordinated by Faculty of Agriculture, Belgrade, will build capacity of Serbian faculties of agriculture to improve teacher's competences in pedagogic skills as well as in their ability to provide distance learning in-service teacher training vocational courses for teachers in agricultural middle/secondary schools (AMSs) and for experts in extension services. Networking of all relevant stakeholders in agricultural education as well as project sustainability will be enabled by creation of the National Repository for Agricultural Education (NaRA).

At all Serbian Faculties of Agriculture and State University of Novi Pazar, courses in active teaching/learning (ATL) including e-learning for young university teachers and teachers from AMSs will be held during project lifetime. ATL courses, given by experts from NGO Education Forum, are important for both groups of teachers (University and AMS) since they did not have any pedagogical training during their graduate courses in agronomy.

University teachers, that have improved teaching competences and other academic skills, will develop and implement classical and web-based vocational courses targeting recent advances in agriculture for AMS teachers and agronomists in the extension services as beneficiaries. It will be done in collaboration with University from Maribor and with University of Foggia, Italy. Implementation of these courses will be done in year 3 at AMSs under the supervision of EU partners.

During the project lifetime NaRA will be formed with the help of EU partner from Agricultural University, Timisoara, Romania, to provide relevant information, to serve as stakeholder data-base and to be used as repository for e-learning courses developed in the project, as well as for various teaching materials developed during ATL trainings of both university and AMS teachers. NaRA will then become a platform for improving teaching skills of both, university and AMS teachers as well as for improving professional skills for AMS teachers and agronomists in the extension services. Since the agronomists working in the extension services lack: modern techniques of communication to work with farmers, as well as skills needed for preparation of project proposals, this project will provide training given by experts from NGO Balkan Security Network (BSN) for agronomists how to communicate with farmers and how to prepare a project proposal.

Academic and communication skill courses, given by experts, will be recorded and stored together with accompanying teaching material as a live stream courses, available at NaRA for all university and AMS teachers and agronomists in extension services to be used after the project lifetime. Creation of NaRA will, therefore, provide sustainability of the project since all project deliverables (all types of e learning courses and teaching materials) developed during project lifetime will be stored and available for future users. NaRA will also provide networking and active communication of all relevant stakeholders (Universities, AMSs, extension services, governmental and non governmental bodies).

Sustainability of NaRA will be ensured after the project life-time by the support and recognition of the Ministries of Education, Science and Technological Development and of Ministry of Agriculture of the Republic of Serbia, as well as with some courses commercialization, while some databases, professional forums, and relevant information will remain open access. Management of the NaRA will be regulated by the Agreement between universities and other project partners.

Project partners:
P1 University of Belgrade Faculty of Agriculture UB – coordinating institution

P2 University of Novi Sad Faculty of Agriculture UNS

P3 University of Kragujevac Faculty of Agronomy Cacak UNIKG

P4 University EDUCONS Faculty of Ecological Agriculture

P5 State University Novi Pazar SUNP

P6 Association of Middle Agricultural Schools AMS

P7 Institute for Science Application in Agriculture IPN

P8 Educational Forum (NGO) EF

P9 Balkan Security network, (NGO) BSN

P10 Ministry of Education, Science and Technological Development ME

P11 Banat University of Agricultural Sciences and Veterinary Medicine USAMVBT

P12 University of Maribor UM

P13 University of Foggia UNIFG

WORK PACKAGES AND PROJECT ACTIVITIES

	WP 1 - Creation of the Repository
	WP leader: Cosmin Salasan, USAMVBT, Timisoara, Romania
A 1.1.	Organizing workshop in Belgrade with all relevant stakeholders to define structure and content of NaRA
A 1.2.	Creating and maintenance NaRA

	WP 2 - Infrastructural support for NaRA functioning / Development of resources
	WP leader, project secretary: Goran Topisirović, UB, Belgrade, Serbia
A 2.1.	Purchase of the equipment for improving/creating faculty e learning platform at every faculty /university and for NaRA at P1
A 2.2.	Training of IT administrators at every faculty/university for maintenance of the platform
A 2.3.	Engaging an IT expert for programming and software support 2.4. Engaging one cameraman and film editor from University of Arts

	WP 3 - Improvement of competences of university teachers
	WP leader: Ana Pešikan, EF, Belgrade, Serbia
A 3.1.	Training of university teachers in ATL
A 3.2.	Training of university teachers in academic skills
A 3.3.	Training of university teachers in methodology of creating vocational courses in e-learning format

	WP 4 - Modernization of teaching contents
	WP leader: Snežana Tanasković, UNIKG, Čačak, Serbia
A 4.1.	Need analysis for knowledge refreshment
A 4.2.	Workshop in Cacak with EU partners to compare experiences and good practices
A 4.3.	Development of classical (f2f) vocational courses for AMS teachers and agronomists in extension service
A 4.4.	Development of web based vocational courses

	WP 5 - Improvement of competences of AMS teachers
	WP leader: Vidoje Vukašinović, AMS, Požarevac, Serbia
A 5.1.	Training of AMS teachers in ATL
A 5.2.	Training of AMS teachers in e-learning

	WP 6 - Improvement of competences of experts in extension services
	WP leader: Snežana Janković, IPN, Belgrade, Serbia
A 6.1.	Training of agronomists in extension services in using e-learning platform
A 6.2.	Training of agronomists in extension services in communication and project proposals preparation skills

	WP 7 - Pilot implementation of vocational courses
	WP leader: Ljubinko Jovanovic, EDUCONS, Sremska Kamenica, Serbia
A 7.1.	Implementation of classical pilot vocational courses
A 7.2.	Implementation of pilot web based vocational courses

	WP 8 - Quality assurance control of project activities
	WP leader: Sofija Pekić Quarrie, SUNP, Novi Pazar, Serbia
A 8.1.	Creation of the body for project quality control
A 8.2.	Development of questionnaires for training courses evaluation
A 8.3.	Analysis of training courses feedback questionnaires
A 8.4.	QA of vocational courses – peer review by EU Partners
A 8.5.	Development of questionnaires for vocational course evaluation
A 8.6.	Analysis of course feedback questionnaires from pilot implementation of vocational courses

	WP 9 - Dissemination of project results
	WP Leader: Dušan Petrić, UNS, Novi Sad, Serbia
A 9.1.	Adopting a dissemination plan and identify target groups for dissemination
A 9.2.	Designing and maintenance of the project web-site
A 9.3.	Organizing other dissemination and visibility activities: briefings, presentations, press conferences and other events
A 9.4.	Publishing and dissemination of training manuals and guidelines
A 9.5.	Dissemination at Final conference in NS

	WP 10 - Exploitation of project results
	WP Leader: Predrag Pudja, UB, Belgrade, Serbia
A 10.1.	Reaching agreement between faculties' managements on: maintenance of NaRA, recognition of teachers work in courses preparation, availability of NaRA content, and courses commercialization
A 10.2.	Defining procedures for intellectual property rights of courses creators
A 10.3.	Preparation for accreditation of vocational courses for AMS teachers
A 10.4.	Preparation for certification of vocational courses for ES experts

	WP 11 - Project Management
	WP Leader, project coordinator: Vesna Poleksić, UB, Belgrade, Serbia
A 11.1.	Organizing kick off meeting in Belgrade and SC meetings in: Belgrade, Čačak and N. Pazar
A 11.2.	Establishment of SC and defining procedures of cooperation between partners
A 11.3.	Daily project coordination and administration
A 11.4.	Meetings of the local project teams
A 11.5.	Regular reporting to EACEA
A 11.6.	Organizing final conference in Novi Sad
A 11.7.	Organizing final SC meeting in Novi Sad
A 11.8.	Financial Audit

REVIEW OF RECENT RESULTS

Need Analysis and Trainings

Those issues were structured through a lot of activities in different work packages. In the following part are presented the activities, including planned and realized deliverables.

5 IT administrators were trained for managing and using Moodle e-Learning software and maintaining distance learning platforms, as well as solving typical problems of users. Their training included following topics: Moodle – Administration; Basics about Moodle LMS; Necessary infrastructure; Installation; Basic system settings; Users administration (identity check); Moodle - Administration II; Administration of courses; Courses structure and format; Sections and blocks; Activities and resources; Add-ons/plug-ins.

Active teaching/learning is an accredited teaching methodology created by experts from EF, applicable and adapted for both school and University level. It consists of 2 trainings: basic and supervision seminar, between the two - a period of at least 30 days is needed, since in that period EF experts analyze teaching scenarios and give advices for improvement, thus preparing the second seminar. 60 university teachers from all 5 Universities, divided in 2 groups, were trained in ATL.

In continuation of the 2nd ATL seminar, University teachers were trained in academic skills: how to conduct quality research, prepare a project proposal and good quality research paper, how to present research results and other academic skills.

University teachers, together with AMS teachers, were trained to create vocational courses in eLearning format using Moodle software. This training was held for 3 days in face to face format and additional 2 days online training.

Knowledge refreshment needs analysis required preparation of questionnaires, their distribution, and final analysis before report preparation. Two detailed and broad questionnaires for training needs analysis for two target groups (secondary school teachers and advisors) were prepared in collaboration with EU project partners. One of the conclusions was that the skill gap assessments in Agriculture on national level is missing and that practice of conduction TNA regularly can contribute to the development of Agricultural education policy in general. The final document is a comprehensive and detailed document of 42 pages. The SC agreed that TNA will be the first brochure to be published in CaSA, and is available for download on NaRA. The whole brochure “Need analysis for knowledge refreshment of agricultural school teachers and extension service advisors in agriculture” can be found at http://arhiva.nara.ac.rs/handle/123456789/582.

Training of AMS teachers in e-learning included 60 teachers trained in eLearning in 3 groups, together with university teachers.

Experts from agricultural extension services were trained in using e-learning platform and in communication and project proposals preparation skills, in order to acquire communication ability with farmers/ agricultural producers. They also acquired project proposals preparation skills. According to the initial idea of the project, it was planned for 60 advisors from 34 Extension Offices to participate in the project. Before the start of trainings 13 advisors more applied. In total, 82 participants from 34 Extension were recruited and trained in three groups in March 2015.

Quality Control Body was created during the first gathering of all partners. This body will be responsible for monitoring project achievements. It was decided that all trainings should be covered by questionnaires and their analyses. QA of vocational courses will be done by detailed peer review by EU experts. Members of the QC body were approved.

Curses and NaRA

Those issues were structured through a lot of activities in different work packages. In the following part are presented the activities, including planned and realized deliverables.

Intensive activities on NaRA organisation, its structure and functionalities were carried out. NaRA domain was registered in July 2014 www.nara.ac.rs.

Decision on NaRA structure was finally decided as follows: Moodle + DSpace software integration as suggested by IT Center of UB. A plug-in was created for connecting Moodle software as an LMS with a DMS such as the already widely used DSpace. NaRA Advisory board was constituted in February this year.

30 University teachers developed classical vocational courses and another 30 University teachers developed online vocational courses. Both courses are actually registered and courses outlines are under review by EF, commented and corrected by UT before sending the translation to EU partners for review. Implementation of both classical and web based pilot courses is foreseen for November 2015 – November 2016.

EU partners peer reviewed all vocational courses and prepared reports with suggestions for courses improvement.

Questionnaires for vocational courses evaluation will be developed by experts from BSN and are foreseen for October - November 2015. Course feedback questionnaires from pilot implementation of vocational courses will be analysed by BSN experts, and report and conclusions prepared.

The Agreement reached between managements of the faculties on: maintenance of NaRA, recognition of teachers work in courses preparation, availability of NaRA content, and qualifications commercialization will be prepared during the kick-off meeting, after discussions of all project partners, including EU partners that will contribute to agreement preparation and consensus of Serbian Universities. After being commented, and improved in communication with all beneficiaries the NaRA Constituent agreement was signed gradually by all project partners.

Procedures for intellectual property rights of courses creators will be adopted. Previously the draft of procedures will be prepared, discussed and modified where needed.

From the first draft, Procedures for Intellectual Property Rights were made available for comments, improved and Revised and adopted at the SC meeting.

Vocational courses for AMS teachers are prepared for accreditation according to the methodology prescribed by the Institute for Education Improvement. Preparation for accreditation of vocational courses for AMS teachers is foreseen for November 2015 – January 2016.

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“Optimization of technological procedures and zoo-technical resources on farms in purpose of milk production sustainability improvement” 2011 - 2015. Project registration number TR31086. Ministry of Science and Technological Development of the Republic of Serbia.

“Building capacity of Serbian Agricultural Education to link with Society (CaSA)”, 544072-TEMPUS-1-2013-1-RS-TEMPUS-SMHES.

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44. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

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Prethodno priopćenje
Preliminary communication

GREEN ENERGY AND RURAL DEVELOPMENT – ROLE OF HIGH EDUCATION

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ABSTRACT

The role of renewable energy sources (RES) is clearly defined by European Union. Targets to be achieved by year 2020 are especially focused. Serbia accepted, by signing Memorandum of understanding, obligation to follow EU energy policies, including introduction of RES. The most of RES potentials in Serbia are located in rural areas, which are faced with a lot of socio-economic and other problems. The hypothesis is that simultaneous support for RES utilization and rural development could result with positive economic and societal advancements. The article deals with analysis of RES production and utilization impacts on rural development, emphasizing the role of high education in its realization.

Key words*: green energy, rural development, employment, high education*

INTRODUCTION

Production and utilization of renewable energy sources (RES), called also *green energy*, have been highly supported world wide, in European Union and in Serbia. RES should contribute to the mitigation of greenhouse gases (GHG), and replacement of fossil fuels. The obligation of RES implementation is strictly defined in EU by Directive 2009/28/EC (Anonymous, 2009), and in Serbia by new Energy Law (Anonymous, 2012a). These documents are followed by EU regulations, and will be very soon supported by national ones in Serbia. Overall objective in EU is to achieve RES share of 20 % in primary energy, 20 % in electricity consumption and 10 % in consumption of transportation fuels up to 2020. Serbia has accepted these targets by signing the Memorandum of Understanding (Anonymous, 2007), which contains obligation to follow EU energy policy.

Other general problem recognized in EU and many other countries is preservation and development of rural areas. The following is mentioned in one EU document related to rural development policy 2007-2013: "With over 56 % of the population in the 27 Member States of the European Union living in rural areas, which cover 91 % of the territory, rural development is a vitally important policy area. Farming and forestry remain crucial for land use and the management of natural resources in the EU's rural areas, and as a platform for economic diversification in rural communities. The strengthening of EU rural development policy is, therefore, an overall EU priority." The EU interests for rural development has been focused and articulated by Council Regulation No 1698/2005 (Anonymous, 2005), making this official and obligatory for members as field of interest. Rural development has different aim and dimensions in underdeveloped and developing countries, where these areas are faced with many problems, and belong to economically weak. This is also the case of Serbia.

The potentials of RES, *green energy*, are, in the most cases, to high extent, located in rural areas. Example for Serbia, biomass potentials of crop residues has been assessed to be about 1.7 Mtoe (Ilic, 2003), and energy wood about 1.0 Mtoe (Anonymous, 2010). Newly, other sources are focused as well, *i.e.* animal wastes and energy plants, located in rural areas too. Most of RES are not suitable for longer transport distances, and should be used in the proximity of their occurrence, that means rural areas. Production and utilization of RES is growing business, connected with investments and new employment possibilities. It would be reasonable to use it for the development of rural areas, but this should be realized appropriately, in order to preserve environment.

It is well known that RES still cost more than fossil fuels, but with higher costs in the most of cases. Principle of *least costs* for RES implementation has been defined (Ragwitz et al., 2006), but it needs time and further technological development to make them economically acceptable. Today utilization of RES is supported by considerable incentives. The same is valid for activities related to rural areas' development. The hypothesis was setup that the support of RES, namely *green energy*, and rural development programs could be complementary and result with positive effect on society at a whole.

The objectives of the paper are: to present importance of simultaneous support for implementation of *green energy* and rural development, and to elaborate role of high education in it.

RELEVANT EVENTS AND ACTIVITIES

Some of recent events and other activities, related to the RES and rural develop-ment, are listed and commented in this chapter.

Probably the most significant was OECD Rural Development Conference held in Paris, June 14-15th 2012, with the title: *Linking Renewable Energy to Rural Development: Drivers and Constraints*. The motto of the Conference was – how the production of renewable energy in rural areas can:

- Create new and viable jobs.
- Boost Investment.

- Empower local communities.

The Conference participants were policy makers from ten OECD countries.

Second example, related to EU, is publication: *Rural Energy in EU* (Groenenberg et al., 2011). This includes case studies for several EU countries, and gives good overview about importance of RES for rural development. Obviously, the problems of rural development are in the developed countries seen from the other point of view. In this publication GHG emissions and possible switch from fossil fuels to RES in the rural areas are mostly focused, with reduction of GHG as positive effect. The economic aspects were neglected.

Next example is the project: *Green Energy as a Rural Economic Development Tool Project*, which has been launched in British Colombia, Canada, under the auspices of Ministry of Energy and other stockholders. The major objectives of the project are: to ensure extensive circulation and understanding of the knowledge, material and tools developed as part of this project; to provide the opportunity for a number of communities to be able to take advantage of highly specialized *green energy* consulting expertise to identify the feasibility of their local *green energy* opportunities. This project offers good example of supporting RES implementation in rural areas by financing some kind of extension service, which supports projects from feasibility study till its commissioning.

