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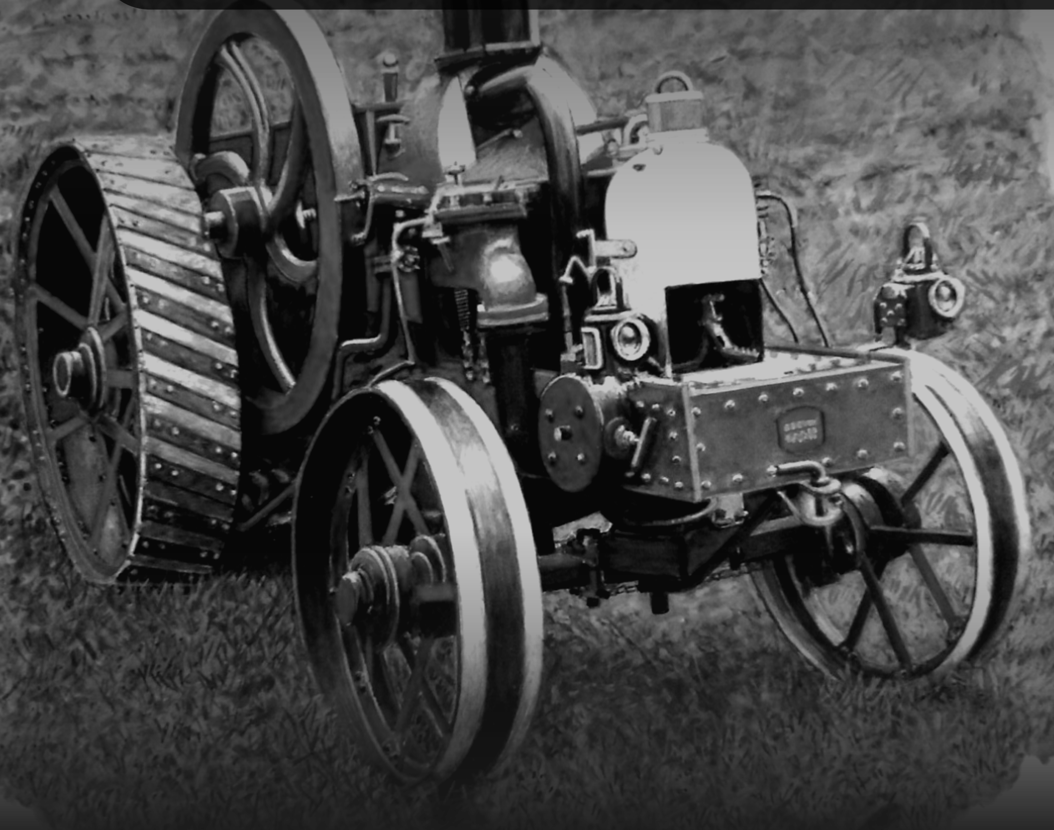

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POLJOPRIVREDNI FAKULTET SVEUČILIŠTA U OSIJEKU
UNIVERZA V MARIBORU FAKULTETA ZA KMETIJSTVO IN BIOSISTEMSKE VEDE
KMETIJSKI INŠTITUT SLOVENIJE
MAĐARSKI INSTITUT ZA POLJOPRIVREDNU TEHNIKU
HRVATSKA UDRUGA ZA POLJOPRIVREDNU TEHNIKU

# AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

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# PRIČA O TRAKTORU S NASLOVNICE

## Hornsby-Akroydov traktor

U posljednjem desetljeću devetnaestog stoljeća, iznimno plodnom u području znanosti i tehnologije, nastao je traktor koji predstavlja prekretnicu u razvoju traktora. Hornsby-Akroydov traktor bio je prvi traktor s motorom s užarenom glavom, a smatra se da je bio i prvo vozilo na svijetu s kompresijskim paljenjem goriva u motoru.

Zanimljivo je da se u stručnoj literaturi kao prvi proizvođač traktora s motorom s užarenom glavom u svijetu uobičajeno navodi tvrtka Lanz iz Njemačke. No, istina je nešto drukčija, švedska tvrtka J. V. Svensons Motorfabrik započela je proizvodnju motornog pluga s motorom s užarenom glavom 1912. godine i proizvodili su ga do 1925. Još jedna švedska tvrtka, Munktells Mekaniska Värkstads, započela je proizvodnju traktora s motorom s užarenom glavom 1913. godine. Masovnu ugradnju motora s užarenom glavom u traktore pokrenula je njemačka tvrtka Lanz (od 1921. do 1957. proizveli su više od 150 000 takvih traktora). Tijekom tog razdoblja, pod njihovim utjecajem, i mnogi su drugi proizvođači traktora ugrađivali ovaj tip motora (različiti proizvođači iz Italije, Francuske, Mađarske, Njemačke, Australije, Južne Amerike).

Kada detaljnije proučimo povijesni razvoj traktora, nalazimo da je povijest traktora s motorom s užarenom glavom još starija. Tvrtka Richard Hornsby & Sons iz Velike Britanije (poznata i po stacionarnim parim strojevima i lokomobilima) već je 1896. proizvela traktor poznat kao Hornsby Akroyd Patent Safety Oil Traction Engine (Hornsby-Akroydov patentirani sigurnosni vučni motor na ulje). Hornsby Akroyd Patent Safety Oil Traction Engine je također prvi britanski traktor. Nastao je oko stacionarnog jednocilindričnog motora s užarenom glavom snage 20 KS. Na sličan način proizveli su čak i jednu malu lokomotivu, tako da se za njihov traktor može reći da je bio prvo cestovno vozilo na svijetu opremljeno motorom s kompresijskim paljenjem, a lokomotiva prvo pružno vozila u svijetu s takvim motorom.

Stacionarni motor s užarenom glavom isprva je konstruiran u Velikoj Britaniji 1892. godine u spomenutoj tvornici koja je proizvela Hornsby-Akroydov traktor. Motor s užarenom glavom izumio je Herbert Akroyd Stuart, koji je prototip motora konstruirao već 1886., a 1890. ga je patentirao. Kasnije su Akroyd Stuartov motor usavršili Mieze i Weiss u SAD kombinirajući ga s dvotaktnim motorom, kojeg je razvio Joseph Day. Jedan traktor bio je prodan u Velikoj Britaniji, a tri u Australiji (od kojih jedan još uvijek postoji). Kasnije je jedan traktor proizveden 1896. i nadograđen gusjenicama.

Hornsby-Akroydov traktor nije prvi u potpunosti funkcionalni traktor na svijetu, ali je važan jer je to prvi traktor u svijetu s kompresijskim paljenjem (danas gotovo svi traktori imaju motore s kompresijskim paljenjem). Također je važno napomenuti da je Akroydov izum u proizvodnji bio dvije godine prije Dieselovog motora. Tvrtka Richards Hornsby & Sons po tom konceptu je proizvela čak 32.417 motora za pogon različitih stacionarnih strojeva. Prema nekim stručnjacima, originalnost Dieseloveg izuma motora s kompresijskim paljenjem je samo u višem kompresijskom omjeru u odnosu na Akroyd Stuartov motor. Današnji dizelski motor objedinjuje koncept izravnog ubrizgavanja goriva i kompresijskog paljenja (predstavljen u Akroyd Stuart - Binney patentu).