There are many other projects related to these issues, like: *Rural Power Community-Scaled Renewable Energy and Rural Economic Development*, in Minnesota, USA, and International Conference: *Renewable Energy: A Rural Economic Development Strategy*, Cincinnati, Ohio, USA, July 22-25, 2012 (Moss et al., 2012). World Bank project: *Renewable Energy for Rural Economic Development* is aimed to support development of *green energy* sector in underdeveloped and developing countries.

Renewable energies from agriculture, *i.e.* rural areas, are widely focused in scientific community. Many reputable journals include articles related to relevant issues. One example is *Biorecourse Technology* (previously called *Energy in Agriculture*), IF 4.98, 2011. There are also other high reputable journals that cover RES, and some of them especially these mostly originated from rural areas: *Biomass and Bioenergy* (IF 3.65, 2011), *BioEnergy Research* (IF 3.56, 2011).

Rural development is closely related to sustainable agriculture, which implies environmental, economic and social aspects. Appropriate implementation of RES fits very well to all mentioned aspects. Field of sustainable agriculture is also covered by numerous reputable journals, *International Journal of Agricultural Sustainability, Journal of Sustainable Agriculture*, etc.

SIMULTANEOUS SUPPORT OF RES IMPLEMENTATION AND RURAL DEVELOPMENT

The most significant definition of *green energy* – rural development correlation has been elaborated in the mentioned OECD Conference (Anonymous, 2012b), whereby the following has been stated:

- Presenting renewable energy as a panacea for energy supply and economic growth has been a mistake in the past.

- When renewable energy is connected to a rural industry such as agriculture, forestry, or manufacturing, its potential to create jobs and have an impact on growth is much higher.
- To be effective, the policy should be linked to skill development, empowerment of institutions, and shared visions about the model of economic development to be put in place.
- Local communities should not be considered as mere hosts of renewable energy installations, but as active participants in key policy decisions, otherwise they will oppose renewable energy deployment and consequently increase the cost of achieving a carbon constrained economy.

Here are given some excerpts from the executive summary related to question "What does renewable energy offer rural areas?":

- New revenue sources.
- New job and business opportunities.
- Innovation in product, practices and policies.
- Capacity building and community empowerment.
- Affordable energy.

As usual, for the implementation of RES in rural areas, potential constrains should be considered as well. These are, first of all, related to the preservation of natural resources, like agricultural soil, waters, air and landscape. The other problem, for some kinds of bioenergy, is the competition of energy to food, if the feedstock is based on agricultural production.

RES and employment in rural areas has been commented by many sources, and can be summarized as:

- RES potentials are dislocated and are suitable for decentralized utilization. Can positively impact rural development, creating new opportunities for employment in the whole chain of production, processing and marketing.
- Especially is suitable application of biomass. Its production and utilization can involve low qualified labor, but high qualified persons with skills in engineering, economy, administration and other fields as well. Employment is direct and indirect.
- Utilization of biomass –crop residues and energy plants, means additional income for agriculture.
- Manufacturing of equipment for production and utilization of RES, as well as other residuals and wastes, is a chance for indirect employment.

Employment in RES sector is very intensive. Some web sites are selected to illustrate it: renewableenergyjobs.com,

greenenergyjobs.com,

thegreenjobbank.com, and

eere.energy.gov/education/clean_energy_jobs.html.

Forecasting of jobs development in RES sector, not only in rural areas, is presented by fig. 1, and for bioenergy by fig. 2.

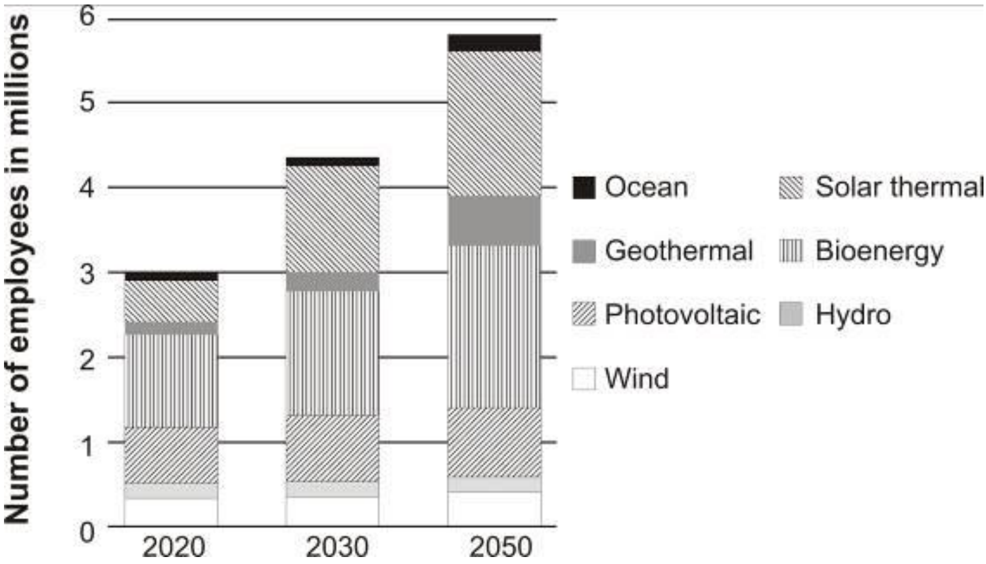

Figure 1 The outlook of employments in RES sector (www.energyunion.eu/intelligent_energy/green_energy_jobs, access January 2013)

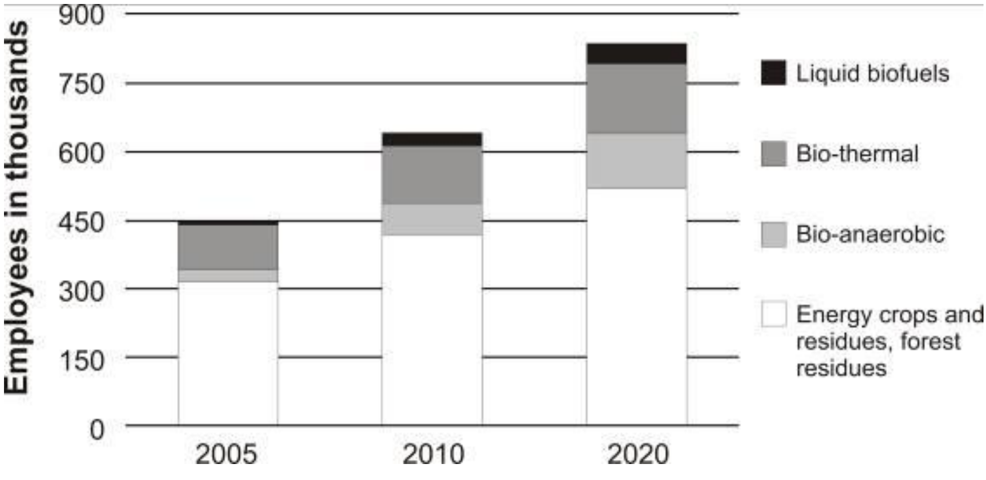

Figure 2 Trends of the employment (full time job equivalence) in EU in the RES sector, relative to 2005 (cited in Martinov, 2012)

The jobs are offered for different activities: development of RES facilities, manufacturing, planning and selling, national or regional administration, operating etc. In table 1 are presented possibilities of involvement of rural areas for diverse activities of RES implementation. Possible intensity for most significant forms of renewables is also marked.

Table 1 Potential involvement of rural areas in renewable energies production and utilization (Martinov, 2012); Legend: I production; II utilization; III processing for own needs or other users; IV production of facilities; ++ very intensive; + intensive; 0 possible; – none

o.	Renewable energy	Activities			
		I	II	III	IV
	Solar energy – heaters	–	+	–	0
	Solar energy – photo voltage	–	+	–	–
	Solid biomass – heating, small units	++	++	++	+
	Solid biomass – heating, big units	++	+	++	0
	Solid biomass – CHP (combined heat and power)	++	++	+	0
	Solid biomass – co-firing	++	–	0	–
	Solid biomass – BtL (Biomass to liquid)	++	0	0	–
	Plant oils – CHP	++	+	+	–
	Biodiesel	++	+	0	–
0	Biogas – heating and process heat	++	++	0	–
1	Biogas – CHP	++	++	0	–
2	Biomethane	++	+	–	–
3	Bio-ethanol	++	0	0	–
4	Wind energy – small scale	–	++	–	0
5	Wind energy – big scale	–	0	–	–
6	Thermal water – heating and CHP	–	0	–	–
7	Thermal water – balneology	–	+	–	–
8	Algae	++	+	–	0

From the previously presented, it is clear that RES production and utilization can be complementary with rural development. With appropriate policy, first of all, the activities of public and private institutions could be motivated to focus toward RES deployment in rural areas, and private investors attracted to this sectors. However, this needs to be performed in sustainable manner, to preserve natural resources, like soil fertility, waters and landscape. Master plans for each country and/or region should be developed carefully, taking into account locally specific conditions. This could result with boost of rural economy and improved social status, as well as positive environmental effects.

As already emphasized, the all activities should be performed taking into account need to preserve environment, soil fertility, water resources, landscape etc. To fulfill these demands, qualified persons in the field of environmental issues are needed, including environmental engineering.

ROLE OF HIGH EDUCATION

High educational institutions are obliged to contribute solution of society demands through three typical fields of activities: education, research/development and knowledge transfer – extension services. Here focused implementation of RES and rural development can be easily included in all of three. In the other hand, this is typical multidisciplinary task and needs coordinated engagement of many professions and branches: natural sciences, engineering, agriculture, environment sciences, sociology, economy, law etc.

The potential engagement of high education institutions can be as follows:

Educational measures

Educational process should include, as a part of courses, or special courses, teaching related to this subjects. The objective of courses is to deliver knowledge about topics, to develop students' awareness and skills to recognize, quantify and solve prob-lems of RES implementation and rural development. Qualified bachelors, masters and doctors should have enough knowledge to contribute improvements and bring positive solutions.

Obligatory part of education should be life long learning courses – short courses, for alumni, special topics for additional education in other disciplines and courses for professionals in this field.

Constant upgrading of teaching materials is compulsory, due to dynamic develop-ment of achievements in these fields.

R&D activities

RES is emerging sector, with booming of innovations. Majority of engineering innovations are coming from manufacturers, *i.e.* their development services. High education institutions and public R&D institutes should develop backgrounds for innovations and development, as well as proper tool for their evaluation. Very important task is also application of adequate LCA (Life Cycle Assessment), and MFA (Material Flow Assessment) methods. It should enable appropriate impact evaluation of certain technology. In rural areas, agriculture and forestry this is even more challenging due to many other influences.

In this group is included also development of methods and tools for economic and social evaluation of technologies and concrete engineering solutions.

Transfer, extension outcomes and deliverables

High educational institutions are best qualified to support extension services, or to create own. Support of extension services can be performed by short courses or work-shops. Through these events, very concrete knowledge and instructions for RES implementation and rural development should be delivered. The participants should gain new skills related to these issues, applicable for own practice. This should be accompanied with high quality and usable publications, in form of studies-instructions.

Important activity is to create education material, supporting tools, for policy makers, and to provide trainings for them.

The all mentioned activities are directly or indirectly market oriented, and market of *green energy* seems to be very promising.

CONCLUSIONS

Renewable energy, *i.e. green energy*, is expected to contribute energy security, climate change mitigation and economic development, including creation of new jobs. However, this sector should be treated realistic, not as a panacea for all economic problems.

Rural development, closely connected to agriculture and forestry, is serious issue in almost all countries, underdeveloped, developing and developed.

The both issues need public attention and support. Idea is, to perform simultaneous support for implementation of *green energy* and rural development. To do it successfully, professional knowledge and well designed framework for national and regional policies is needed.

The high education should have significant role in supporting of stated objectives. This can be performed through all three activity types: education, research/development, and transfer, extension services.

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44. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

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KOMASACIJA POLJOPRIVREDNOG ZEMLJIŠTA U HRVATSKOJ U FUNKCIJI VEĆE KONKURENTNOSTI POLJOPRIVREDNE PROIZVODNJE

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SAŽETAK

Kao jedna od osnovnih prepreka za povećanje konkurentnosti hrvatske poljoprivrede često se spominje mala veličina poljoprivrednih gospodarstava. Jedno od rješenja je komasacija čija je glavna svrha stvaranje većih i/ili pravilnijih parcela radi boljeg korištenja i stvaranja povoljnijih uvjeta za poljoprivredu. Komasacija poljoprivrednog zemljišta predstavlja poželjan niz postupaka koji će uvažiti tri dimenzije održivog razvitka: gospodarsku, socijalnu i okolišnu. Gospodarska dimenzija ogleda se u većoj učinkovitosti i produktivnosti poljoprivredne proizvodnje, okolišna dimenzija sastoji se u omogućavanju poljoprivrednicima da koriste manje intenzivne metode, a socijalna dimenzija očituje se u privlačenju i ostanku ljudi na ruralnim područjima.

U radu se promatra komasacija s naglaskom na gospodarsku dimenziju održivog razvitka. U radu se polazi od pretpostavke da komasacija pozitivno djeluje na konkurentnost poljoprivredne proizvodnje što se u radu dokazuje metodom izračuna troškova domaćih resursa (DRC – Domestic Resource Cost).

Ključne riječi: *komasacija, poljoprivredno zemljište, konkurentnost, Hrvatska*

UVOD

Komasacija je agrarna operacija s ciljem okrupnjavanja posjeda pri čemu se oblikuju veće i za korištenje ostalih inputa, posebice strojeva, prikladnije poljoprivredne parcele što je u konačnici osnovica cjenovno konkurentnije poljoprivredne proizvodnje. Samo okrupnjavanje odnosno komasacija poljoprivrednog zemljišta je tek početak u rješavanju mnogih problema poljoprivrede i prostora, a ne konačni cilj.

U mnogim državama komasacija je najzahtjevnija agrarna operacija koja potiče promjenu agrarne strukture (smanjenja broja poljoprivrednih gospodarstava uz istovremeno povećanje prosječne veličine posjeda) te uređenje i razvoj sela. Postupkom komasacije se rješavaju dugo neriješena imovinsko-pravna pitanja, poboljšava se prometna povezanost s parcelama, izvodi uređenje tla (hidromelioracije) i drugo.

Sam postupak komasacije mogu pokrenuti vlasnici poljoprivrednog zemljišta te država. I kada to čini država, pretpostavka je dobro „pripremljen teren“ odnosno odobravanje od većine vlasnika zemljišta.

Općenito, u procesu komasacije su nezaobilazna tri sudionika i to poljoprivredni proizvođači, lokalna zajednica i Država, pri čemu osim zajedničkog postoje i pojedinačni ciljevi odnosno očekivanja od postupka komasacije.

Poljoprivredni proizvođači odnosno vlasnici zemljišta u postupku komasacije rješavaju neriješene imovinsko-pravne odnose pri čemu se često otkriju i značajne poljoprivredne površine najčešće uzurpiranog državnog zemljišta.. Nakon provedenog postupka dobivaju manji broj površinski većih pravilnijeg oblika parcele te s obzirom na konfiguraciju terena i s povoljnijom orijentacijom. Ovo je naročito značajno za voćarsku i vinogradarsku proizvodnju ali i zbog vodozaštite (otjecanja viška voda ili čuvanja vlage). Novoformirane parcele su u pravilu i bliže gospodarskom dvorištu te se smanjuju transportni troškovi i omogućava veća i stalna briga o usjevima. Uređenjem kanalske mreže povećava se zaštita od elementarnih nepogoda ali olakšan je i omogućen pristup parcelama. Suvremena mehanizacija bolje se koristi jer je manje praznih hodova i manje utroška pogonskog goriva, povećava se prirod, ukupna proizvodnja te produktivnost i sam dohodak. Tako uređenom poljoprivrednom zemljištu povećava se tržna vrijednost jer se „podigla“ inicijalna plodnost ali i smanjile opasnosti od poplava i suša zbog hidromelioracijskih zahvata. Komasacijom se mora osigurati raspored površina svih korisnika i svakog pojedinačno, koji će omogućiti da se poljoprivredna proizvodnja odvija sa što nižim troškovima (Rajković, Gostović i Otašević, 1978).

Lokalnoj samoupravi otvara se mogućnost lakše izgradnje infrastrukturnih objekata, jer je u postupku komasacije moguće riješiti potrebe za zemljištem u svrhu zadovoljenja općih potreba (izgradnja škola, vrtića, ambulanti, športskih igrališta….). Nakon provedene komasacije jednostavnije je održavanje katastra odnosno katastarskih planova te se omogućava stvaranje poslovnih zona i lakša promocija lokalnih razvojnih projekata. Općenito, potiče se decentralizacija te jača uloga i odgovornost lokalnih nositelja vlasti, u cijeli projekt se uključuju lokalne agencije i u konačnici se potiče bottom up pristup. Ali za dio domicilnog stanovništva prilika je da tijekom komasacije jednostavnije i povoljnije ponude /prodaju svoje poljoprivredne površine.

Država, zbog boljeg korištenja (ograničenog) zemljišnog potencijala, potiče količinski veću i konkurentniju poljoprivrednu proizvodnju, veću zaposlenost te ostanak u ruralnom prostoru. Uredne vlasničke knjige olakšavaju i potiču tržište poljoprivrednim zemljištem te se često „otkriva” nekada uzurpirano državno poljoprivredno zemljište. Nakon komasacije lakše se sprječava „uzurpacija“ poljoprivrednog zemljišta za različite nepoljoprivredne namjene, ali ispravlja i često proširuje granice građevinskog dijela naselja što olakšava legalizaciju i uknjižbu objekata.