Povjesničari iz oblasti traktorske tehnike slažu se da je s Froelichovim traktorom 1892. godine u SAD uspješno započela povijest traktora. U to vrijeme, John Froelich iz Iowe, ugrađuje stacionarni benzinski motor proizveden u Van Duzen Gas and Gasoline Engine Co. na zupčaničku transmisiju i podvozje traktora vlastite izvedbe. Froelichov traktor s benzinskim motorom upisao se u povijest kao prvi traktor s, u to vrijeme, dobrim tehničkim karakteristikama i pouzdanošću. Međutim, benzinski motor na Fröelichovom traktoru imao je nižu iskoristivost u usporedbi s motorima s kompresijskim paljenjem. Traktori s benzinskim motorima u Europi su napušteni vrlo rano, dok su u SAD bili u upotrebi do šezdesetih godina prošlog stoljeća.

Hornsby-Akroydov traktor prikazan na slici dizajnom je sličan parnim vršnjacima iz tog razdoblja (lokomobilima). Vidljivo je da je tehnologija lokomobila u značajnoj mjeri utjecala na koncepciju traktora s motorom s unutarnjim izgaranjem. Na prednjem dijelu traktora ističe se ispušna cijevna mjestu gdje se na lokomobilu nalazi odimnjak, bočno se nalazi zamašnjak motora, a stražnji i prednji kotači slični su kotačima lokomobila. Sličnosti su uočljive čak i na svjetlima i prostoru za vozača. Razlika je vidljiva sprijeda gdje se nalazi metalna zaštita užarene glave. Prije pokretanja motora bilo je potrebno prijenosnim plamenikom zagrijati užarenu glavu–prostor za sagorijevanje u prednjem dijelu motora. Po završenom zagrijavanju vozač je mogao pokrenuti motor.

Zanimljivo je napomenuti da su jednom Hornsby-Akroydovom traktoru kotače zamijenili gusjenicama. Navedenu izvedbu traktora predstavili su britanskoj vojsci, koja međutim nije pokazala interes. Kasnije je tvrtka Hornsby & Sons taj gusjeničar prodala tvrtki Holt u SAD, koja ga je uspješno promovirala (od Holta je nastao Caterpillar) i prije Prvog svjetskog rata počela prodavati u SAD i Europi (u Europi su ispočetka bili u vojnoj primjeni). Motori s užarenom glavom bili su upotrebi, osim na traktorima, i u različitim radnim strojevima (primjerice valjci za ceste), u energetici, industriji i raznim plovilima. Na brodovima su ušli u upotrebu početkom prošlog stoljeća u Švedskoj. Proizvodilo ih je nekoliko različitih proizvođača, primjerice tvrtka Bolinder je proizvodila jedno-, dvo- i četiri-cilindarski motor s užarenom glavom snage od 7 KS do 600 KS. Na brodovima (uglavnom ribarskim) bili su rašireni u svim skandinavskim zemljama do početka šezdesetih godina prošlog stoljeća kada su ih počeli istiskivati moderniji četverotaktni dizel motori.

Tekst: Viktor Jejčič

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Dear colleagues and readers,

Second, genuine electronic issue of Proceedings "Actual Tasks on Agricultural Engineering" will be available at this web site: https://atae.agr.hr. on 30th of March 2014. This 42nd Proceedings contains 46 papers among them are: Czech Republic, Italy, Germany and Ukraina with (1); Estonia with (2); Slovenia and Serbia with (7), Croatia with (8) and Romania with (19) papers. Organiser is grateful to all authors, sponsors and attendees for their continuous professional and colleagues' support. We wish all participants, our colleagues, pleasant time, weather and company during symposium.

Chief Editor

Prof. dr. sc. Silvio Košutić

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42. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

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# MODELING JET FLOW IN SPRINKLER IRRIGATION SYSTEMS: CLASSICAL AND BOHMIAN WATER DROPLET TRAJECTORIES

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**ABSTRACT**

*The design of a sprinkler irrigation system is always associated with a full understanding of the kinematics of the droplets during their aerial path. Resolving this problem involves both theoretical and experimental considerations. Among the theoretical studies the classical mechanical approach, based on the Newton's law, offers a useful tool to describe the trajectories of water droplets from the sprinkler nozzle to the ground. 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 repulsion, mainly due to electrical interactions between the hydrogen and the oxygen atoms of the different water molecules. An alternative to traditional classical procedures, to analyze water droplet dynamics in sprinkler irrigation, has been recently proposed in the form of a quantum approach. In this context , the whole classic-quantum and single-droplet versus multi-droplet alternatives need to be discussed and pinpointed and these are 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. On the whole, the new approach leads to the concept of Bohmian trajectory, in analogy to the well-established concept of classical trajectory, and allows recasting the classical fluid dynamic equations into the so-called quantum equations.*

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

## 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 modeling 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 modeling 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 (Edling, 1985; Keller & Bliesner, 1990; Kincaid & Longley, 1989; Kinzer & Gunn, 1951; 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 (De Wrachien & Lorenzini, 2006; Lorenzini, 2004; 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 (TDSE) 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 behavior of both single- and multi-droplet systems during their aerial path in according to both the classic (i.e. Newtonian) and quantum approach. Moreover, a new procedure, the so-called Density Functional Theory for many-particle systems, has been highlighted, that allows to design a common 3-D space for the assessment of both the droplet trajectories and their interactions, and, so, to recast the TDSE into the quantum fluid-dynamic (continuity and Navier-Stokes) equations (Gosh, 2011).

The basic picture that emerges is that of a multi-component fluid mixture moving into a 3-D space under the effects of common electric and magnetic fields and classic and quantum potentials.

## THE CLASSIC MECHANICAL PICTURE

We do not wish to review the whole classic approach, as reported in the literature, but to explore the modeling 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 & 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 et al.,1990; Teske et al., 1998a,b; Teske & Ice, 2002), while spray drift Lagrangian modeling is treated in Hewitt et al. (2002), and in Bird et al. (2002). Recently the Authors_(Lorenzini, 2004; De Wrachien & Lorenzini, 2006; Lorenzini, 2006) defined and validated (see also: Edling, 1985, and 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:

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

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

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

$$\dot{y}(t) = -\sqrt{\frac{ng}{k}}\tan\left[-\frac{\sqrt{ngk}}{m}t + \arctan\left(\sqrt{\frac{k}{ng}}v_{0y}\right)\right] \tag{2}$$

being: $f$ the friction factor according to Fanning (Bird et al., 1960); $g$ gravity; $h$ [m] the initial $y$ co-ordinate; $k=\frac{f\rho A}{2}$ 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 $m_k$ ($1 \le k \le N$) 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 $\nabla_k$ is the 3-D gradient operator referred to the $k$-th particle.

On the basis of a comparative approach the model here defined proves to be reliable in its predictions from both a qualitative and quantitative points of view, particularly when droplets having a “not too small diameter” are considered (Lorenzini, 2004). What is relevant in such an approach is that, being fully analytical, its results can be applied to any particular system and process configuration which may occur, provided that the conditions for which the equations have been written are respected.

## 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):

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

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

where: $F$ is force, $m$ particle mass, $V_{qu}^{\psi_t} = -\sum_{j=1}^{N} \frac{\hbar^2}{2m_j} \frac{\nabla_j^2 |\psi|}{|\psi|}$ ($1 \leq j < k \leq N$) 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 TDSE 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):

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

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

($\rho$ 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):

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

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 TDSE, 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 TDSE 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 (Gosh, 2011):

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

being $V\left(\overrightarrow{x^N},t\right)$ the electric potential, $\phi(\vec{x_j},t)$ 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:

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

and the Euler-type equation:

$$\frac{\partial\vec{v_k}\left(\overrightarrow{x^N},t\right)}{\partial t} + \sum_j\left(\vec{v_j}\left(\overrightarrow{x^N},t\right)\nabla_k\right)\vec{v_j}\left(\overrightarrow{x^N},t\right) + \sum_j(1-\delta_{jk})\vec{v_j}\left(\overrightarrow{x^N},t\right)\times (\nabla_k\times)\vec{v_j}\left(\overrightarrow{x^N},t\right) = -\left(e\vec{E}(\vec{x_k},t) + \frac{e}{c}\vec{v_k}\left(\overrightarrow{x^N},t\right)\times\vec{B}(\vec{x_k},t)\right) - \frac{1}{m}\nabla\left[V_0\left(\overrightarrow{x^N},t\right) + U\left(\overrightarrow{x^N},t\right) + Q\left(\overrightarrow{x^N},t\right)\right] \tag{16}$$

$\nabla_k$ is the gradient operator related to the coordinate $\vec{x_k}$ 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;

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

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

The first integrations of equations (15) and (16) were carried out by Madelung (Madelung, 1926), and the work was successively extended by Bohm (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 (Gosh, 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:

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

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

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

and:

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

The quantum potential can be expressed as:

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

which is trajectory dependent.

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

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

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

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

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 (Gosh, 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 characterized 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 follow 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 mesh less 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). Obviously it would not be inconceivable to imagine a mixed numerical-dynamical approximation approach and we feel that on this aspect research will invest a part of its future resources: 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 take 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, characterized 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 modeling approach suggested to make it more and more suitable for practical applications.

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# A VIEW ON LAND DEGRADATION AND DESERTIFICATION ISSUES

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## ABSTRACT

*Land degradation and desertification are important global issues in the third millennium. While land degradation is world-wide spread, desertification is referring only to degradation of drylands. In a world with more than 7 billion people and a limited pedosphere there is great need to restore existing despoiled drylands and to combat increasing desertification.*

*Actual statistics are presenting alarming values. 25% of Europe and 40% of the world lands are drylands. 30% of semiarid Mediterranean drylands are affected by desertification and more than 30% of the region's population suffers from severe degradation.*

*Even if exists a lot of information about the issues that have lead to the loss of land quality and desertification, this information is dispersed, diffuse and largely unavailable to users. This paper will try to conclude on some points but without admitting that will offer the best picture for understanding land degradation and desertification issues*

***Key words**: land degradation, desertification, drylands*

## INTRODUCTION

During the last decades, the scientific community in special and the humanity in general agreed that topics like land degradation and desertification are "hot" topics and they are surrounded by many, again, hot questions.

Perhaps the most 5 important questions (which were raised by Stafford Smith & Reynolds in 2002) on these two concepts are the following [1]:

- Which are the causes and the consequences of land degradation?
- Which is the border between natural land changes and anthropogenic land changes?
- The observed changes are reversible or not?

- Which is the amount of land affected or at risk?
- Which is the role and success of various abatement efforts?
- In addition to these questions, Ellis et all (2002) raised another 3 questions [2]:
- The deserts are expanding?
- Which is the extension of this phenomenon?
- What are the causes (natural or anthropogenic)?
- Then what is land degradation? What is desertification? How we should make the difference between them? One option may be to differentiate them using two terms: time and value, both of them being strongly linked to land degradation and land restoration.

## LAND DEGRADATION

First of all we must understand the difference between soil and land. Soil represents the layer of material which covers the land (part of the world uncovered by water). The land is a complex ecosystem comprising beside soil and vegetation, biota as well as eco-hydrological processes operating within the system [3]. In this way, when we discuss about land degradation we must consider the loss of lands productivity and delivery of services.

Using as base two important international documents, UNCCD land definition from 1986 as well as the conceptual framework of Millennium Ecosystem Assessment, land as concept can be reduced to “terrestrial ecosystem”, in this way, land degradation being a “reduction or loss of ecosystem services, notably the primary production services” [4]. In addition, Blaikie and Brookfield (1987) consider that land degradation has validity only in the social context of benefits for humanity which results from ecosystems using by people [5].

Wasson (1987) defines land degradation as being “a change to land that makes it less useful for human beings” [6]. Kimpe and Warkentin (1988) consider that “land degradation is a decrease in the optimum functioning of soil in the ecosystems” [7].

A 'classic-type' definition of land degradation was by Arntzen & Veenendaal in 1986 stating that land degradation comprises "all processes which cause bush encroachment, soil erosion and ultimately result in desertification". In this case, desertification refers to "land degradation which is difficult and/or costly to reverse". [8]

Warren & Agnew (1988) use changes in productivity as one of the main factors in defining land degradation while Ponzi (1993) stresses that present changes in productivity must be distinguished from changes in long-term production potential. [9, 10]

The definition of Abel and Blaikie (1989) has a more general meaning: [land degradation can understand it as an effectively permanent decline in the rate at which the land yields livestock products under a given system of management. 'Effectively' means that natural processes will not rehabilitate the land within a time-scale relevant to humans, and that capital or labour invested in rehabilitation are not justified. [...] This definition of degradation excludes reversible vegetation changes even if these lead to temporary declines in secondary productivity. It includes effectively irreversible changes in both soils and vegetation”. [11]

Arntzen (1990) consider that reserving the term degradation for ecologically irreversible changes it becomes too narrow and he propose a more inclusive definition which states that "man-induced decreases in productivity are considered rangeland degradation when they have a lasting impact on rangeland productivity". [12]

The role played by economics was emphasize especially by Warren & Agnew (1988) and Biot (1991), the last one defining land degradation as „an environmental process which occurs when the ability of the land to produce the goods and/or services people demand from it is found to be declining. [...] what matters in the case of land degradation is not the reduction in soil depth or the increase in salinity, the reduction in organic matter or surface sealing, but its impact on the ability of the soil to generate 'well-being' through the range of goods and services this land produces. Economics is a fundamental part of any definition of and deliberation about land degradation.” [9, 13]

GLASOD (Oldeman et all, 1991) consider land degradation as being a state, a situation when land lost its function, or its productivity is reduced. The main feature of land degradation – agreed by most of the researchers – diminishing land productivity. We discuss here about “an action” which may take us to a preliminary conclusion: land degradation is not a state but a process. [14]

Land degradation is certainly a state if we analyse not the processes leading to a situation but the final state of the land. A clearly difference must be made between degradation (reversible/temporary situation) and desertification (which is a result and in almost all cases is irreversible). Going further, if we will analyze deeper the meaning of „degradation”, we will see that degradation is not meaning „removing” but „not having” or „acting in opposite to”. In this way, land degradation will not mean the loss or decreasing some of its qualities but a land without necessary (requested) qualities or with qualities which are not in concordance with the expectances from this land.