Osim pozitivnih efekata, komasacija zemljišta može imati i neke negativne posljedice kojima se stvaraju nepovoljni uvjeti za život divljih biljnih i životinjskih vrsta što dovodi do smanjenja biološke raznolikosti.

Postupak komasacije poljoprivrednog zemljišta je vrlo zahtjevan proces, emotivno i financijski.

MATERIJAL I METODE

U ukupnim troškovima biljne proizvodnje poljoprivredno zemljište može biti mali (ako je proizvođač i vlasnik zemljišta) ili veliki trošak (u uvjetima zakupa ili hipoteke na zemljište) što utječe i na međunarodnu konkurentnost domaće proizvodnje.

Vrlo često se u ocjenjivanju poljoprivredne konkurentnosti koristi metoda izračuna troškova domaćih resursa (*DRC – Domestic Resource Cost*), pri čemu se međunarodna konkurentnost mjeri uspoređujući troškove domaćih resursa korištenih u proizvodnji nekog dobra koji nisu predmet međunarodne trgovine (zemljište, rad i kapital) s dodanom vrijednošću toga dobra (odnosno vrijednost proizvodnje umanjena za troškove tržišnih inputa) (Monke i Pearson, 1989).

$$\mathrm{DRC}_i = \frac{\sum_{j=k+1}^{n} a_{ij} P_j^D}{P_i^B - \sum_{j=1}^{k} a_{ij} P_j^B}$$

a_{ij} – količina j-tog utrženog (ako je $j \leq k$) ili neutrženog (ako je j>k) inputa (j=1,2,...,n) korištenih u proizvodnji jedne jedinice ouptuta i;

P_j^D – domaća (obračunska) cijena inputa j;

P_i^B – granična cijena outputa i;

P_j^B – granična cijena inputa j.

Vrlo često na konkurentnost mjerenu pomoću ovoga koeficijenta utječe veličina korištenih površina te smo utjecaj zemljišta kao proizvodnog čimbenika na ostvareni stupanj konkurentnosti istražili kod proizvodnje kukuruza, jabuke i tova junadi. Parametri za izračun konkurentnosti prikupljeni su anketiranjem obiteljskih poljoprivrednih gospodarstava na području Koprivničko-križevačke županije iz godine 2009. Ovi izračuni služe za dokazivanje opravdanosti postupka komasacije poljoprivrednog zemljišta i podložni su promjeni s obzirom na područje ili na godinu istraživanja.

REZULTATI I DISKUSIJA

Uređenje poljoprivrednog zemljišta kroz različite agrarne postupke često se spominju u radovima koji se bave zemljišnom usitnjenošću kao ograničavajućim čimbenikom poljoprivredne proizvodnje.

Organizirano razmišljanje o unapređivanju poljoprivredne djelatnosti i seoskoga gospodarstva provođenjem komasacije u Republici Hrvatskoj javlja se već u 18. stoljeću, no tek se 1836. godine, na zajedničkoj sjednici Hrvatskog i Ugarskog sabora, donosi prvi pravni akt–Urbarski zakon–koji se koristi na ovim prostorima, pa tako i na području današnje Požeško-slavonske županije (Boban 2012).

Komasacija se zahvaljujući svojoj primjeni pokazala nezamjenjivom u razrješavanju nesređenog zemljišnog stanja. U prošlosti je imala veliku važnost samo za poljoprivredu, dok se u budućnosti težište komasacije pomiče k integralnom djelovanju i razvoju cijelog društva (Boban 2012).

Kranjčević i Prosen (2003) promatraju komasaciju kao doprinos održivom razvitku ruralnog prostora, a kao dobrobit za društvo Backman i Ősterberg (2004).

Za Kovacs (2003) komasacija je najkompletniji i najkompleksniji agrarni postupak kojim se ne rješava samo okrupnjavanje zemljišta, nego se utječe i na ruralni razvoj kroz uređenje i razvoj sela. Slično misle i Ivković i sur. (2005) koji kroz postupak komasacije vide rješenje imovinsko-pravnih odnosa, usitnjenosti zemljišta, ekonomičnosti poljoprivredne proizvodnje, potrebe uređenja prostora i drugih aktualnih problema vezanih uz zemljište.

Usitnjenost posjeda i njegova rascjepkanost su ograničavajući faktori u poljoprivrednoj proizvodnji jer dovode do velikog rasipanja radnog vremena na prazne hodove i nepotrebne transporte te do osjetnog smanjenja učinka poljoprivrednih strojeva koji se smanjuje razmjerno s rascjepkanosti i udaljenosti parcela (Bebek i Škegro, 1978).

Da je okrupnjavanje površina postupkom komasacije jedan od bitnih čimbenika razvoja poljoprivrede smatraju i Cetl i Prosen, (2001) Dolanjski i sur. (2003) te i mnogi drugi. Nepovoljno na poljoprivrednu proizvodnju osim usitnjenosti utječe i stalni gubitak poljoprivrednog zemljišta zbog urbanizacije, neučinkovito gospodarenje državnim zemljištem, znatan udio neobrađenog i zapuštenog zemljišta, neodgovarajuća provedba postojećih zakonskih propisa, nesređenost zemljišnih knjiga te spori postupak usklađivanja i ažuriranja zemljišnoknjižnog stanja u katastru i gruntovnici što ograničava tržište zemljištem.

Svrhovitost smanjenja broja parcela komasacijom pokazalo je istraživanje Svjetske banke (Lerman i Cimpoieş, 2006) jer je utvrđen negativan odnos između produktivnosti i broj parcela u vlasništvu poljoprivrednika. Produktivnost zemljišta i rada smanjuje se povećanjem parcela i negativni odnos produktivnosti i parcelizacije je statistički značajna ($p<0,1$). Austrija je u jednoj proizvodnoj zajednici proizvodnju mlijeka povećala za 50% nakon konsolidacije zemljišta. U Švicarskoj i Njemačkoj istraživanjem se pokazao temeljni utjecaj agrarna rekonstrukcije na produktivnost rada i volumen poljoprivredne proizvodnje.

Tablica 1 Primjer komasacije na području općine NN – broj parcela
Table 1 Land consolidation at district NN - Number of plots

Redni broj OPG-a * Order number	Broj parcela po OPG-u / Number of plots		% smanjenja % decrease
	Prije komasacije Before land consolidation	Poslije komasacije After land consolidation	
1	10	3	70,0
2	12	3	75,0
3	9	2	77,8
4	14	4	71,4
5	15	5	66,7
6	28	4	85,7
7	7	2	71,4
8	6	2	66,7
9	10	3	70,0
10	7	2	71,4
Ukupno / Total	118	30	74,6

Izvor/Source: Gašparović (1990)
* OPG - family farm

Tablica 2 Primjer komasacije na području općine NN – udaljenost parcela
Table 2 Land consolidation at district NN- spot distance from main yard

Redni broj OPG-a Order number	Ukupna udaljenost parcela od gospodarskog dvorišta, km Total distance of spots from main yard km		Smanjenje udaljenosti Decrease of spot distance	
	Prije komasacije Before land consolidation	Poslije komasacije After land consolidation	km	%
1	22,078	3,065	19,013	86,12
2	14,791	2,653	12,138	82,06
3	9,728	1,839	7,890	81,10
4	30,466	5,080	25,386	83,33
5	19,453	6,157	13,296	68,35
6	49,189	4,131	45,058	91,60
7	11,063	2,225	8,839	79,89
8	11,728	3,499	8,229	70,17
9	9,214	4,210	5,004	54,31
10	12,067	2,213	9,849	81,62
Ukupno/ Total	189,779	35,077	154,702	81,52

Izvor/Source: Isti kao za Tablicu 1./ same as Table 1.

U komasaciji provedenoj 80-ih godina prošlog stoljeća broj parcela se smanjio sa 118 na 30 ili za 74,6%. Efekti komasacije su bili znatno izraženiji kod gospodarstava s većim brojem parcela gdje je smanjenje nakon komasacije bilo 85,7%, čime se postiže učinkovitija organizacija rada (obrada zemljišta, sjetva, zaštita, žetva/berba) i smanjivanje troškova rada (smanjivanje gubitka radnih sati ljudi i mehanizacije).

Mnoštvo parcela prosječno male površine su i za pojedina gospodarstva značajno udaljena od gospodarskog dvorišta. Kako je nadioba zemljišta jedan od najvažnijih postupaka komasacije sa ciljem da ono bude što bliže vlasniku, time se značajno smanjuje i ukupna udaljenost.

Ukupna udaljenost svih parcela smanjila se za čak 81,52% ili za oko 155 km, čime se izravno utječe na smanjenje transportnih troškova i troškova goriva.

Komasaciju treba promatrati prvenstveno sa stajališta komasacije određenih kultura, a ne samo kao mjeru okrupnjavanja parcela. Prema tome, ostvarivanjem ove mjere otvara se prostor za daljnju specijalizaciju u poljoprivredi, razvijanje robne proizvodnje i povećanje dohotka poljoprivrednika (Stanić, 1978).

Poznata je činjenica da u Hrvatskoj još uvijek prevladavaju poljoprivredna gospodarstva s nedostatnom veličinom poljoprivrednog zemljišta za postizanje konkurentnosti na domaćem, a naročito na EU tržištu. Danas se konkurentnost uglavnom promatra kroz teoriju M. Portera (1990) prema kojoj konkurentnost ovisi o strateškim izborima, pri čemu su ključni elementi za ekonomski razvitak znanje, razvijena infrastruktura, visoka tehnologija i inovacije. Najčešće citirana definicija međunarodne konkurentnosti je definicija OECD-a (engl. Organisation for Economic Co-operation and Development – Organizacija za ekonomsku suradnju i razvoj) *„Konkurentnost je sposobnost zemlje da u slobodnim i ravnopravnim tržišnim uvjetima proizvede robe i usluge koje prolaze test međunarodnog tržišta, uz istovremeno zadržavanje i dugoročno povećanje realnog dohotka stanovništva"*. Prema tome se konkurentnost može definirati kao produktivnost kojom država ili poduzeća koristi svoje ljudske resurse, kapital i prirodne resurse, pa se često i citira misao spomenutog autora da *nije važno koje proizvode proizvodite, već kako ih proizvodite*. U poljoprivrednoj proizvodnji troškovi zemljišta imaju značajan udio u ukupnim troškovima za mnoge poljoprivredne proizvode, pa postoje brojni radovi koji istražuju veličinu poljoprivrednih gospodarstava i konkurentnosti te ukazuju na potrebu okrupnjavanja poljoprivrednog zemljišta kojom bi se povećala produktivnost gospodarstava. Svržnjak (2012) putem DRC metode ispituje je li poljoprivredna proizvodnja Hrvatske međunarodno konkurentna i razlikuje li se prema veličini poljoprivrednih gospodarstava koja se bave proizvodnjom kukuruza, jabuka i tovom junadi (tablica 3).

Vrijednost proizvodnje kukuruza raste s porastom površine i to sa 7.817 kn/ha na 11.471 kn/ha. Trošak tržnih inputa je isti (4.418 kn/ha), a troškovi domaćih resursa neznatno se mijenjaju. Troškovi tržišnih inputa koji se izračunavaju u cijenama EU su konstantni kod proizvodnje kukuruza i tova junadi s obzirom da u bazama FADN (Farm Accountancy Data Network) imamo izražene prosječne troškove proizvodnje u EUR/ha, odnosno ne prikazuju se prema veličini poljoprivrednih gospodarstava. U bazama FADN nisu pronađeni troškovi tržišnih inputa za proizvodnju jabuka. Stoga je izračunat postotni udio tržišnih inputa u vrijednosti proizvodnje na temelju dobivenih podataka iz ankete, a tada je dobiveni postotni udio pomnožen s vrijednosti proizvodnje u EU cijenama po svakoj kategoriji veličine zemljišta. Stoga troškovi tržišnih inputa kod proizvodnje jabuka variraju. Rezultati pokazuju da je proizvodnja kukuruza bila konkurentna kod OPG veličine veće od 10 ha.

Tablica 3 Konkurentnost u proizvodnji kukuruza, jabuka i tovu junadi
Table 3 Competitivness in corn, apples production and bullocks fattening

Kukuruz / Corn			
	Veličina OPG / Farm area (ha)		
	< 5	5 – 10	> 10
Vrijednost proizvodnje (kn/ha) Production value (kn/ha)*	7.817	9.292	11.471
Trošak tržišnih inputa (kn/ha) Input expenses (kn/ha)	4.418	4.418	4.418
Troškovi domaćih resursa (kn/ha) Expenses of domestic resources	4.323	4.779	4.339
DRC/ Troškovi domaćih izvora	**1,3**	**1,0**	**0,6**
Jabuka / Apple			
	Veličina OPG (ha) / Farm area		
	< 1	1 - 3	> 3
Vrijednost proizvodnje (kn/ha) Production value (kn/ha)	102.824	103.628	132.541
Trošak tržišnih inputa (kn/ha) Input expenses (kn/ha)	74.367	52.488	55.710
Troškovi domaćih resursa (kn/ha) Expenses of domestic resources	33.585	38.654	33.317
DRC/ Troškovi domaćih izvora	**1,2**	**0,8**	**0,4**
Tov junadi / Bullocks fattening			
	Veličina OPG (ha) / Farm area		
	< 10	10 - 20	> 20
Vrijednost proizvodnje (kn/ha) Production value (kn/ha)	6.619	6.619	6.258
Trošak tržišnih inputa (kn/ha) Input expenses (kn/ha)	3.240	3.240	3.240
Troškovi domaćih resursa (kn/ha) Expenses of domestic resources	7.770	4.063	1.134
DRC/ Troškovi domaćih izvora	**2,3**	**1,2**	**0,4**

Izvor/Source: Svržnjak (2012)
* 1 kn = 0.1316 €

Kod proizvodnje jabuka vrijednost proizvodnje se progresivno povećava s porastom veličine gospodarstva. Kod gospodarstava iznad 3 ha veća je za 28,9% u odnosu na vrijednost proizvodnje kod gospodarstava ispod 1ha te za 27,9% od vrijednosti gospodarstava od 1 do 3 ha. Trošak tržnih inputa se razlikuje shodno promatranim veličinama zemljišta, najveći je kod gospodarstava veličine ispod 1 ha a najmanji kod onih od 1 do 3 ha. Razlike se očituju zbog već napomenutog nedostatka FADN (Farm Accountancy Data Network) podataka EU i procjene udjela tržišnih inputa u ukupnoj vrijednosti proizvodnje na temelju dobivenih podataka iz ankete. Troškovi domaćih resursa najveći su kod gospodarstava od 1 do 3 ha, a kod druge dvije skupine su neznatne razlike. Koeficijent DRC pokazuje da je proizvodnja jabuka konkurentna već na površinama većim od 1 ha, a posebno većim od 3 ha.

Vrijednost proizvodnje junadi se neznatno povećava s povećanjem površina uz stalnost troška tržnih inputa. Troškovi domaćih resursa se značajno smanjuju s porastom površina i to sa 7.770 kn/ha kod onih s manje od 10 ha na 1.134 kn/ha kod onih s preko 20 ha ili za 85.4%. Iz tablice 3. se može vidjeti da tov junadi postiže konkurentnost kod proizvodnje iznad 20 ha, s obzirom da je koeficijent DRC manji od 1 (0,4).

ZAKLJUČAK

Za svaku uspješnu poljoprivrednu proizvodnju jedan od preduvjeta je poljoprivredno zemljište. Današnja usitnjena poljoprivredna gospodarstva u Hrvatskoj ne doprinose uspješnosti poljoprivredne proizvodnje, čime se umanjuje konkurentnost na tržištu.

Provođenje komasacije ima izravan učinak na konkurentnost s obzirom da se rješava uređenje cjelokupnog ruralnog prostora, a poljoprivredna gospodarstva se potiču na kupnju/prodaju ili zamjenu parcela u cilju smanjivanja broja parcela i povećanje prosječne veličine OPG-a.

Istraživanje je pokazalo da veće parcele bliže gospodarstvima, pravilniji oblici parcela, smanjivanje neobrađene površine zemljišta među parcelama i slično, daju osjetnu ekonomsku prednost gospodarstvima u smislu učinkovitije organizacije rada, smanjivanja troškova rada, transportnih troškova i troškova goriva. Također, istraživanja vezana uz utjecaj zemljišta na konkurentnost proizvodnje kukuruza, jabuka i tova junadi u Hrvatskoj u uvjetima međunarodnog tržišta pokazuju da se konkurentnost povećava s povećanjem veličine gospodarstava.

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LAND CONSOLIDATION OF AGRICULTURAL LAND IN THE REPUBLIC OF CROATIA FOR BETTER COMPETITIVENESS OF AGRICULTURAL PRODUCTION

ABSTRACT

The small size of farms is often referred as one of the major obstacle to increasing the competitiveness of Croatian agriculture. The consolidation is one of the solutions whose main purpose is the creation bigger and/or more regular land parcels to better use and to create favorable conditions for agriculture.

Land consolidation represents the preferred set of operations which will take into account the three dimensions of sustainable development: economic, social and environmental. The economic dimension is reflected in greater efficiency and productivity of agricultural production, the environmental dimension is to enable farmers to use less intensive methods, and the social dimension is reflected in attracting and people staying in rural areas.

In this paper the consolidation is studied with a focus on the economic dimension of sustainable development. The survey starts from the assumption that consolidation has a positive effect on the competitiveness of agricultural production which is proved by the method of calculating the cost of domestic resources (DRC - Domestic Resource Cost).

Key words*: redistribution of land, agricultural land, competitiveness, Croatia*

44. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

UDK 165.5:378.663:631.171
Prethodno priopćenje
Preliminary communication

PROMJENE U ZNANJU O POLJOPRIVREDNOJ MEHANIZACIJI STUDENATA AGRONOMSKOG FAKULTETA SVEUČILIŠTA U ZAGREBU

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SAŽETAK

Poljoprivredna mehanizacija je imala veliki utjecaj na povećanje produktivnosti u poljoprivredi i predstavlja jedno od najvažnijih inženjerskih dostignuća dvadesetog stoljeća. Poljoprivredna mehanizacija nadomjestila je „manjak“ radne snage u poljoprivredi ali istovremeno i „oslobodila“ dio radne snage koji je mogao, izravno ili posredno, napustiti poljoprivredu. Ona je sve sofisticiranija te zahtijeva nova znanja i stalno usavršavanje korisnika-poljoprivrednika. U radu se daju rezultati istraživanja o poznavanju poljoprivredne mehanizacije studenata Agronomskog fakulteta u Zagrebu. Cilj rada je usporednom analizom rezultata istraživanja iz 2013. i 2015. godine istražiti poznavanje poljoprivredne mehanizacije studenata prve godine izabranih preddiplomskih studija te utvrditi nastale promjene. U radu se pošlo od pretpostavke da je u razdoblju 2015./2013. došlo do promjene u razini znanja studenata prve godine Agronomskog fakulteta o poljoprivrednoj mehanizaciji, ali da je znanje u prosjeku skromno. Za potrebe rada korišten je istovjetan anketni upitnik, a rezultati dobiveni istraživanjem obrađeni su pomoću SPSS-a. U istraživanju je sudjelovao ukupno 361 ispitanik studenata prve godine preddiplomskih studija koji slušaju modul Osnove agroekonomike“ (141 u 2013. i 220 u 2015. godini). Iako je najveći dio ispitanika žena (64,58%) njihov udio se smanjio sa 68,8 na 61,8%. Porastao je udjel ispitanika koji su iz urbanih sredina (sa 68,1 na 70,9%) te koji su završili gimnaziju (sa 62,4 na 68,2%). Neznatno se povećao dio onih koji su završili srednju poljoprivrednu školu (sa 5,7 na 6,4%). Studij agronomije je sve manje atraktivan za mlade i smanjuje se udjel ispitanika kojima je ona bila prvi izbor kod upisa na Sveučilište (sa 41,8 na 38,6%). Istraživanje 2015. godine je pokazalo da čak 77,3% ispitanih ne zna upravljati niti jednim poljoprivrednim *strojem što je povećanje od 5,7% u odnosu na 2013. Najveći dio ih zna upravljati traktorom, zatim motokultivatorom te frezom te niti jedan ne zna upravljati kombajnom. U 2015. godini nešto više od polovice (55%) ih zna da je rigolanje oranje na dubinu više od 50 cm, za što se koristi kombajn (78,2%) te ih je nešto manje koji znaju da se rolo preša primjenjuje pri sakupljanju sijena (72,3%). Ipak, studenti su upoznati s ulogom mehanizacije u poljoprivredi, ali i s važnošću ekonomičnog gospodarenja, naglašavajući pri tom potrebu poslovnog povezivanja poljoprivrednika zbog smanjenja troška mehanizacije u proizvodnji. Podijeljenog su mišljenja oko potrebe formalnog obrazovanja za upravljanje mehanizacijom. Istovjetno, kao i prethodno istraživanje rezultati su pokazali da veću razinu znanja o poljoprivrednoj mehanizaciji imaju muški ispitanici i oni odrasli na selu.*

Ključne riječi: *poljoprivredna mehanizacija, studenti, agronomija, usporedna analiza*

UVOD

Jedan od ciljeva poljoprivredne proizvodnje je zadovoljiti potražnju stanovništva i prehrambene industrije količinom i kakvoćom te cijenom prihvatljivom i proizvođačima i potrošačima. Neki autori (Diamond, 2007.; Landes, 2003.; Tracy, 1996.) navode da niti jedna država nije ekonomski napredovala sve dok nije riješila pitanje svoje poljoprivrede i opskrbe hranom. Osim navedene zadaće, poljoprivreda ima i šire značenje za ruralni prostor od kojih su značajniji održivo gospodarenje poljoprivrednim resursima te ekološki principi proizvodnje.

Danas su prisutna tri tipa proizvodnje i to konvencionalna, integrirana i ekološka (Grgić i sur., 2015). Suvremena poljoprivredna proizvodnja nezamisliva je bez upotrebe poljoprivredne mehanizacije koja omogućava tehnološke operacije u optimalnim rokovima što donekle jamči proizvodnju ekonomične i zdravstveno sigurne hrane (Nikolić i sur., 2009).

Poljoprivredna mehanizacija je i jedno od najvažnijih inženjerskih dostignuća dvadesetog stoljeća i primjenjuje se u cijelom tehnološkom postupku proizvodnje i dorade poljoprivrednih proizvoda. Uporabom i dobrim gospodarenjem poljoprivrednom mehanizacijom smanjuju se troškovi proizvodnje (manji je trošak radne snage kao i prosječni trošak mehanizacije zbog povećane proizvodnje) te onečišćenje i pritisak na okoliš što se posebice odnosi na zadnje generacije mehanizacije i EU direktive koje uređuju to područje. Kod uvođenja novih tehnika i tehnologija u proizvodnju, jedan od preduvjeta je praktično znanje ali posebno znanja stečena tijekom obrazovanja kako srednjoškolskog još više visokoškolskog.

MATERIJAL I METODE

Za potrebe rada provedena su dva anketna ispitivanja identičnim anketnim upitnikom i to 2013. (Grgić i sur., 2014) i 2015. godine te je obavljena usporedna analiza rezultata. U radu polazimo od pretpostavke da je došlo do promjene razine znanje studenata prve godine Agronomskog fakulteta o poljoprivrednoj mehanizaciji u razdoblju od 2013. do 2015.

godine. Cilj ovog rada je usporednom analizom dobivenih rezultata istražiti poznavanje poljoprivredne mehanizacije studenata prve godine izabranih preddiplomskih studija te nastale promjene.

Istraživanja su provedena početkom mjeseca studenog 2013. i 2015. godine na Agronomskom fakultetu Sveučilišta u Zagrebu. Ukupno je anketiran 361 student i to njih 141 u 2013. i 220 u 2015. godini prve i druge godine studija Zaštita bilja, Agroekologija, Animalne znanosti, Hortikultura, Ekološka poljoprivreda, Agrarna ekonomika, Biljne znanosti. Većina anketiranih (74,6%) je bila prve, a manji dio druge godine studija (25,4%). Uzorak je bio slučajan jer je anketa bila nenajavljena i obavljena je u vrijeme nastave iz modula Osnove agroekonomike.

U okviru studijskih programa preddiplomskog studija Poljoprivredna tehnika te diplomskog Poljoprivredna tehnika-Mehanizacija studenti stječu znanja o poljoprivrednoj mehanizaciji dok je kod drugih studija to znatno manje zastupljeno te vrlo često u obliku izbornih predmeta. Iz navedenog razloga, ovim istraživanjem nisu obuhvaćeni studenti studija Poljoprivredne tehnike za koje se pretpostavlja da već u prvim godinama stječu dovoljno znanja o poljoprivrednoj mehanizaciji.

Za potrebe rada primijenjena je anketa koja se sastojala od ukupno 17 pitanja otvorenog, poluotvorenog i otvorenog tipa. Za određene tvrdnje korištena je Likertova skala od pet stupnjeva. Skala se sastoji od niza tvrdnji posvećenih različitim aspektima nekog stava. Ona se daje ispitaniku sa zadatkom da za svaku pojedinu tvrdnju izrazi stupanj svoje suglasnosti, po pravilu na petostupnoj skali kao: „opće se ne slažem“, „ne slažem se“, „niti se slažem niti ne slažem“, „slažem se“, „u potpunosti se slažem“. Nakon logičke kontrole, kodiranja i unosa obrada podataka je obavljena pomoću statističkog paketa SPSS. Odgovori su križani s nezavisnim varijablama (mjesto odrastanja, spol, studij), a u analizi rezultata primijenjen je statistički hi^2-test koji je jedan od najpoznatijih neparametrijskih testova. Hi-kvadrat test je vrlo praktičan test koji može osobito poslužiti onda kad želimo utvrditi da li neke dobivene (opažene) frekvencije odstupaju od frekvencija koje bismo očekivali pod određenom hipotezom. Kod ovog testa katkada tražimo postoji li povezanost između dvije varijable i on pokazuje vjerojatnost povezanosti (Grubišić, 2014)

REZULTATI I DISKUSIJA

U posljednja dva desetljeća primjetna je promjena spolne strukture upisanih studenata na studije Agronomskog fakulteta. Do devedesetih godina prošlog stoljeća Fakultet su većinom upisivali muškarci koji su dolazili i/ili odrasli u ruralnim područjima, a danas je taj trend u potpunosti izmijenjen. Većina anketiranih u ovom istraživanju su bile žene pri čemu se njihov udio neznatno smanjio, ali povećao se udjel upisanih koji dolaze iz gradova, odnosno urbaniziranih sredina. Potencijalni uzrok tomu jesu prisutni procesi deruralizacije i deagrarizacije u ruralnim prostorima. „Jaz“ između upisanih koji su odrasli na selu i gradu, povećao se u korist onih iz gradskih sredina, a pretpostavka je da će se ta razlika povećavati i u budućnosti.

Primjetna je i promjena strukture upisanih studenata obzirom na stupanj srednjoškolskog obrazovanja. Većina ispitanih završila je gimnaziju (prosječno 65,9%) pri čemu se povećao njihov udjel kao i udio onih sa završenom srednjom poljoprivrednom školom iako je u prosjeku i dalje relativno mali (6,1%). Smanjio se udjel onih koji dolaze iz drugih strukovnih škola „šarolikog spektra i to do srednje medicinske do škole cestovnog prometa“.

Prilikom završetka srednje škole i položene Državne mature, studenti rangiraju poželjne fakultete za upis. Za njih oko 40% Agronomski fakultet je bio prvi odabir pri čemu se taj udjel smanjio sa 41,8% u 2013. na 38,6% u 2015. godini. Neznatno je porastao udjel onih kojima je to bio drugi odabir iako je i dalje relativno mali (23,0%) što skupa sa onima koji je bio prvi čini oko dvije trećine upisanih. Iako se smanjuje relativni udjel onih kojima je agronomija četvrti i viši odabir, on je i dalje visok u tu kategoriju spada preko petine upisanih.

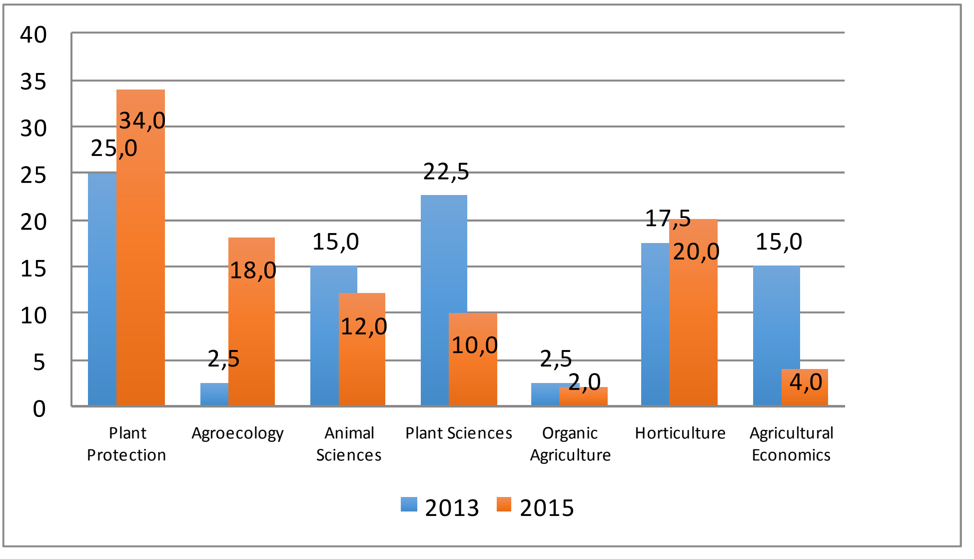
Tablica 1 Neke socio-demografske značajke upisanih u 2013. i 2015. godini
Table 1 Some socio-demographic features of enrolls in 2013 and 2015

	2013	**2015**	**Prosjek/Avg.**
Ukupno ispitanika/ Total examinees	141	220	
Spol/Gender			
Muški/Male	31,2	38,2	35,5
Ženski/Female	68,8	61,8	64,5
Ukupno/Total	100,0	100,0	100,0
Mjesto odrastanja / Growing up place			
Grad/Town	68,1	70,9	69,8
Selo/Village	31,9	29,1	30,2
Ukupno/Total	100,0	100,0	100,0
Završena srednja škola / High school accomplished			
Gimnazija/Gymnasium	62,4	68,2	65,9
Poljoprivredna/Agricultural	5,7	6,4	6,1
Drugu srednju školu/Other high school	31,9	25,4	28,0
Ukupno/Total	100,0	100,0	100,0
Agronomija kao / Agriculture as			
1. izbor/ First choice	41,8	38,6	39,8
2. izbor/ Second choice	22,7	23,2	23,0
3. izbor/ Third choice	11,4	15,5	13,9
Ostalo/Other	24,1	22,7	23,3
Ukupno/ Total	100,0	100,0	100,0

Izvor: Anketa: „Studenti prve godine Agronomskog fakulteta i poljoprivredna mehanizacija“, Sveučilište u Zagrebu Agronomski fakultet, Zavod za agrarnu ekonomiku i ruralni razvoj, studeni 2013 i 2015.
Source: Enquiry: ”First year students of Faculty of Agriculture and Farm machinery”, Department of Agroeconomics and rural development, November 2013 and 2015.

Grgić i sur (2014) u svom istraživanju konstatirali su da „podrijetlo, spol i vrsta završene srednje škole značajno utječu na mogućnost korištenja odnosno upravljanja nekim od poljoprivrednih strojeva od strane anketiranih“. Istraživanje (2015.) je pokazalo da čak 77,3% ispitanih ne zna upravljati niti jednim poljoprivrednim strojem. U odnosu na 2013. godinu to je povećanje od 5,7%, a pretpostavka je da će taj postotak u budućnosti biti i veći.

Najveći postotak onih koji znaju koristiti neki od strojeva zabilježen je kod studenata studija Zaštita bilja, a najmanji kod studija Ekološka poljoprivreda (Grafikon 1). Najznačajnije smanjenje poznavanja upravljanja poljoprivrednim strojem uočen je kod studenata studija Biljne znanosti (za 12,5% u odnosu na 2013. godinu). Utvrđena je statistički značajna (χ^2-15,209; p-0,019) kod odgovora na pitanje o vještini upravljanja poljoprivrednim strojevima s obzirom na studij kao nezavisnu varijablu.



Grafikon 1 Udio onih koji znaju upravljati nekim poljoprivrednim strojem s obzirom na studij u odnosu na ukupni broj ispitanika, N_{2013}=141; N_{2015}=220
Izvor: Isti kao za Tablicu 1

Graph 1 Part of examinees who are capable to handle some of agricultural machines regardnig to study type and total number of examinees, N_{2013}=141; N_{2015}= 220
Source: Same as in Table 1

Istraživanjem je utvrđena statistički značajna razlika kod poznavanja upravljanja strojevima s obzirom na spol (χ^2-31,352; p-0,000), pri čemu je veći postotak muških (16,4%) nego ženskih (6,4%) koji posjeduju vještinu upravljanja strojevima.

Statistički značajne razlike su i s obzirom na mjesto odrastanja pri čemu je više onih koji znaju upravljati odraslo na selu (12,7%) od onih koji su odrasli u gradu (10%). Najveći dio ispitanih zna upravljati traktorom, zatim motokultivatorom te frezom. Za razliku od rezultata iz 2013. u 2015. godini niti jedan ispitani ne zna upravljati kombajnom.

U jednom od pitanja, na jednostavan način smo provjerili osnovna znanja o korištenju pojedinih strojeva u tehnološkom procesu poljoprivredne proizvodnje.

Tablica 2 Poznavanje upotrebe pojedinih strojeva u poljoprivrednoj proizvodnji (% ispitanika), usporedba rezultata istraživanja 2013. i 2015.
Table 2 Knowledge of using some machines in agricultural production (% of examinees), comparison of results in 2013 and 2015.