A better option will be to use the expression of land declassing instead of land degradation. Land declassing can be defined as a lowering of land services delivering due to some causes, factures and pressures (natural of human induces).

A very interesting analysis of what „degradation” means is given in the work „Patterns of Land Degradation in Drylands”. When we analyse the state of land degradation, we will measure its physical and biological properties and not its inherent or potential utility. „Degradation” can be „measured” only with respect to a known use (past, present or future). [15]

Land degradation as is understands it today can be natural or human induced. Looking at the previous paragraphs, land degradation due to natural causes can be expressed as land declassing while land degradation due to human causes (and considering that we are leaving in a world dominated by selfish financial purposes) can be understand as land despoiling.

Which is the genesis of land degradation? According to a study realized in 2009 for the European Parliament, there are at least 5 macro-pressures driving land management changes [16]:

- Demography
- Economy;
- Policy;
- Technology;
- Climate changes.

According to Lal R., land degradation implies replacement of climax vegetation with secondary vegetation, alteration of humus quantity and composition and adverse changes in soil quality and related ecosystem services. In contrast to land degradation, soil degradation is caused by natural and anthropogenic perturbations in the hydrological cycle, nutrient cycling, energy budget and activity and species diversity of soil biota. [17]

A common conceptual framework for land degradation (using actual terminology) can be represented as it follows:

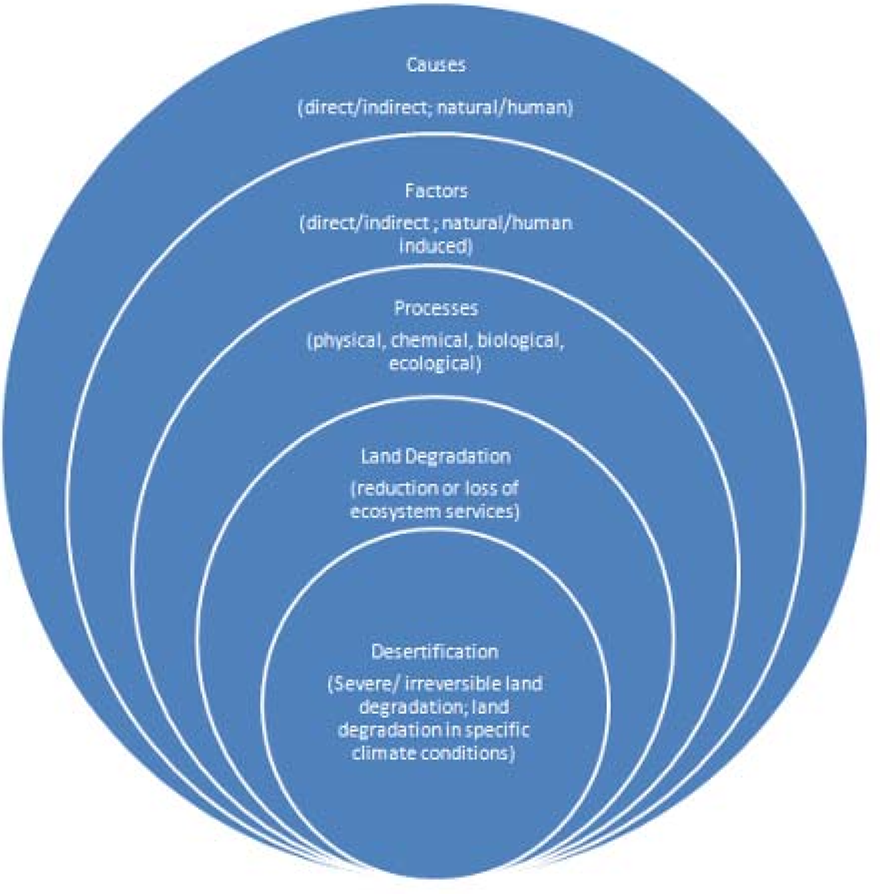


**Figure 1** Conceptual framework for Land Degradation Study

## DESERTIFICATION

Desertification is the most severe form of land degradation – the wasteland. Desertification doesn't mean that land is turn to desert because typical desert land forms in the geomorphic sense do not usually form in sub-humid or semi-arid zones due to land degradation.

Historical evidence during the last few centuries shows three main epicentres of desertification: the Mediterranean region, Mesopotamia and the loessial plateau of China, with serious and extensive land deterioration [18].

If we are going to analyze the word „desertification" from etymological point of view, we can conclude the following:

- The word is derived from Latin language
- The word "desert" has a twofold origin. On the one hand we have the adjective "desertus" meaning uninhabited and on the other hand we have the noun desertum meaning a desert area
- We have the also the verb "fication" meaning an act of doing [19].
- What desertification means? Where and how we should use it?

Lavauden is credited to having used the word desertification in a paper in 1927. He said „'throughout the whole Sahara – I dare to say – desertification is fully artificial: uniquely man-made'[20].

The concept of desertification was first introduced in the scientific literature by Aubreville in 1949. Aubreville described desertification as the changing of productive land into a desert as a result of ruination of land by man-induced soil erosion in the humid and sub-humid tropics where he worked. The following, many times contradictory, meanings were partially reviewed by Verstraete in 1986. [21, 22]

Who we should blame? First of all maybe we should take a look back in the history. Ancient writers were aware about the influence of humans on landscape degradation. Some clues can be found in the Bible, Jeremiah 12:10-11: "Many shepherds will ruin my vineyard and trample down my field; they will turn my pleasant field into a desolate desert. It will be made a wasteland, parched and desolate before me; the whole land will be laid because there is no one who cares". Even from that times, a definition of desertification included economical aspects (in this case references to a vineyard).

Columella, in his great work De Re Rustica, emphasizes human's carelessness on natural factors leading to agricultural degradation. In the first century, it was estimated that our world had a population of about 200 millions while now we are more than 7 billions . Using this comparision can be desertification considered as an entirely humans fault? Hardly to say in our days but probably no. Geologists, geographers and paleoclimatologists are all aware that deserts known expansion and contractions in the past due to natural causes. But what is natural now? Still, we can't consider desertification strictly literally. We didn't create and probably that, only humanity, will not be able to create typical desert land forms in the geomorphic sense.