		2013	**2015**	**Prosjek (Avg)**
U obradi tla ne koristi se In soil tillage we don't use	traktor/tractor	1,5	3,6	2,8
	motokultivator /motocultivator	26,2	19,5	22,2
	kombajn/combine	65,2	65,5	65,3
	drljača/harrow	7,1	11,4	9,7
	ukupno/total	100,0	100,0	100,0
Poljoprivredni kombajn je Combine harvester is	kombinacija dvije ili više proizvodnji/ Combination of 2 or more productions	3,5	5,9	5,0
	stroj za obradu tla/soil tillage implement	9,9	9,5	9,7
	stroj za mužnju/milking machine	0,8	1,9	1,4
	stroj za izgnojavanje na velikim farmama/ manure handling equipment	1,4	4,5	3,3
	stroj za žetvu/harvesting machine	84,4	78,2	80,6
	ukupno/total	100,0	100,0	100,0
Četveroredna sijačica za kukuruz u istom prohodu sije (koliko) redova? How many rows can four row corn planter sows?	dva/two	2,9	2,7	2,8
	tri/three	0,0	1,9	1,1
	četiri/four	83,7	79,1	80,8
	šest/six	3,5	3,2	3,3
	osam/eight	3,5	8,6	6,6
	koliko se naštima/as many as it is set to sow	6,4	4,5	5,3
	ukupno/total	100,0	100,0	100,0
Rigolanje je Deep ploughing is	problem kod preživača/ issue at ruminants	2,9	2,7	2,8
	postupak kod žetve pšenice/procedure in wheat harvest	7,8	13,6	11,4
	oranje na dubinu više od 50 cm/ ploughing over 50 cm	65,2	55,5	59,2
	usitnjavanje prije sjetve/ crumbling prior to sowing	24,1	28,2	26,6
	ukupno/total	100,0	100,0	100,0

Izvor/Source: isti kao za Tablicu 1 / Same as in Table 1

Na pitanje „Koja se mehanizacija ne koristi u obradu tla?“ ponuđeni odgovori su bili traktor, motokultivator, kombajn i drljača. Ne postoje značajnije razlike u rezultatima između 2013. i 2015. godine.

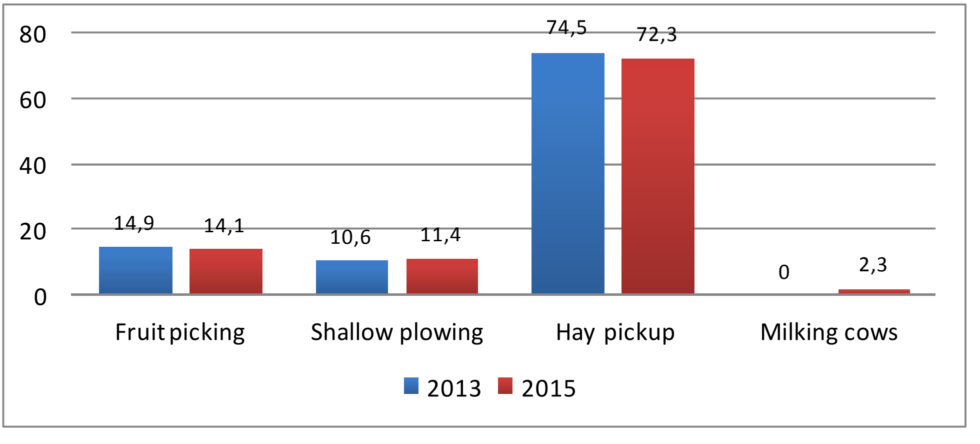
Dvije trećine anketiranih je znalo da se kombajn ne koristi u obradi tla, oko petine misli da je to motokultivator, a nešto manje smatra da je to drljača. Muški ispitanici su u znatno većem postotku (77,3%) točno odgovorili u odnosu na žene (59,8%). Također, ispitanici odrasli u ruralnoj sredini u većoj mjeri su znali točan odgovor (80,0%) nego oni iz urbanih (58,3%).

Na izravno pitanje „Što je poljoprivredni kombajn?“ većina ih je dala točan odgovor. U 2015. godini nije zabilježena statistički značajna razlika u odgovorima s obzirom na spol (χ^2-2,710; p-0,607) no za razliku od 2013. godine zabilježena je statistički značajna razlika s obzirom na mjesto odrastanja (χ^2-13,509; p-0,009).

Kao odgovor na pitanje koliko redova sije četveroredna sijačica, nešto manje ispitanika (79,1%) ponudilo je točan odgovor za razliku od 2013. godine (83%). Njih 4,5% smatra da se redovi sjetve kod navedenog priključka mogu podesiti (6,4% u 2013.). Kod ostalih ponuđenih odgovora ispitanici su vrlo slično odgovorili kao i u prethodnom istraživanju: četveroredna sijačica sije *dva* (2,7% anketiranih), *šest* (3,2%) ili *osam* (8,6%) redova.

Postupak rigolanja je jedan od načina osnovne obrade tla prije podizanja nasada. Za rigolanje se koriste jednobrazni plugovi velikih dimenzija tzv. rigoleri. Smanjio se postotak onih koji zna da je to *oranje na dubinu više od 50 cm* i to sa 55% u 2015. u odnosu na 65,2% u 2013. godini. Da je to *postupak usitnjavanja prije sjetve* smatra 28,2% ispitanika, *postupak kod žetve pšenice* 13,6% te *problem kod preživača* 2,7% (u 2015. godini).

Rolo preša (balirka) je stroj koji se koristi za sakupljanje i pripremu sijena za skladištenje ili „konzervaciju“. Većina ispitanika (72,3% u 2015.) kao i u 2013. godini (74,5%) znala je namjenu rolo preše.



Grafikon 2 Kod kojih tehnoloških procesa se koristi valjkasta preša, usporedba 2013 i 2015.
Izvor: Isti kao za Tablicu 1
Graph 2 At which technological process we use roll baler, comparison 2013 and 2015.

Tablica 3 Suglasnost s nekim tvrdnjama[1] o poljoprivrednoj mehanizaciji, usporedba 2013. i 2015.
Table 3 Agreement with some statements[9] of farm machinery, comparison 2013., 2015.

	2013		2015		$\dot{X}$	
	Vrijed.	σ	Vrijed.	σ	Vrijed.	σ
Udruživanje proizvođača smanjilo bi troškove nabave poljoprivredne mehanizacije. Producers merging would decrease expenses of buying machinery	3,94	0,87	4,19	0,79	4,09	0,83
Svaki poljoprivrednik za uspješnu proizvodnju treba poljoprivrednu mehanizaciju Every farmer needs machinery for succesful production	4,16	0,93	3,89	1,02	4,00	0,99
Primjena mehanizacije smanjuje troškove proizvodnje Farm machinery decreases production expenses	3,74	0,93	3,90	0,92	3,84	0,92
Za stručno upravljanje mehanizacijom potrebno je i formalno obrazovanje Professional machinery management needs proper education	3,30	1,02	3,44	1,12	3,38	1,08
Poljoprivredna mehanizacija je u RH u odnosu na druge države EU u prosjeku „mlađa“ Average age of Farm machinery in Croatia is in comparison to other EU countries, ”younger”	3,03	1,27	3,30	1,23	3,20	1,25
Poljoprivrednici rado prihvaćaju inovacije u poljoprivrednoj mehanizaciji Farmers gladly accept inovations in farm machinery	3,04	0,94	3,06	1,07	3,05	1,02
Primjena mehanizacije smanjuje onečišćenje okoliša Using of farm machinery decrease nature pollution	2,26	0,94	2,08	1,01	2,15	0,98
Primjena mehanizacije smanjuje produktivnost u poljoprivredi Using of farm machinery decrease productivity in agriculture	2,04	0,98	2,09	0,98	2,07	0,98

Izvor/Source: isti kao za Tablicu 1/ same as in Table 1

[1] „uopće se ne slažem (1)“, „ne slažem se (2)“, „niti se slažem niti ne slažem (3)“, „slažem se (4)“ ili „u potpunosti se slažem (5)“, ”completely disagree (1), disagree (2), nor dissagre nor agree (3), agree (4), completely agree (5)

Za 2015. godinu nema statistički značajne razlike s obzirom na spol (muški 76,2% i žene 69,9%), ali je značajnija razlika u odgovorima (χ^2-10,536; p-0,015) s obzirom na mjesto odrastanja (grad 66,7% i selo 85,9%).

Ispitanicima je u upitniku ponuđeno nekoliko izjava za koje su mogli izraziti stupanj suglasnosti i to sa „uopće se ne slažem (1)“, „ne slažem se (2)“, „niti se slažem niti ne slažem (3)“, „slažem se (4)“ ili „u potpunosti se slažem (5)“.

Na skali suglasnosti na prvom mjestu je tvrdnja da je bi udruživanje proizvođača doprinijelo smanjenju troškova nabave poljoprivredne mehanizacije. Na poslovanje poljoprivrednika utječe mnoštva čimbenika od kojih se najznačajnijim smatraju promjene cijena repromaterijala, ali i relativno visok trošak mehanizacije (kupnja, trošak pogonskog goriva, amortizacija).

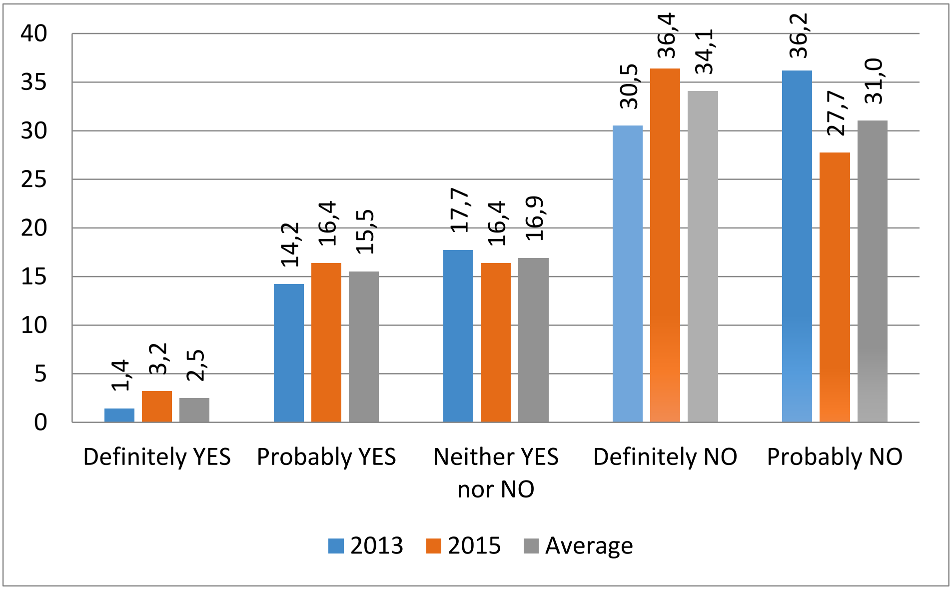
Ispitanici smatraju da interesnim povezivanjem (kooperacija, klaster, zadruga i sl.) poljoprivrednici imaju mogućnost rješavanja većeg dijela navedenih problema. Imajući na umu neorganiziranost, nestandardiziranost i usitnjenost hrvatske poljoprivredne proizvodnje, veću pozornost trebalo bi svakako posvetiti proizvođačkim organizacijama koje bi trebale obavljati poslove prilagodbe proizvodnje zahtjevima tržišta, zajedničkom marketingu proizvoda i uspostavi zajedničkih pravila proizvodnje. Udruživanjem proizvođači dobivaju mogućnost zajedničkog korištenja mehanizacije (npr. strojni prsteni) i snižavanja troškova proizvodnje. U suprotnom, visoki fiksni troškovi negativno utječu na profit i uzrokuju gubitke (Asi i sur., 1999.). Kod ovog pitanja postoji normalna distribucija odgovora obzirom na muški i ženski dio ispitanika, i nema statistički značajne razlike, kao što je zabilježena u prethodnom istraživanju.

Karakteristike suvremene poljoprivrede su velika važnost poljoprivredne mehanizacije, napredna tehnologija te prosječno velike površine obradivog zemljišta po proizvođaču. Ipak, još uvijek je veliki dio proizvođača prosječno mali te za njih investicije iziskuju velika novčana sredstva i rijetko si koji poljoprivrednik može priuštiti kompletnu poljoprivrednu mehanizaciju. Samo značajnim povećanjem proizvodnih površina poljoprivrednih gospodarstava i usmjeravanje na tržnu proizvodnju uz primjenu odgovarajućih strojeva mogu se postići pozitivni ekonomsko-financijski učinci (Filipović i sur., 2005). Prema Grgić i Šnajder (1999) većina pri nabavljanju strojeva i opreme uzimaju kredite ili nabavljaju neodgovarajuće strojeve (tehnički zastarjele, istrošene, slabe pogonske snage).

Anketirani su podijeljenog mišljenja kod izjave kako je formalno obrazovanje preduvjet boljem korištenju mehanizacije kao i da poljoprivrednici rado prihvaćaju inovacije kod mehanizacije. Također su svjesni da poljoprivredna mehanizacija utječe na onečišćenje okoliša ali i da značajno djeluje na povećanje produktivnosti rada u poljoprivredi.

Prilikom upisa na fakultet pristupnici su u jednakoj mjeri i dalje nedovoljno upoznati i informirani o studijima i studijskim programima kao u prethodnom istraživanju. Tako i nakon nekoliko mjeseci studija (2015. godine) oko jedne trećine ne zna da na Agronomskom fakultetu postoji preddiplomski studij koji izučava poljoprivrednu mehanizaciju (73,8% muški te 51,1% žene), 67,9% ispitanika iz grada te 71,9% iz ruralnih sredina. Od onih koji znaju da postoji, veći dio (60,5%) ih zna da se radi o studiju Poljoprivredna tehnika.

Manji postotak (39,5%) u odnosu na istraživanje iz 2013. (47,5%) ih zna da na Agronomskom fakultetu postoji diplomski studij koji nudi znanja o poljoprivrednoj mehanizaciji. Ne postoje statistički značajne razlike s obzirom na spol i mjesto odrastanja, a nešto su veće razlike s obzirom na studij (najveći udjel koji zna su sa studija Hortikultura, a najmanji studija Ekološka poljoprivreda).



Grafikon 3 Voljnost upisa (% ispitanika) izbornog predmeta koji izučava poljoprivrednu mehanizaciju, usporedba rezultata 2013. i 2015. godine
Izvor: isti kao za Tablicu 1
Graph 3 Willingness of enrollment (% of examinees) chosen module who is connected with farm machinery, comparison 2013 and 2015.
Same source as Table 1

U razvijenim zemljama ljudski kapital je glavni razvojni resurs, čiju kvalitetu u velikoj mjeri određuje upravo obrazovanje, formalno i neformalno. Svržnjak i sur. (2006) u svom radu zaključili su da će specijalistički seminari čiji su polaznici mladi poljoprivrednici (prosječna dob 38 godina, iskustvo od 13,5 godina bavljenja poljoprivredom) pozitivno utjecati na budući društveno-gospodarski razvoj seoskih područja.

Od onih koji su izrazili želju za upisom modula u okviru kojeg mogu steći znanja o poljoprivrednoj mehanizaciji 19,6% ispitanika bi i upisalo taj modul. Kod odgovora na ovo pitanje zabilježena je statistički značajna razlika obzirom na spol (χ^2-21,805; p-0,000) i mjesto odrastanja (χ^2-10,536; p-0,015).

ZAKLJUČAK

Suvremena poljoprivreda nezamisliva je bez upotrebe mehanizacije koja zbog sve bržeg tehničkog napretka traži i višu razinu specijaliziranog znanja. Programima preddiplomskih i diplomskih studija Agronomskog fakulteta potreba za tim znanjima je prepoznata. Matični studij „Poljoprivredna tehnika" u većoj mjeri svojim polaznicima pruža ta specijalizirana znanja, nego drugi studiji Fakulteta.

Unatoč postojećem trendu promjene strukture polaznika koji upisuju Agronomski fakultet (značajan porast žena kao i osoba odraslih u urbanoj sredini, ali i smanjenje onih sa završenom srednjom poljoprivrednom školom) znanje studenata prve i druge godine o poljoprivrednoj mehanizaciji je na nezadovoljavajućoj razini i u razdoblju između dva istraživanja prisutne su negativne tendencije.

Većina anketiranih izjavama prepoznaje neophodnost ali i trošak mehanizacije za poljoprivrednu proizvodnju. Unatoč tome, relativno mali dio bi ih upisao izborni modul u kojem bi dobili više znanja o toj problematici.

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CHANGES IN STUDENTS' KNOWLEDGE LEVEL ABOUT AGRICULTURAL MECHANIZATION ON FACULTY OF AGRICULTURE, UNIVERSITY OF ZAGREB

ABSTRACT

Agricultural mechanization has had a major impact on increasing productivity in agriculture and is one of the most significant engineering achievements of the twentieth century. Agricultural mechanization replaced the "lack" of labor force in agriculture but also "liberated" part of the workforce that is able, directly or indirectly, to leave agriculture. Mechanization is more sophisticated and requires new knowledge and continuous training of users/farmers. The paper presents the results of research on knowledge of agricultural mechanization by students of Faculty of Agriculture in Zagreb.

The aim of paper is to research results from 2013 and 2015 and to compare the knowledge of agricultural mechanization first-year students of selected undergraduate programs and to determine the change occurred in knowledge level using comparative analysis. The paper is based on the assumption that in the period 2015/2013 there was a change in the level of knowledge of first year students of the Faculty of Agriculture about agricultural machinery, but that knowledge is still on modest in average. For that purposes we used the identical questionnaire, and the results obtained from the research were analyzed using SPSS. The study included 361 respondents - first-year students of undergraduate studies listening module "Basis of agricultural economics "(141 in 2013 and 220 in 2015). Though most of respondents were women (64.58%), their share reduced from 68.8 to 61.8% compare with previous survey. In 2015 increased the share of respondents who are from urban areas (from 68.1 to 70.9%) and who have completed gymnasium (from 62.4 to 68.2%). Proportion of those who have completed secondary agriculture school slightly increased (from 5.7 to 6.4%). The study of agriculture is becoming less attractive for young people and there was reduced the share of respondents that she was the first choice of enrollment at the Faculty of agriculture (from 41.8 to 38.6%). Research in 2015 showed that 77.3% of respondents do not know how to manage any agricultural machine and that is increase of 5.7% compared to 2013. The most of them knows how to run a tractor, then motor cultivator and a rotary cultivator and no one knows to manage the harvester. In 2015, just over half (55%) of them knew that the furrowing is plowing to a depth of more than 50 cm, which is purpose of harvester (78.2%)

and somewhat fewer who knew that roller presses are used in gathering hay (72.3%). However, students are familiar with the role of mechanization in agriculture, but also with the importance of cost-effective management, emphasizing the business connections of farmers due to reduced cost of mechanization in production. Respondents had divided opinions about the formal education need for machinery management. Similarly, as in the previous survey, the results showed that male respondents have a higher level of knowledge about agricultural mechanization and those who grew up in the countryside.

***Key words**: agricultural machinery, students, agronomy, comparative analysis*

44. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

UDC 631.2:711.582.7:636](497.16)
Stručni rad
Expert paper

THE KATUNS – RURAL BUILDINGS AS A PERSPECTIVE OF SEASONAL MOUNTAIN SETTLEMENTS IN MONTENEGRO

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SUMMARY

Rural buildings play a central role on the environmental characteristics of the extra-urban land. They accompanied in the centuries the development of agricultural activities of the man who was so able to breed cattle, to grow and yield crops, and to store, transform and process agricultural products in a functional and efficient way, working into intensive conditions, so being unaffected by the external climate. On the other hand, construction built by the farmer-man marked the territory, influencing and steering the spontaneous development of nature, while leading to production that enabled humanity to get food.

The Montenegrin katuns constitute a special example of rural buildings; used as seasonal settlements, they are organized in areas of mountain pastures for summer cattle grazing. Even if in most case they were abandoned during recent years - since people living there moved to more confortable residences within urban settlements - their contemporary potential for preserving traditional cattle-raising procedures and dairy products, rich cultural-historical heritage and perspectives of organized tourism activities, appears a very intriguing task to be approached.

With the aim to valorise Montenegrin katuns, in the present paper a first approach was proposed, through the implementation of a Geographical Information System aimed to a survey about the current situation. This first step could pave the way for future possible planning of their restoration, within the general framework of a concerted approach aimed to their safeguard and the general sustainability of the areas where they are located, fighting the progres-

sive abandonment of rural land. The exploitation of their unexpressed potential in the sector of tourism usage, together with cultural heritage, rich tradition and old infrastructure, would therefore reveal an efficient way for their valorisation. Articulating their place within the course of modern development of Montenegrin approaching the EU, would be a step towards enriching common European heritage with one of the most recognizable country's traditions.

Agro-tourism offers indeed new opportunities for enjoying the agricultural land in close contact with naturally untouched landscapes. It enables to appreciate some traditional aspects that the new industrialized modern society may have forgotten. The opportunities that an agro-tourism farm may offer are so many and differentiated, going from the tour of the dairy farm, nature trail and flower gardens, farm animals, the traditional local genuine agro-food products, whose preparation can be personally observed, often coupled with the opportunity to taste and buy them, until the role of the farm as a location for educational farming. The agro-tourism in Montenegrin katuns may therefore encourage economic development through sustainable use of natural and cultural resources. Additionally, all the above mentioned opportunities could help in the development of environmentally friendly tourism, which is growing three times faster than those choosing mainstream trips.

***Key words**: Katun; rural building; cultural heritage; historical heritage; agro-tourism*

INTRODUCTION

Rural buildings are living witnesses of how humans have populated, in harmony with the natural elements, the agricultural land, joining the agricultural production needed for human nutrition with the control and care of extra-urban territory [Dal Sasso & Caliandro, 2010; Picuno P., 2012; Van der Vaart J.H.P., 2005]. The interventions made by the man strongly influenced then the agricultural environment and the visual perception of its landscape [Hernández et al., 2004; Picuno et al., 2011; Statuto et al., 2013; Tortora et al., 2015]. As in many cases all over Europe, and more specifically in the Mediterranean area, these factors led to the realization all over the centuries of many buildings that, designed in order to satisfy their main agricultural role, now constitute a widespread heritage of unrivaled architectural value, that should be taken into the highest consideration during the landscape planning [Fuentes et al., 2010; Statuto et al., 2014/a; Picuno et al., 2015].

A very interesting example of farm building is that one constituted by a temporary settlement, widespread over some Mediterranean mountainous regions, where the agricultural households stay with livestock during the summer season, most frequently for 4 to 5 months (*i.e.*, typically from the end of May or beginning of June until October). Movement from the villages to the mountains is also known as vertical transhumance or nomadic pastoralism. The main purpose is to use mountain pastures for rearing of farm animals for producing traditional milk and meat products, which is the main source of income for these households. Similar buildings take locally specific names in different Mediterranean countries, *e.g.* “malghe” in Italy [Scarascia-Mugnozza et al., 1996; Scarascia-Mugnozza et al., 1998], or “katuns” in Montenegro.

In Montenegro, the katuns are a unique social-cultural resource of the Country which should be preserved and revitalised via implementing new activities to enable them to become distinctive and attractive tourism destinations. There were quite strong non-return rules for using mountain pasture in the whole country. All villages (clans) had precisely defined areas for founding the summer settlements - the katuns. The katun’s way of livestock rearing presented the dominant way of conducting this activity throughout the entire Montenegrin history. Even the name of the country itself came in colloquial use after the “katuns of Montenegro”, area on the western slopes of Lovćen mountain, where the local population was bringing the livestock for summer grazing even in the 14th century. During all this time, katuns and the adherent area presented the most important parts of the economical life of central Montenegro. The importance of the amount and quality of grass on pastures led to a strict territorial demarcation of which pasture belongs to which katun, having often been followed with the use of weapons in the case of its violation. On internal side, the most important rule treated the right of clan member to build the cottages freely within the district of the katun belonging to clan, while denying this possibility to any other. Although the social atmosphere has dramatically been changed since the introduction of these rules, building of new housing facilities dominantly follows their inertia even today. With changes in Montenegrin society during the XX century, this kind of economy has been constantly decreasing, resulting in depopulation of the rural areas and complete abandonment of the most distant ones. Consequently, mountain pastures and katuns are used at much lower scale and the mountain as a whole.

Traditionally, livestock production has the highest economic significance (more than 50%) in the Montenegrin agricultural sector. Due to high percentage of meadows and pastures in the total agricultural area (around 90%), the Montenegrin livestock sector is dominated by rearing of ruminants. The cattle breeding with 84,701 heads in 2012 is the largest sub-sector of the livestock production. Sheep breeding (207,047 heads in the same year) is characterized by semi-extensive way of production, mainly in the North of the country. Goat breeding is also an important sector, especially in the karst areas (Central and South Regions). Poultry and pig production are weak primarily due to lack of domestic production of animal feed. Hence, utilisation of the vast areas of natural resources (mountain pastures) is closely linked with the traditional way of rearing livestock (ruminants) during the pasture season at the mountains where katuns are located. Trends in size of sheep and cattle populations are anyway decreasing. During the sixties of 20th century Montenegro had about 600,000 heads of sheep. Since that period intensive industrialization led to a drastic reduction of the total sheep population. Only during last 20 years sheep population had been decreased by 53%, from 480.000 heads in 1991 to 227,000 heads in 2010. These trends are reflected directly to the katuns - significantly smaller number of sheep and cattle are moved to the katuns during summer season. In spite of that, in many parts of the country, traditional livestock systems still survived. Transhumance or moving livestock from permanents settlements to the summer pastures in mountains is still practised in all of the municipalities of the northern part of the country and also widely used in the Central region (Podgorica, Danilovgrad and Nikšić), and even in some coastal municipalities like Herceg Novi and Bar.

In terms of buildings, the Montenegrin katuns’ settlements (fig. 1) include different types of wooden or stone structures - cottages (local names: *koliba, glada* or *stan*) for household members, mainly without electricity and water, where traditional production of milk and cheese is still in few cases going on. According to the most recent estimations, there are at least n.1.000 katuns in Montenegro, of which a significant number is still used, but at a much lower scale (smaller numbers of households with reduced numbers of animals use those resources). Noteworthy, the households in katun can earn significantly. Total income of one household (with 100 sheep and 5 cows) from production of dairy products during 100 days in katun is up to 10.000 euro, including incomes from marketing of livestock for slaughtering, while production costs (in cash) are very low and do not exceed 1.000 euro. By practising that way of livestock production, the rural holdings contribute to maintenance of the mountain pastures and reduction of the negative effects of abandonment of the pastureland. However, there are many underutilized pastureland resources, including some non-used for many years. Preserving mountain pastures and transhumance is also important for preserving the nature and rural heritage. The implementation of a suitable planning tool would be therefore very useful as a knowledge basis for the consequent formulation of sound policies and actions aimed to the valorisation of this very interesting farm building heritage.

Figure 1 A Montenegrin katun

Geographical Information Systems (GIS) are very powerful tools for developing and implementing tourism programs able to diversify and reinvigorate local economies

[Beedasy & Whyatt, 1999; Parolo et al., 2009]. In some countries, especially in Europe, tourism development strategies have combined agriculture and tourism to create agro-tourism, developing a GIS based model that maps the spatial distribution of rural buildings [Baskerville, 2013; Romano et al., 2015; Statuto et al., 2015/b]. The first step in this research involved the identification of location-based factors that may influence agro-tourism development based on the building valorization. This was accomplished through a survey of the literature and associated topics such as general tourism, rural economics, travel research, and geographic information systems. Secondly, a comprehensive geo-database of agro-tourism operations in the rural area was developed. The resulting geo-database contains for each building their corresponding location, the relation with infrastructures, land cover, morphology, vegetation, etc. In recent years, there have been numerous examples of Geographic Information Systems utilized for suitability modeling, which is commonly used to identify the best location for an agricultural enterprise and the surrounding context. Using GIS in the decision making process helps reduce the risk of failure and creates opportunities for efficient marketing and advertising.

MATERIALS AND METHODS

In order to verify the typological characteristic, building condition and status of use of Montenegrin katuns, an analysis was conducted in order to identify the most popular features of these buildings, in order to assess the possibilities to restore them, converting them to an agro-tourism use. This new way for offering tourism in a sustainable way, in fact, is in close agreement with the new EU Strategy for the Adriatic and Ionian Region (EUSAIR), a macro-regional strategy adopted by the European Commission and endorsed by the European Council in 2014. One of the main four pillars of this new EU macro-regional strategy is concentrated in sustainable tourism (http://www.adriatic-ionian.eu/).

Study area

There are several quite compact mountain areas with recognizable type of katuns, Durmitor mountain area (so-called Durmitor ring), Kuči mountains, vast area of Sinjajevina mountain, Bjelasica mountain, Morača mountains including Lukavica, the katuns in Berane (Mokra planina), Andrijevica, Plav (Bogićevica), Rožaje municipalities and many others dispersed through the country. Each of them has many specificities or particular characteristics.

For the purpose of this article, the “Mountains of Kuči” area was selected (fig. 2), thanks to its social aspects (richness in cultural heritage, customs related to the life in the katuns, tourism attractions, architecture, *etc.*) and certain positive trends in development of agriculture (sheep and cattle rearing and production of specific dairy products, as well as new sectors of agriculture like growing of potatoes, buckwheat, cereals, *etc.*).

The “Mountains of Kuči” area is located in the eastern part of Montenegro, containing the parts of Komovi and Prokletije as well as whole Žijevo mountain’s massif. Geographically, it covers c.ca 220 square kilometres. In the mentioned mountains, there are some 20 peaks of 2000m and higher. The southern part (Žijevo massif) is more rugged, rocky terrain, with Bosnian pine (munika) in higher and some beech forests in lover parts, while the middle (Crna planina – Maglić – Širokar) and northern (Komovi) range are characterized with larger pastures and beech forests. In this area, there are two significant glacial lakes (Rikavačko and Bukumirsko) two streams (Opasanica and Verušica) that create the Tara river and one (Vučji potok) that flows into it. According to the existing data, this area is also rich in diversity of plant and fungal species which could be valuable for commercial use and benefits for rural populations. Best management practice is necessary to be established, in order to provide balance between commercial usage and needs for protection (sustainable management). Due to landscape characteristics, this area is becoming very popular among the backpackers of all kinds, being situated in the nearest vicinity of the Podgorica and its transport, infrastructure and logistic facilities. The tourism development here is aimed on following two directions – further promotion of the existing activities from the domain of active – adventure tourism, as well as introducing the agro tourism as a new category.

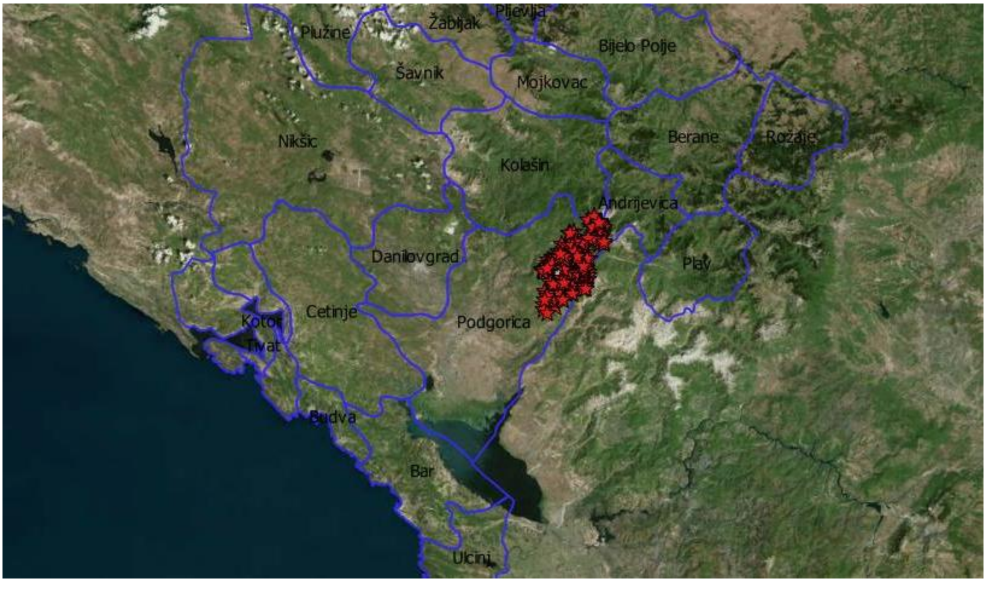

Figure 2 Study area in the Kuči mountains and distribution of selected katuns

Geographical Information System

Spatial data analysis was conducted with a Q-GIS software using Bing Aerial Maps, the katuns located in the study area where identified and a geo-database was implemented. It is possible to consider other parameters like roads, administrative boundaries, vegetation and geomorphology. These data were extracted from an on-line geodatabase [www.gadm.org] that allows the possibilities to download the administrative boundaries and other geographical parameters. The variables were combined into a GIS model to produce maps portraying the location of katun that can be used for touristic purposes. The maps generated with this GIS-based model can be used by farmers considering starting an agro-tourism enterprise on their farm or by state-wide economic and tourism development entities.

RESULTS AND DISCUSSION

The resulting geo-database contains for each building its location, the relation with infrastructures, land cover, morphology, vegetation, *etc.*

To promote the natural heritage for touristic purpose, some step in the GIS analysis were identified:

- Identification of the position of katun;
- Selection of the most stimulating points of interest;
- Creation of a geo-database, whose attribute table is represented by points of interest;
- Insertion of the points of interest in the GIS (with auxiliary level of information);
- Creation of exemplificative maps useful to describe the territory.

In order to promote the communication and to contribute to tourism development, the results of the present work consist on the creation of an innovative GIS database specially designed; this should be considered as a method/instrument for the representation of the territory and the identification of particular point of interest. This instrument allows appreciating from a cartographic point of view the distribution of the type of natural heritage, some parts of the old roads, some rural buildings and farms.