In 1924, Huntington view the land degradation in the Mediterranean area as a result of adverse climatic changes (hypothesis of climatic determinism). 20 years later, Lowdermilk emphasized the human factor as a cause for desertification: “By neglect, ignorance and suicidal agriculture, peoples have bequeathed to their descendants “man-made deserts” of sterile, rocky and gullied lands”. [23, 24]

In 1976, Meckelein identified 5 components which can define desertification [25]:

- climate
- hydrological processes
- morphodynamic processes
- soil dynamics;
- vegetation dynamics.

Glantz (1977) consider that exists more than 100 definitions for desertification, this number proving the complexity of this problem. None of these definitions includes all of the desertification study directions (causes, mechanisms, manifestations, impact) [26].

There is a common point in all these definitions: desertification is an adverse environmental process. It was developed an entire list with negative descriptors of desertification:

- deterioration of ecosystems [27];
- degradation of various forms of vegetation [28];
- destruction of biological potential [29];
- decay of a productive ecosystem [30];
- reduction of productivity [31];
- decrease of biological productivity [32];
- alteration in the biomass [33];
- intensification of desert conditions [34, 35];
- impoverishment of the ecosystem [18].

Nelson (1988) states that „desertification is a process of sustained land (soil and vegetation) degradation in arid, semi-arid and dry sub-humid areas, caused at least partly by man” and which „reduces productive potential to an extent which can neither be readily reversed by removing the cause nor easily reclaimed without substantial investment”. [36]

Soule (1991) and Reynolds (2001) state that desertification principally consists of three major components [37, 38]:

- Meteorological (drought, atmospheric dust, air temperature, elevated atmospheric $CO_2$, variability of precipitation)
- Ecological (nutrient cycling, plant growth, regeneration, mortality, microbial dynamics, plant cover, herbivore life cycles, evapotranspiration)
- Human dimension (loss of habitat, fragmentation of habitat, overexploitation, spread of exotic organisms, air, soil and water pollution, climate change).

In a much more complex approach, desertification should also include in its definition and other concepts as land capability, land sustainability, vulnerability, resilience and carrying capacity [39].

In 2002, Prince gave the following definition for desertification: “Desertification refers to the process by which changed biogeophysical conditions emerge owing to human actions that cannot be supported by the resource base (mainly rainfall) and that will not quickly return to their former, non-desertified conditions, either naturally or by application of minor management practices”. [40]

The definition proposed in this paper has the following form: Desertification is the process by which emerge unsustainable biogeophysical conditions due to human actions supported by a water scarcity climatic factor, conditions that will not quickly return to their non-desertified form, either naturally or by application of an integrated management based on sustainable land reclamation practices.

## CONCLUSIONS

On a planet with more than 7 billion people land and soil health are more than essential in order to cover the necessary quantities of food. Meanwhile we need to sustain land and soil health in order to be able to response properly at the climatic changes and to maintain the so much necessary hydrological flows.

Land degradation is a very complex system involving different types of interactions and links between processes, generated by causes and affected by factors. If we want to reduce the extent of land degradation, scientifically robust and accurate information is needed for a consistent monitoring, for establishing priorities in land restoration and for adopting appropriate solutions. For a better understanding of desertification we must continue our researches on the links between social and economic factors, we must better understand the factors affecting the ecosystem services and we must involve all the stakeholders bridging together the people with know-why and those with know-how.

There will be a continuous need to develop new specific solutions for land degradation, tailored measures for land restoration. We will have to better understand the land’s value to society considering the continuous demand for new lands.

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# CHANGES IN AGRICULTURAL WATER DEMANDS FOR WESTERN ROMANIA

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## ABSTRACT

*The changes in Earth's global climate show a trend of increasing average air temperature and causing drastic changes in hydrologic cycle. As a result, the vegetation period is expected to become shorter and an even more irregular distribution of precipitation will occur, both from year to year. Essentially, the periods of semi-drought or even drought conditions are going to become more frequent.*

*In Romania, the problem of drought was confirmed from many years and the impacts on agriculture are more than obvious. More than 2.8 million hectares of agricultural fields presents a tendency of land degradation at different levels.*

*Timiş County, situated in the western part of Romania, knew several transition periods, from humidity excess to humidity deficit (because of a long period with intensive drainage) returning to a period with normal precipitation volumes. The lack of humidity in soils was more evident in the north-western part of this county, around Sannicolaul Mare area.*

*This paper presents an analysis of water demands for agricultural areas from western part of Romania using a comparison between 2000 and 2010 and with the help of some computer programs.*

**Key words**: *water demands, humidity excess, humidity deficit, Timis County*

## INTRODUCTION

The analyzed area covers the Aranca River's hydrographic basin, a plain area having a slope around 0.30 ‰, meaning that the plain is almost horizontal. Aranca Plain is low subsidence plain of meadow with microform beds and abandoned meanders, surface drainage channels, fluvial and anthropogenic mounds. Climate falls under temperate continental climate with mild winters and significant amounts of rainfall. The summer is defined by unstable weather with showers and thunderstorms. The hydrography of the analyzed area is the result of the combined action of climatic factors, morphology and geology. The region Aranca groundwater contributes to excess soil water, but only up to a depth of 2 m; starting from a 2.3 m depth, the groundwater has no influence on soil, but contributes to his water supply during drought. The channel water supply is from precipitation, groundwater springs and fountains of waters. In terms of soils, we can find in this large surfaces area with Chernozem, Fluvisols, Vertisols and Pelosols [1, 2].

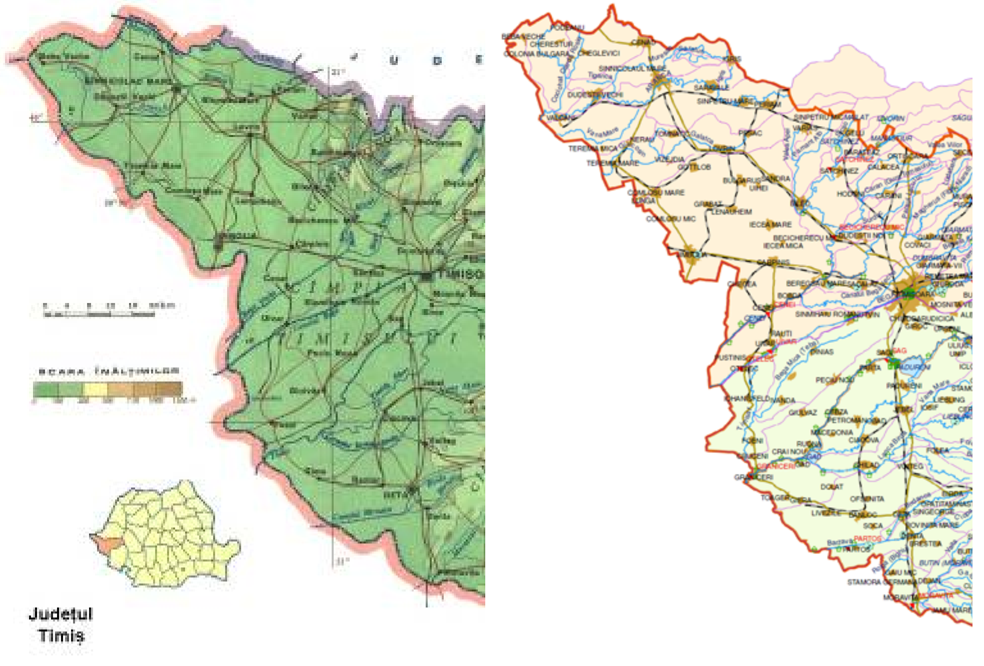


**Figure 1** Studied area

## DROUGHT AND ARIDITY IN WESTERN ROMANIA

Water demands in agriculture are strongly linked with the climate in general and with precipitations and temperatures in special. Water scarcity as well as water excess phenomenon often occurred in western part of Romania. If in the case of water excess phenomenon there are unanimously agreed definitions we can’t affirm the same thing for water scarcity. Drought, aridity, dryness, water scarcity, water shortage, desertification are only a part of the terms which created very interesting debated among the experts. The lack of single agreed definitions conducted to confusions and to wrong interpretations and approaches in this field.