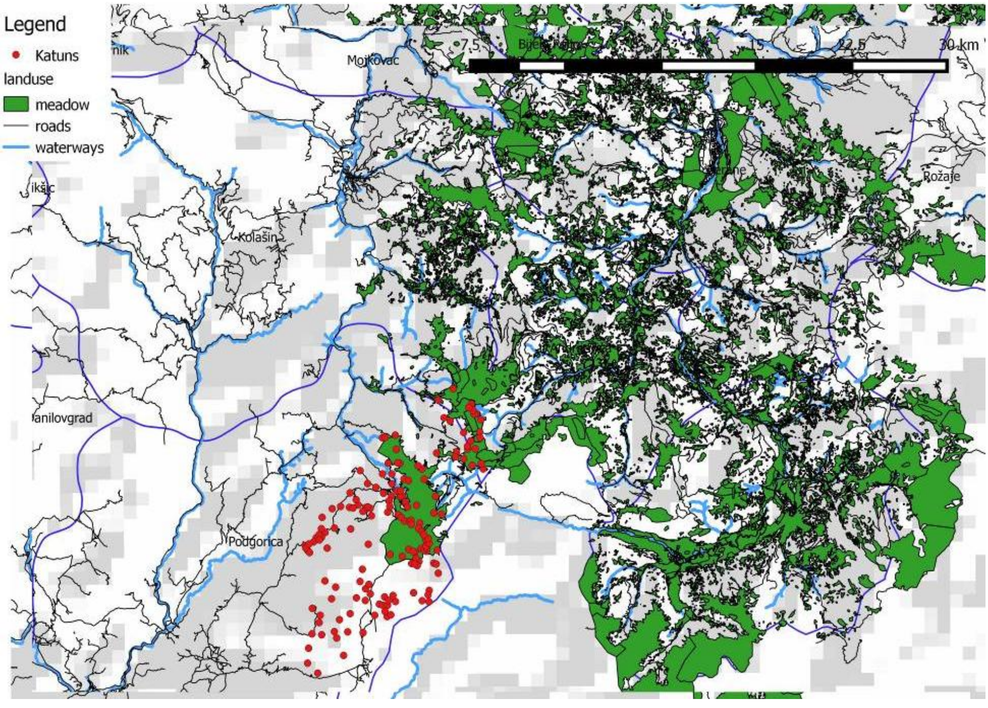

Figure 3 Natural vegetation and katun distribution

Main result of the present work is the map that was produced through the implementation of the Geographical Information System (fig. 3), showing the localization of the katuns, in close connection with the road system and the waterways. The dominant vegetation is constituted by meadows, that play an active role for the livestock activities and for the dairy production, since the characteristics of vegetation can influence indeed the smell of dairy products, through the feeding chain of the animal that are bred there [Manera et al., 2001]. The limited distribution of road network, the presence of natural vegetation, the mountain aspect and the absence of urbanized area are all important characteristics that constitute an unexpressed potential in the sector of tourism usage. Tourists that visit this place have the opportunity for enjoying the natural landscape, to visit the farms, taste local products, and take part into the agricultural practices. In this natural landscape, there is also the chance to taste some of the "forgotten" national specialties.

CONCLUSIONS

The geodatabase presented, that is the results of the territorial analysis with the support of a GIS System, represents an instrument for safeguarding the territory (Statuto et al., 2014) and promote katun buildings for touristic purposes. It is a consolidated practice for sustainable and alternative tourism which would be enlarged and completed with more useful information in the next future.

Livestock production, particularly rearing of ruminants, is the only rational way of valorisation of less favoured areas and prudent tool of preserving the cultural landscape of the katuns. In addition to its economic and nature conservation role, agriculture is also important for its social component and the katuns settlement value. Integration of nature conservation measures into development of the katuns is for sure an important contributor to the concept of the ecological state, proclaimed by the Constitution of Montenegro.

Since sustainable tourism is one of the pillars of the EU Strategy for the Adriatic and Ionian Region (EUSAIR), a plan for the identification and cataloguing of katun through the implementation of ICT tools as a GIS and a Decision Support System may reveal a fruitful way for implementing suitable actions aimed to the valorisation of rural building heritage all over this area, so contributing to the protection of natural resources and stimulating at the same time the local economies.

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Original scientific paper

ENVIRONMENTAL LIFE-CYCLE ASSESSMENT (LCA) – A TOOL TO ASSESS SUSTAINABILITY IN AGRICULTURAL ENGINEERING

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SUMMARY

Present-day agricultural technology is facing the challenge of limiting the environmental impacts of agricultural production – such as greenhouse gas emissions and demand for additional land – while meeting growing demands for agricultural products. This article first presents the well-established method of life-cycle assessment (LCA) as a tool to quantify the environmental sustainability of engineered agricultural production chains and to optimize the technologies involved. Secondly, three case studies are used to demonstrate the ability of LCA to identify hot spot processes of greenhouse gas emissions and options to reduce this climate change impact (100-year reference period). Third, some methodological limitations and challenges of applying LCA to engineered agricultural production are discussed.

The first case study analyzes a common Austrian tractor model over its life-cycle. Impacts are mostly dominated by diesel combustion during the operation phase of the tractor's life-cycle, with 84.4-99.6% of total impacts. The second case study models the production chain for maize silage. Tractor operation was found to cause 15 g CO_2eq per kg silage or 64% of total climate change impacts. In the third case study, a hypothetical grassland production chain supplies a grass-fed biogas plant which in turn is part of the waste management and energy system in an Alpine municipality. Here, the prospective relative environmental impacts depend strongly on which fuels are assumed to be displaced by the biogas energy.

Methodological challenges that are characteristic for LCA applications to agricultural production chains systems are largely due to the challenge of using ever-evolving technical systems to create, modify and exploit highly complex and variable natural ecosystems, limiting data availability and necessitating statistical uncertainty analyses. For example, data on the effects of the studied production chains (maize silage, stover utilization, and Alpine grasslands) on soil greenhouse gas emissions require spatially resolved long-term studies that are not yet available.

Taken together, the case studies demonstrate the potential and limitations of LCA as a technique to quantify the environmental impacts of agricultural production technologies at a variety of scales, despite some methodological challenges.

Key words: life-cycle assessment, agricultural engineering, tractor, maize silage, biogas

INTRODUCTION

Globally, demand for agricultural products will increase in the coming decades (Foley et al. 2011). Agricultural technology is thus facing the challenge of meeting growing demands for agricultural products while at the same time limiting the environmental impacts of agricultural production – such as greenhouse gas emissions, human and ecotoxicity and demand for additional land. This requires a quantitative and comprehensive method to compare the environmental sustainability of agricultural engineering systems (technologies, processes, process chains), and to identify on the one hand those “hot spot” processes that cause the highest environmental impacts (such as enteric fermentation in beef production) and on the other hand to identify engineering potentials for optimisation.

The well-established method of environmental life-cycle assessment (LCA) can provide quantitative information to reduce the potential environmental impacts of engineered agricultural production systems, and thus it can support policy decisions and substantiate marketing claims in agriculture.

The objective of this study is to (1) outline the LCA method as applied specifically to engineered agricultural production chains, (2) briefly present three recent case studies (Stampfel, 2014; Kral et al. 2015; Saylor et al., 2016) that demonstrate the application of the LCA method to quantify environmental sustainability and thus to guide efforts to decrease the environmental impacts of agricultural production processes, and (3) discuss some methodological limitations and challenges posed by applying LCA to engineered agricultural production.

METHODS

Life cycle assessment (LCA) as a tool to quantify environmental sustainability in agricultural engineering

LCA typically follows the four-phase framework of the ISO 14040 family of standards (Fig. 1; ISO 14040, 2006), and this framework will be briefly outlined here.

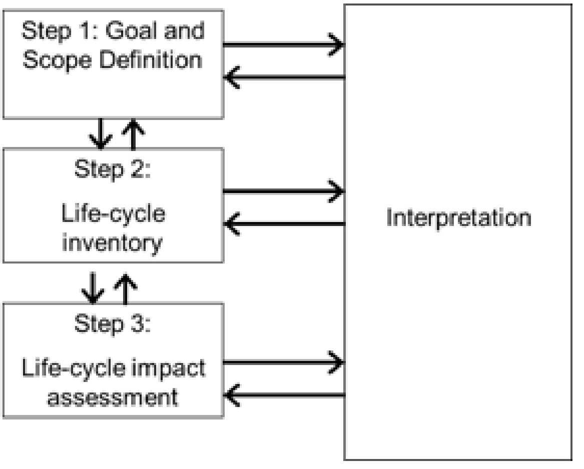

Fig. 1 The four phases of environmental life-cycle assessment (ISO 14040, 2006)

LCA is a systems approach aimed at quantifying as much of the potential environmental impacts of a product as possible. It can be defined as "a compilation and evaluation of the inputs, outputs, and the potential environmental impacts of a product system throughout its life cycle." (ISO 14040, 2006). A product or product system (e.g., a tractor, a specific crop) is normally evaluated over its entire life-cycle, from the extraction of raw materials through manufacturing and use to the disposal. In agricultural engineering applications of LCA however, the model typically focuses on an agricultural production chain, and therefore it covers only the first part of a full agricultural product life-cycle. Such LCA models can therefore be called “cradle-to-gate” LCAs, as they usually end at the farm gate. Regardless of the chosen system boundaries, the LCA method consists of four distinct phases (Fig. 1).

In the first phase, the goal and scope of the LCA are identified and described. In the second phase, a comprehensive inventory of all resource uses and emissions is developed, the so-called life-cycle inventory. This phase is usually the most time-consuming, as data (material inputs, energy consumption, engine emissions, product yields, etc) on the entire production chain have to be collected and integrated into a comprehensive, interlinked model. The third phase – the life-cycle impact assessment – translates resource uses and emissions into their potential environmental impacts and aggregates them into similar environmental impacts, so-called impact categories. In the interpretation phase, the results of the previous phases are structured, carefully evaluated for completeness, quality (including the effect of data and model uncertainties), and consistency, and finally the assessment results are summarized and interpreted in a report.

LCA modelling approach, data, and software

LCA models were assembled using the software OpenLCA v.1.4 (Green Delta GmbH, Berlin, Germany). Potential environmental impacts were evaluated using six selected categories from the the ReCiPe (H) midpoint impact assessment method (Goedkoop et al., 2013). ReCiPe’s climate change characterization factors were adjusted to reflect the most current IPCC estimates for global warming potentials (a 100-year GWP of 34 kg CO2-eq per kg methane including climate-carbon interactions; IPCC, 2013). In this paper, as an example for potential environmental impacts, greenhouse gas emissions are discussed in more detail, in addition to other environmentally significant emissions. As characterization factors for greenhouse gas emissions, the most recent factors for a 100-year reference period (IPCC, 2013) were used. In the case of biogenic methane, the 100-year GWP of sequestered carbon was subtracted, resulting in 31.25 kg CO2-eq/kg methane. Leading manufacturers of the combined heat and power (CHP) generator and steam explosion pretreatment unit provided primary data on their respective technologies (personal communication, 2014). Primary LCA data was supplemented with secondary data from literature and from the Ecoinvent database v.2.2.(Ecoinvent Centre, 2010).

Case study system descriptions

This work gives overviews of three recent case studies (Stampfel, 2014; Kral et al. 2015; Saylor et al., 2016) that demonstrate the application of the LCA method. The case studies are selected to represent increasing degrees of system complexity.

Case study 1 describes the life cycle (Fig. 2) of a mid-sized tractor (81 kW rated power, Type Steyr Profi 4110). The main system function is the provision of draught power for agricultural processes.

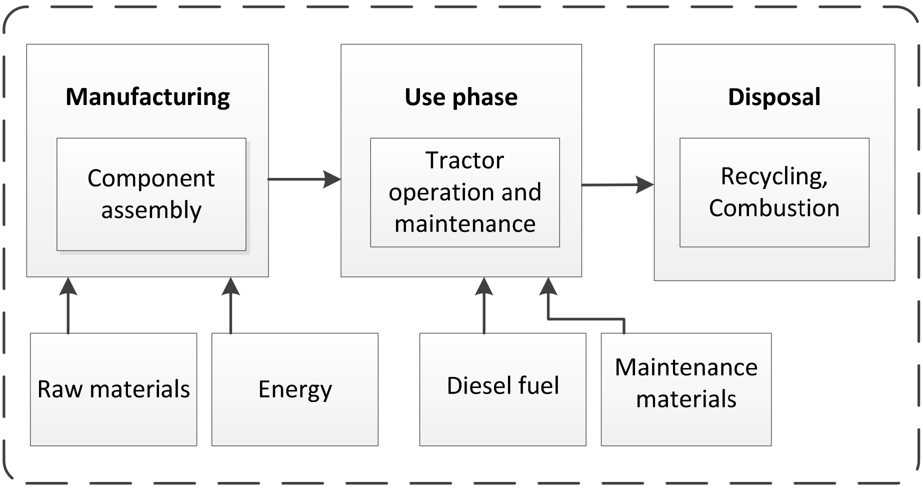

Fig. 2 System diagram of the life-cycle model for the studied tractor

The LCA model includes the manufacturing, use, and disposal of the model year 2004 tractor, with an assumed technical lifetime of 24 years and 6747 hours of operation. The manufacturing phase was modelled using primary data that include an aggregate bill of materials for the tractor components, as well as the tractor assembly plant's energy consumption (tractor manufacturer, 2015, personal communication). For the use phase, the tractor was assumed to be operated at an organic 140-ha farm in eastern Austria. The farm grows mixed grains in an eight-year rotation, and five farming processes (ploughing, cultivation, harrowing, baling and bale transportation; see Table 1) were selected that can be performed with the tractor size studied. Fuel consumption and emissions during operation were approximated by weighted averages of individual cycles from an ISO 8178-4 C1 eight-cycle test for a tractor with a similar engine (Landis, 2014, personal communication). The cycles were weighted according to field-determined load profiles by Rinaldi et al. (2005). The calculations yielded specific estimates of the hourly fuel consumption and air emission factors for each of the five chosen processes (Table 1). The emission factor for diesel Particulate Matter (PM) was not determined during the ISO test cycle, but expected to behave similar to CO emissions, as both are results of incomplete combustion. Emission increases due to engine aging over the tractor's life span were calculated based on Schäffeler and Keller (2008). Maintenance during tractor use was assumed to be the replacement of engine oil, filters, filter pump (all every 600 hours), and of other oils and transmission belts (every 1200 hours).

The second case study describes an average production of maize silage in Austria, up to the point of storage. Calculations are based on a reference quantity (functional unit) of one kilogram (fresh matter, FM) of maize silage at 30% dry matter (DM) content. Details of the system are given in Kral et al. (2015). Briefly, the system includes all auxiliary materials, from seed production to the production of machinery and machine sheds to the transportation of auxiliary materials to the farm.

Table 1 Cultivation processes for the studied tractor, process-specific hourly fuel use and exhaust emission factors. HC = Hydrocarbons, PM = Particulate matter

Farming process	Fuel use ($kg\ h^{-1}$)	CO_2 ($kg\ h^{-1}$)	HC ($g\ h^{-1}$)	NO_x ($g\ h^{-1}$)	CO ($g\ h^{-1}$)	PM [a] ($g\ h^{-1}$)
Ploughing, 4-furrow reversible mounted plough	12.64	39.82	10.42	304.81	34.07	6.81
Cultivation, 3 m shallow cultivator	12.57	39.61	10.82	301.85	32.20	6.44
Harrowing (seedbed preparation), harrow and packer, 3 m	13.33	42.00	11.23	316.54	35.27	7.05
Baling, round bales, 1.2 m	8.99	28.32	7.42	205.66	28.25	5.65
Bale transport, double trailer, 8 t each	4.94	15.57	5.01	115.91	20.12	4.02

[a] Emission factors estimated by scaling up CO emission factors using a constant ratio of 0.2 between CO and PM emission factors (tractor manufacturer, personal communication).

The system is based on data from the ecoinvent database (Nemecek and Kägi, 2008), with several adaptations to Austrian production specifics: A 15-year average Austrian maize silage yield of 45.55 t fresh matter per hectare and year (1999 to 2013; Statistik Austria, 2014) was assumed at 70% dry matter content. As the sole fertilizer, liquid digestate (159 kg N per hectare and year) from a silage/slurry-fed biogas plant was modelled. The herbicides applied were adjusted to reflect Austrian practices (BMLFUW, 2008). As is further described in Kral et al. (2015), the silage was used as the main substrate (80% of total substrate FM) of a hypothetical 500 kW_{el} biogas plant (Laaber, 2011) that generates electricity and heat through a combined-heat-and power (CHP) module.

The third case study describes how the hypothetical biogas plant mentioned above would be embedded into a larger system - the energy and waste management system of an Alpine municipality in Western Austria (Saylor et al., 2015). The main outputs of the biogas system are heat and electricity, as well as management of the organic waste streams from the municipality and of manure. For simplicity, and to allow comparison with other biogas LCAs, a functional unit of 1 kWh of electricity output from the CHP module was chosen. The primary biogas substrate is grass (conserved as hay) from Alpine grasslands. Grassland management processes include seeding, fertilizing, harvest and outdoor drying, and hay transport and storage. Other biogas substrates include green waste, municipal organic wastes, oils and fats, and solid manure. Before entering the biogas fermenters, hay would undergo steam explosion pretreatment (Bauer et al., 2014), as would municipal organic and green wastes. The biogas generated in the fermenters is fed into a CHP module that is assumed to operate during 7,470 hours per year, combusting 240 m^3 biogas with a 55% methane content per hour, at an electrical efficiency of 38%, and at a thermal efficiency of 42%. Air emissions due to CHP operations were calculated using exhaust pollutant concentrations provided by a CHP manufacturer (personal communication, 2014). Most of the CHP heat output (69% of 4,128158 $kWh_{th}*a^{-1}$) is assumed fed into the local district heating system where it would replace currently operating residential heaters fuelled with heating oil (2,416,042 $kWh_{th}*a^{-1}$). Some of the remaining CHP heat is used on-site for steam explosion pretreatment and fermenter heating, and the rest is wasted due to seasonal demand fluctuations. Some of the substrates for the hypothetical biogas plant are currently treated in a regional waste treatment plant that generates heat. If used locally in the hypothetical biogas plant, they would no longer contribute to that regional plant, and the missing heat would have to be supplied by a generic regional heat mix. The impacts of providing materials for the biogas plant, agricultural machines for grassland management, and additional materials for the steam explosion unit are considered in the analysis presented here.

RESULTS AND DISCUSSION

The following section describes the selected environmental impacts of the three case studies described above. They quantify the impacts for the chosen impact categories and identify hotspots for the climate change impact.

Case study 1 – Tractor life-cycle environmental impacts and hot spots

Potential environmental impacts over the tractor’s 24-year life-cycle were mostly dominated by the use phase, with 84.4% to 99.6% of the impact score, and not by its manufacturing or disposal impacts, as indicated by the main processes that contribute to each impact category (Table 2).