Drought is perhaps the most difficult event to be defined from the category of water scarcity events. Lack of water was defined, using a matrix, in 1982 by Vlachos [3]. But the world has changed. 30 years later we improved this matrix which has reached now this new form. In this matrix, perhaps the most discussed phenomenon is drought. Drought was debated by many valuable researchers (as Wilhite, Palfay etc.) but it was never defined in manner acceptable for all situations and by all scientists. We know about drought that it is a creeping protracted phenomenon. It is not a distinctive event and in most of the cases without recognizable beginning and end [4]. When we discuss about drought we should have in mind 2 key terms: “demand” and “supply”. Using these words, we can create the simplest definition of drought: Drought is a situation when water supply is insufficient to meet the demand.

**Table 1** Typology of water scarcity proposed by Halbac C.Z. R. (2013)

| Typology of water scarcity | | Time scale | | |
|---|---|---|---|---|
| | | Short term | Medium term | Long and very long term (even permanent) |
| Causes | Natural | dryness | drought | Aridity |
| | Man-made | Water shortage | Water stress | Water crisis |

Following the definition from Encyclopedia of World Climatology we will observe that aridity is referring to the dryness of the atmosphere and can be defined as a function of a continuum of environmental factors as temperature, precipitation, evaporation, low vegetative cover etc. In order to quantify aridity for a specific area we must take into account at least three main factors: precipitation, temperature and evaporation. Nowadays aridity is quantified by using more than 50 indexes. We must have in mind that aridity indexes are generally considered from the standpoint of their eventual use [5].

The author proposes an indicator for natural water scarcity analysis which uses precipitation, temperature, potential evapotranspiration and the index of dry days. A dry day it was defined by M. Nedealcov as being a day when relative humidity is below 30% and temperature is higher than $25^0$C [6]. This index is proposed to be used for the period between April and September and was tested for Sinnicolau Mare area with good results.

$$WSCI = \frac{P^2}{ETP(T+10)} I_{DD}$$

$I_{DD}$ has the following values according to the number of dry days in a month:

**Table 2** Values proposed for $I_{DD}$

| No. of dry days in a month | $I_{DD}$ |
|---|---|
| 25 … 30 days | 0.25 |
| 20 … 25 days | 0.5 |
| 15 … 20 days | 0.75 |
| Less than 15 days | 1 |

Using WSCI we can analyze a month from dryness point of view:

**Table 3** Months analysis using WSCI indicator

| WSCI values | Type of month |
|---|---|
| <0.25 | Very dry month (VD) |
| 0.25 – 1.25 | Dry month (D) |
| 1.25 – 2.5 | Normal (N) |
| > 2.5 | Humid (H) |

We used this indicator for two years (2000 and 2010) to determine the month's dryness for the period between April and September.

**Table 4** Analysis of months from 2000 and 2010, Sinnicolaul Mare area, using WSCI index

| Year | April | May | June | July | August | September |
|---|---|---|---|---|---|---|
| 2000 | 0,60727 | 0,075689 | 0,527569 | 0,177597 | 0,080127 | 0,297377 |
| | D | VD | D | VD | VD | D |
| 2010 | 1,555486 | 7,278833 | 1,444658 | 0,150058 | 2,562077 | 2,487074 |
| | N | H | N | VD | H | N |

The values presented above are comparable with the results obtained with consecrated methods. Nevertheless, this indicator still needs further calibrations for more accurately climate analysis.

## DRY PERIOD INDEX AND PINNA COMBINATIVE INDEX

Dry period index is based on the relation between dry days sum registered in a specific year and the multiannual average for the analyzed period.

The Index of dry periods ($I_{zu}$), which represents a relation (1) between the numbers of dry days registered during years in study ($NDD_{V\text{-}VIII}$) and these years' multiyear average ($MYA_{V\text{-}VIII}$) allows determining aridization degree of dry days' periods by its value's increase. Dry days are considered those days which are characterized by air's temperature T higher than $25^0$C and decrease in air's relative humidity (U<30%).

$$I_{zu} = \frac{\sum NDD_{V-VIII}}{MYA_{V-VIII}} \qquad (1)$$

**Table 5** Characterization of Izu values proposed by Nedealcov M. [3]

| $I_{zu}$ values | Characterization |
|---|---|
| 0.1 – 1 | Normal period |
| 1.1 – 2 | Moderate dry period |
| 2.1 – 3 | Significant dry period |
| 3.1 – 4 | Dangerous dry period |
| > 4 | Exceptional dry period |

Pinna combinative index (2) is used to classify the climate in tropical and subtropical regions in Southern Europe and takes into account the annual mean temperature and precipitation as well as the precipitation and air temperature of the driest month [7].

$$I_P = \frac{1}{2}\left(\frac{P}{T+10} + \frac{12P_d^{'}}{T_d^{'}+10}\right) \tag{2}$$

where P and T are the annual mean values of precipitation and air temperature and $P'_d$ and $T'_d$ are the mean values of precipitation and air temperature of the driest month.

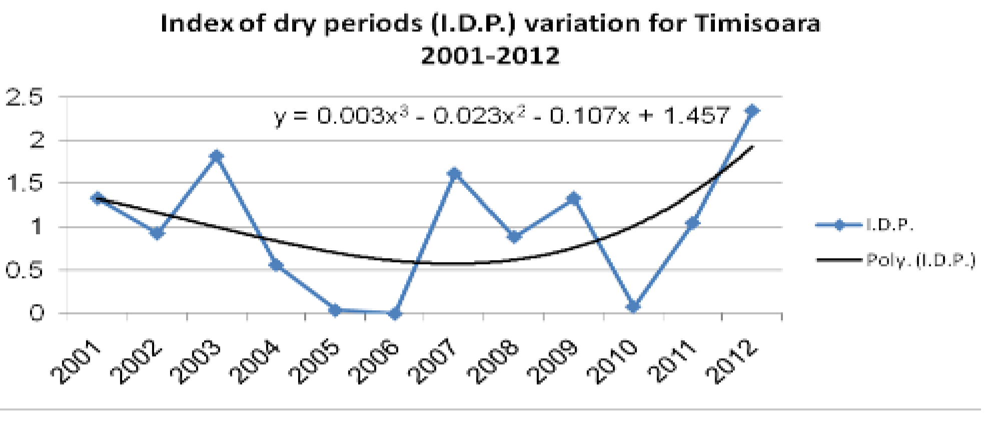


**Figure 2** Index of dry periods variation for Timisoara (2001-2012)

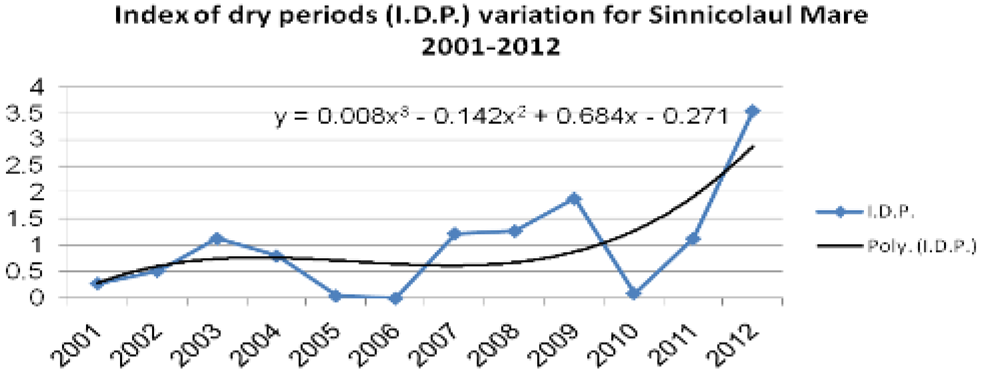


**Figure 3** Index of dry periods for Sinnicolaul Mare area (2001-2012)

If the $I_P$ has values smaller than 10, we have a dry climate. The values between 10 and 20 indicate a semi-dry Mediterranean with formal Mediterranean vegetation. For values above 20, Pinna doesn't offer any kind of classification.

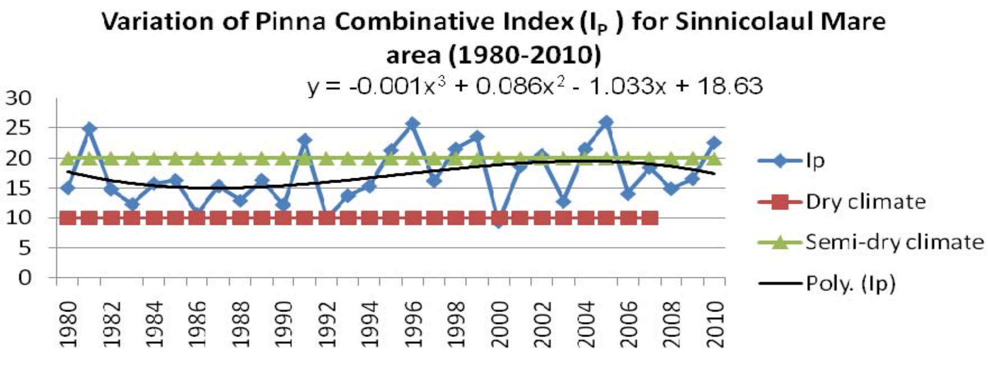


**Figure 4** Variation of Pinna Combinative Index for Sinnicolaul Mare (1980-2010)

We can observe from equation 2 that this index is based on De Martonne index formulas, being computed using annual De Martonne index and monthly De Martonne index with the mention that, for the last report, instead of using monthly values, Pinna proposed to be used the precipitation and temperature for the driest month in a year without defining a dry month. According to Gaussen, a dry month is defined by $P< 2T$ where $P$ and $T$ are the monthly mean values of precipitation (mm) and air temperature (°C). Due to the importance of air humidity in analyzing biological drought, Gaussen provide more additional characteristics of a dry month. He characterizes a month as dry if the following conditions are fulfilled [8]:

a. P < 10 mm and the mean monthly value of temperature is less than $10^0$C;

b. P < 25 mm and the mean monthly value of temperature vary between 10 and 20°C;

c. P < 50 mm and the mean monthly value of temperature vary between 20 and 30°C;

d. P < 75 mm and the mean monthly value of temperature are greater than 30°C.

We have seen in the previous paragraph that M. Nedealcov considers as dry days those days which have an air's temperature T higher than 25$^0$C and air's relative humidity U lower than 30%.

## DROUGHT STUDY OF SANNICOLAUL MARE AREA USING SPI AMD RDI INDEXES

The Standardized Precipitation Index (SPI) was developed for the definition and monitoring of drought and is based on the long-term precipitation record during a period of time. The SPI is an index based on the probability of recording a given amount of precipitation, and the probabilities are standardized so that an index of zero indicates the median precipitation amount [9, 10].

The Reconnaissance Drought Index (RDI) is based both on the precipitation and on the potential evapotranspiration. RDI can be estimated for any period of time from one month to one year which allows an effective linkage of the RDI with the expected rainfed crop production and therefore with the anticipated losses in the agricultural sector due to the occurrence of drought. There are some advantages of RDI in comparison with SPI (it has a physical meaning, it can be estimated for any period of time, the estimated value is comprehensible etc.) and it can be directly linked to the climatic conditions of the region. RDI can be used for also climate instability conditions and to examine the effect of various changes of climatic factors on drought and desertification [9, 10].

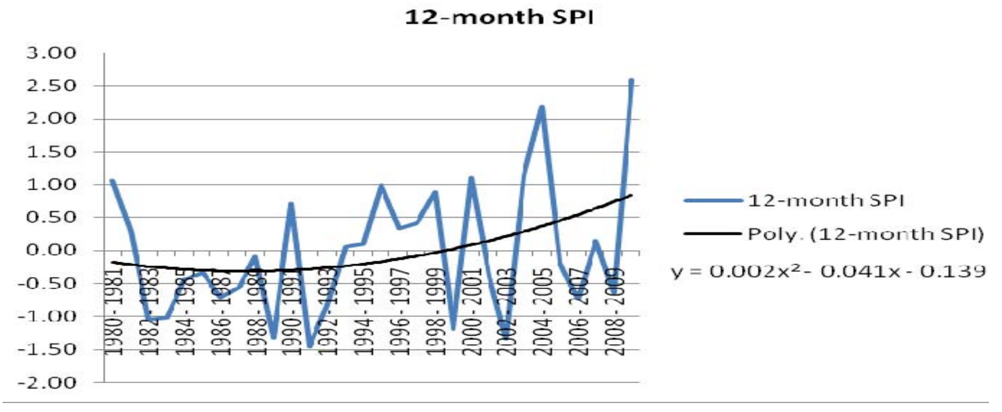


**Figure 5** 12-month SPI values for Sannicolaul Mare area

With the help of a computer program (DrinC) and using temperatures, precipitations and evapotranspiration values (computed by using Thornthwaithe method), records for the last

30 years for Sannicolaul Mare area, were calculated the SPI values (12-month) and respectively the RDI values (12-month, normalized and standardized), results which are presented in the next figures.