Manufacturing the tractor, which includes the production of the materials and final assembly, causes only 0.4 to 12.1% of the impact scores, depending on the specific impact category. This result is in agreement with Lee et al. (2000), who found that 85% of a small

(28 kW) tractor's total environmental impact score was due to the use phase, with 11.3% due to manufacturing and distribution, and the remainder due to the end-of-life disposal of the tractor. Within the use phase, supplying and combusting diesel fuel causes most impacts, while maintenance is of secondary importance.

Table 2 Potential environmental impacts of 24-year tractor life-cycle (at 281 operating hours per year)

	Tractor lifetime impacts (24 years)		
Impact category	Unit	Quantity	Main contributing Process
Climate change (GWP 100)	kg CO_2-Eq	287,822	Diesel combustion during cultivation
Freshwater ecotoxicity	kg 1,4-DCB-Eq	329	Diesel extraction and refining
Human toxicity	kg 1,4-DCB-Eq	12,609	Diesel extraction and refining
Particulate matter formation	kg PM10-Eq	555	PM emissions during diesel comb.
Terrestrial acidification	kg SO_2-Eq	1,335	NOx emissions during diesel comb.
Non-renewable energy resources	MJ-Eq	4,182,198	Diesel use for cultivation processes

With regard to impacts on climate change due to greenhouse gas emissions (carbon footprint, GWP100), the fuel-intensive tillage processes (ploughing, harrowing, cultivating) were by far the largest contributors, with 55%, 13%, and 10% of the total (Fig. 3).

Case study 2 – Maize silage environmental impacts and hot spots

The second case study models the production chain for maize silage. The operation of machinery for cultivation and harvest was found to cause most environmental impacts. With regard to impacts on climate change, emissions from tractor operation accounted for a GWP100 of 15 g CO_2eq per kg silage, or 64% of the total, followed by nitrous oxide emissions during fertilizer (biogas digestate) application with 6 g CO_2-eq/kg silage or 24% of total GWP100.

The production of maize silage under typical Austrian conditions shows low impacts in the climate change impact category (Table 3), but impacts in the terrestrial acidification category due to ammonia emissions during digestate application are within the range of literature. This is in comparison with Dressler et al. (2012), who report for maize cultivation at three German study sites a GWP of 0.0454-0.0577 kg CO_2-eq per kg maize (FM), but an acidification potential of 0.00026-0.00037 kg SO_2-eq per kg maize (FM). An evaluation of conventional maize silage production as modeled in the Swiss Ecoinvent database (Ecoinvent-Centre, 2010) yields a higher GWP of 0.0531kg CO_2-eq per kg maize (FM), and a higher acidification potential of 0.00117 kg SO_2-eq per kg maize (FM) as well.

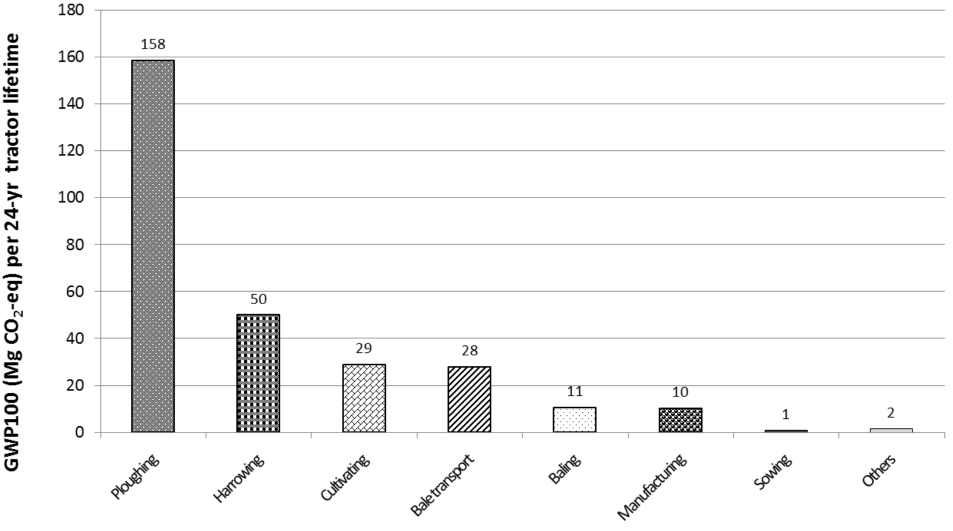

Fig. 3 Contribution of individual processes to total climate change impact of a tractor life-cycle

Table 3 Potential environmental impacts of typical maize silage production per ha cropland and per kg silage (fresh matter)

Impact category	Unit	Potential impact		Main contributing
		per hectare[a]	per kg FM	Process
Climate change (GWP 100)	kg CO_2-Eq	1,057	0.0232	Harvesting maize, diesel emissions
Freshwater ecotoxicity	kg 1,4-DCB-Eq	2,151	0.0472	Herbicides application
Human toxicity	kg 1,4-DCB-Eq	345	0.0076	Zinc in digestate[b]
Particulate matter formation	kg PM10-Eq	28	0.0006	PM emissions, digestate application
Terrestrial acidification	kg SO_2-Eq	197	0.0043	NH_3 emissions, digestate application
Non-renewable energy resources	MJ-Eq	11,735	0.2576	Harvesting maize, diesel emissions

[a] 15-year average Austrian yield of 45.55 t FM*ha^{-1} (Statistik Austria, 2014).
[b] Zinc in digestate originates mainly from feed in pig slurry that is assumed to be a co-substrate in digestate production.

A contribution analysis specifically of the climate change category (Fig. 4) shows the dominance of the most fuel-intensive processing step, the harvesting (and chopping) of the silage maize with a forage harvester, followed by digestate application that is associated with emissions of the greenhouse gases nitrous oxide and methane (0.0057 g CO_2-eq per kg FM silage, or 24% of total GWP100). The other contributors to the GWP100 score are again various processes of sowing, tillage, and seedbed preparation (harrowing); CO_2 emissions from tractor and forage harvester operations account for 0.0148 kg CO_2-eq per kg FM silage, or 64% of the total score.

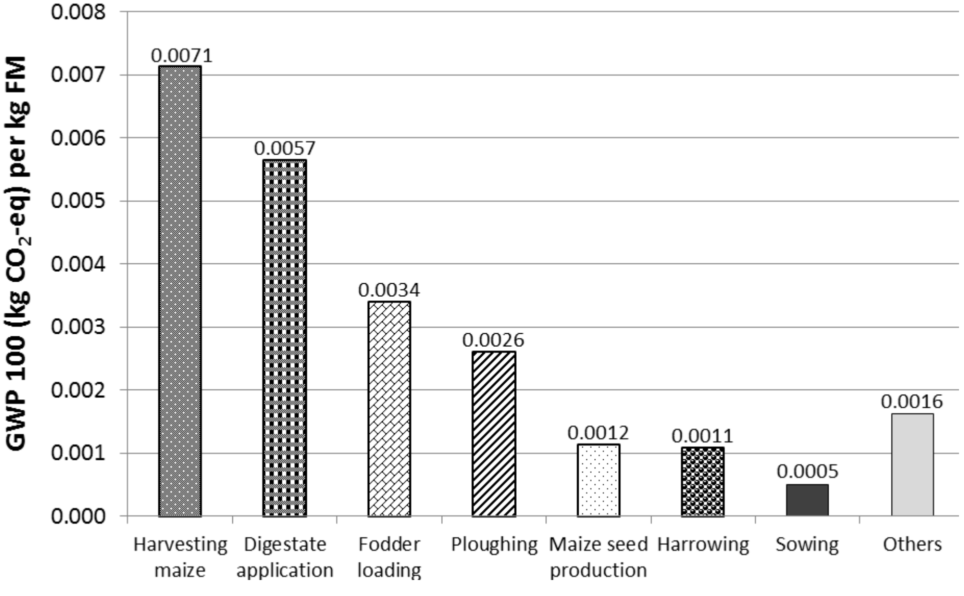

Fig. 4 Contribution of individual processes to total climate change impact of producing 1 kg FM maize silage

Case study 3 – Alpine grassland biogas environmental impacts and hot spots

In the third case study, a more complex system models the impact of establishing a biogas plant in an Austrian Alpine municipality. The plant would use grass (hay) and various organic wastes and solid manure, supplying electricity to the regional grid and heat to an existing local district heating network. The LCA analysis (Table 4) shows that hot spots in this system are varied. The climate change category is dominated by methane slip in the biogas combustion CHP exhaust, while other contributions are dominated by raw materials acquisition (diesel fuel, copper for infrastructure) and digestate emissions.

The hot spot analysis of climate change contributions (Fig, 5) shows that digestate application and grass/hay production are the largest contributors after the afore-mentioned methane emissions in the biogas CHP exhaust. A small contribution comes from a mix of regional heat sources (mostly natural gas) that is necessary to replace heat from organic wastes in a regional centre. This heat would no longer be available if these wastes are used as substrates for the local biogas plant. In contrast to the climate change score listed in

Table 4, Fig. 5 includes "credits" for the biogas plant's outputs – the energy replaced by electricity and heat from biogas can be counted as large (negative) contributions, with net "negative" emissions.

Table 4 Potential environmental impacts and main contributing processes of biogas production from grass and organic wastes in a 500-kW_{el} biogas plant in an Alpine Austrian municipality

Impact category	Unit	Potential impact per kWh_{el} from biogas [a]	Main contributing Process
Climate change (GWP 100)	kg CO_2-Eq	3.78E-01	Methane slip in CHP exhaust
Freshwater ecotoxicity	kg 1,4-DCB-Eq	5.35E-05	Diesel extraction and refining[b]
Human toxicity	kg 1,4-DCB-Eq	1.98E-02	Cu in construction materials
Particulate matter formation	kg PM10-Eq	2.14E-03	PM emissions, digestate application
Terrestrial acidification	kg SO_2-Eq	4.35E-05	NOx emissions, digestate application
Non-renewable energy resources	MJ-Eq	2.23E+00	Diesel use for hay production

[a] numbers without credits for heat and electricity replaced by the output from the local biogas plant.
[b] Diesel is mainly used here for grass/hay production.

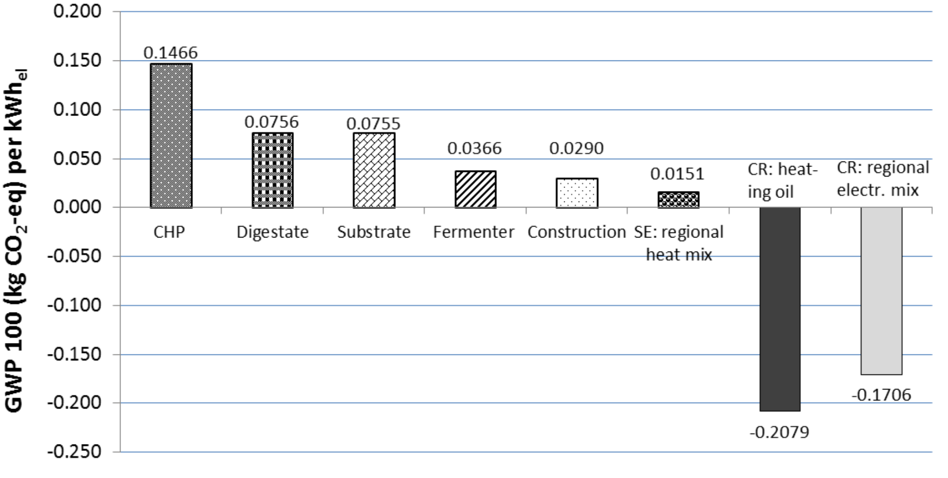

Fig 5 Contribution of individual processes to total climate change impact of producing 1 kWhel from biogas with grass/manure and organic wastes as substrates SE = System expansion process, to account for missing heat that is no longer generated through off-site organic wastes treatment. CR = credits for oil-based residential heaters and regional electricity demand that are displaced by the heat and electricity from the local biogas plant

A clearer picture is obtained by setting up a proper reference system that reflects the status quo of the current management scheme for organic wastes (grassland is not being used at this time, organic wastes shipped to a regional centre). This reference system shows a GWP100 of 0.451 kg CO_2-eq*kWh_{el}^{-1}, in contrast to the local biogas production with a GWP100 of 0.378 kg CO_2-eq*kWh_{el}^{-1} (Saylor et al., 2015).

Discussion of case study hot spots and mitigation options

The analysis of hot spots can point towards options for reducing the environmental impacts of the agricultural systems shown. In case study 1, the clear focus of mitigation efforts for a tractor's life-cycle impacts would be efficiency measures and exhaust controls. Renewable fuels such as biodiesel and vegetable oils may also assist in reducing some of the analysed impact scores. In case study 2, the mitigation measures from case study 1 should also be a focus, was well as low-emission technologies for digestate application as a fertilizer with low-emission technologies and under favourable conditions. Finally, case study 3 demonstrates that agricultural process chains – if seen as part of an agromunicipal infrastructure – may not be the only drivers of environmental impacts for extended systems that reach beyond agricultural systems. Here, results are substantially influenced by what heat sources are replaced by biogas heat. Other biogas systems mitigation measures include well-maintained gas engines and low-emission digestate application, as well as efficient machinery operation (grass harvesting). Overall, these hot spot analyses show that larger systems may retain key hotspots of agricultural subsystems, such as machinery use, but they also may add new ones.

Methodological challenges

Agricultural LCA faces the same methodological issues as other LCA fields (Caffrey and Veal, 2013). However, some questions can become especially important. One of the key determinants of LCA results in general are the – necessarily subjective – choices to be made, particularly the choice of system boundaries. In agricultural process chain LCA, this leads to question such as including or excluding the impacts of the end-of-life of machinery. Thus, modelling tractor disposal has to make assumptions on the prevalence of machine recycling, or it may altogether be neglected. Another agriculture-specific issue with system boundaries is the intersection between animal production and plant production. For example, animal manure as a fertilizer for plant production could come either with a share of the animal production system's impacts or it could be regarded as a waste without any associated environmental impacts. Besides system boundaries, the choice of allocation method for multi-output processes can be critical to the outcome of an agricultural LCA. This affects for example the allocation of steel manufacturing emissions between the subsequent, recurring uses of steel due to recycling. The environmental impacts of crop cultivation may have to be allocated between plant products and plant residues, for example corn and corn stover.

Data availability and data uncertainty is a constant problem in most LCA work, but particularly so in agricultural LCA. Examples for data gaps include a lack of manufacturer-specific data on steel production emissions, as well as detailed data on engine emissions from old tractors that are nevertheless still being used. The unavailability of comprehensive emissions data and load profiles for tractors limited the scope of the first case study to a specific tractor type and to literature data of measured load profiles. Also, in case studies two and three, the prospective impacts of an innovative biogas substrate pretreatment technology could only be coarsely estimated from a few pilot-scale data. As a conceptual issue, regionalized data on the effects of the studied production chains on soil greenhouse gas emissions are scarce because they require long-term measurement results that are largely unavailable. An example would be data on long-term soil emissions due to avoided land-use change from grassland to alpine scrubland. Data uncertainties are of particular concern in the modeling of agricultural process chains and their emissions, in part because of a high variability of emissions from the biological systems – such as N_2O emissions from soils – that are at the center of agricultural production (Gibbons et al. 2006).

Beyond the impact categories discussed in the case studies above, there are environmental problems in agriculture that are not well described by the impact categories commonly used in today's LCA (for example, impacts of maize silage cultivation on biodiversity, soil quality, and water availability; Caffrey and Veal, 2013). Such impacts are beginning to be addressed, but are not yet fully integrated in the available life cycle databases or are just difficult to quantify.

On a broader scale, a modern concept of sustainability combines environmental protection with balanced economic growth and social progress (EU 2012). A comprehensive sustainability assessment of agricultural processes would therefore add economic ("life-cycle costing") and social ("social LCA") considerations (Guinee et al. 2011). These are, however, emerging methods that have yet to become fully established.

CONCLUSIONS

Different process steps/techniques can be identified as main contributors to environmental impacts in the 3 studied cases. However, operating agricultural machinery as efficiently as possible would be a good option to reduce some environmental impacts in all three case studies. In particular, the life-cycle impacts of a mid-sized tractor are dominated by fuel use and resulting emissions during its use phase, but tractor manufacturing and disposal contribute considerably less. When tractors and other machinery are used in the production of an energy or fodder crop such as maize silage, the impacts from operation of agricultural machinery are still important in categories such as climate change and non-renewable energy demand. In other categories however, fertilizer and pesticides applications can dominate the score. At a larger system scale, environmental hot spots grow even more diverse; with the studied Alpine grassland biogas system, net impacts depend critically on the energy system that it replaces.

In general, as the system complexity grows, the potential to reduce environmental impacts critically depends on the chosen system boundaries and allocation procedures. Equally important in establishing a high-quality agricultural process chain LCA is the availability of pertinent data that reflect the variability of agricultural technologies and process chains and an appropriate statistical evaluation of resulting uncertainties.

In summary, life-cycle assessment is established in other disciplines as a key method to quantify the environmental sustainability of products and product systems. For agricultural engineering applications, the three case studies discussed here demonstrate the potential and limitations of LCA as a technique to quantify the specific environmental impacts of agricultural production technologies. This can be done at a variety of scales, despite some methodological challenges. For a consistent methodology and high-quality results, agricultural LCA requires the specific process knowledge of agricultural engineers and the research efforts of agricultural engineering as an established engineering discipline.

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