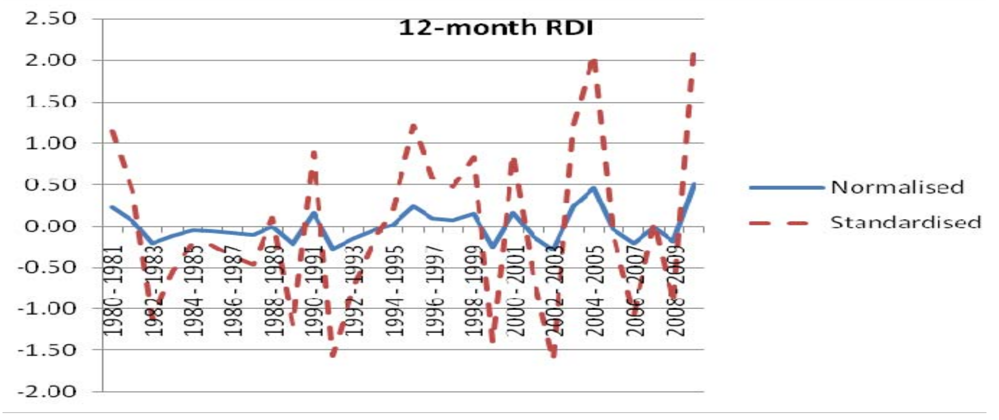


**Figure 6** Figure 5 12-month RDI values for Sannicolaul Mare area

## WATER DEMANDS IN WESTERN ROMANIA

Agriculture is a major user of water resources but also contributes to water pollution from excess nutrients, pesticides and other pollutants. Sustainable management of water in agriculture is critical to increase agricultural production, ensure water can be shared with other users and maintain the environmental and social benefits of water systems. Climate change could affect water supply and agriculture through changes in the seasonal timing of rainfall and snow pack melt, as well as higher incidence and severity of floods and droughts.

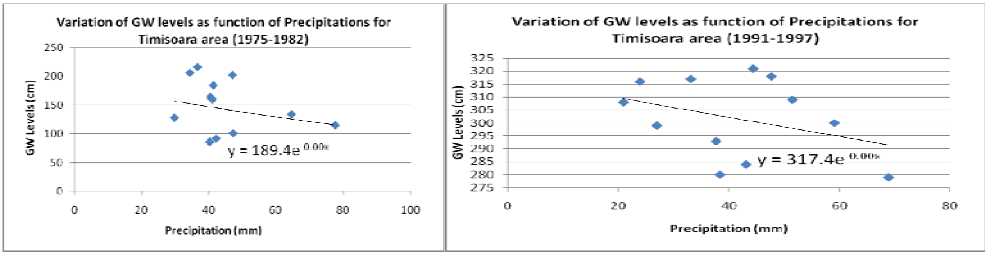


**Figure 7** Variations of GW levels as function of precipitations for Timisoara area

We study the link between the precipitations volume recorded for a specific period and the variation of water levels in some drills for the same period. There is presented below a comparison between 1975-1982 and 1991-1997 on the variation of water levels from drills located in Timisoara area and on the precipitations recorded for the same area. It can be observed that on the base of relative similar values of precipitations recorded, the groundwater levels observed in the second period of analysis were found to be below the levels measured in the first period of time.

Unfortunately due to an improper maintenance of hydrogeological wells, today (2013) on the whole area of Timis County, there are no readable, functioning hydrogeological wells.

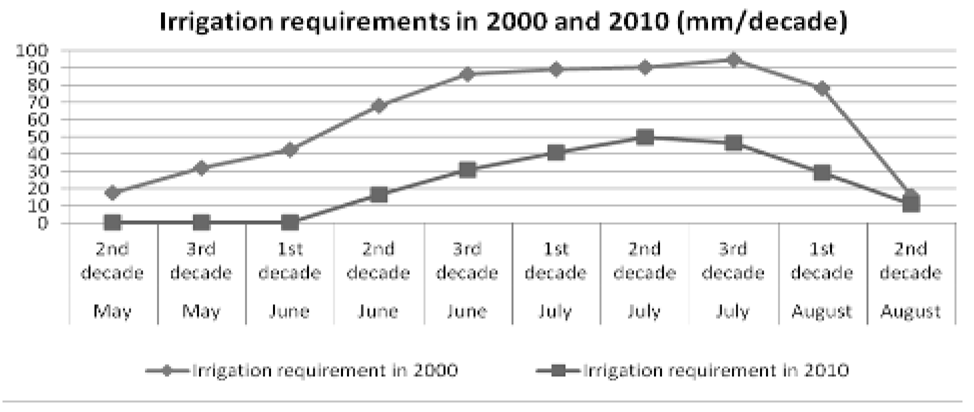


**Figure 8** A comparison between the irrigation requirements (2000 and 2010) for Sinnicolau Mare area (peas, chernozem)

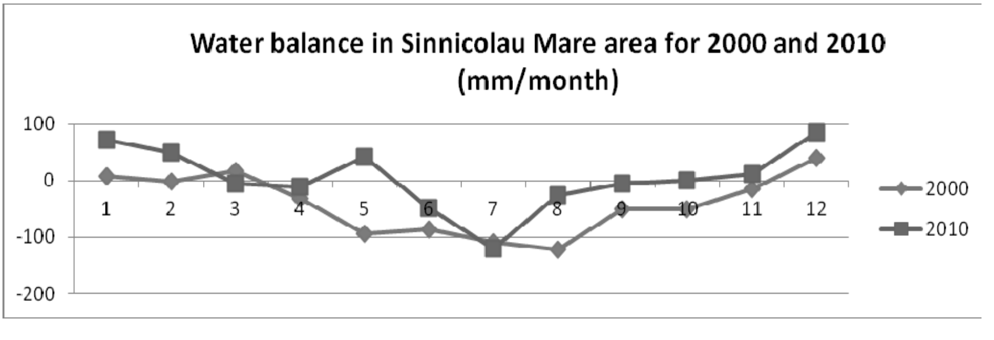


**Figure 9** Water balance in Sinnicolaul Mare area (2000 and 2010). Values obtained with HidroEsta

In a second phase, using computer programs (as CropWat 8.0 and Hidroesta) we determined and we compare (years 2000 and 2010) the irrigation requirements for a vegetable as well as the water balance for the same years.

## CONCLUSIONS

For Western Romania, using a series of records for 30 years and comparing 2000 with 2010, we determined a tendency of climate from dryness to normal with some humid intervals. This area was covered by large surface of land reclamation and improvement systems which affected, sometimes in a negative manner, the variation of groundwater levels being affected in this way the agricultural activity from the mentioned area. The study of groundwater levels is relative difficult to be made in western part of Romania due to the lack of maintained and functioning drills. Using past records and with the help of specialized programs we can determine, using actual climatic data, the evolution of groundwater levels, information necessary especially for agricultural sector but in the same manner and for other sector.

According to SPI 12-month indicator, only 37% of the last 30 years are characterized by light and medium drought, the driest period being the one between 1982 and 1993. The results obtained with RDIst 12-month are relative similar. With the help on this indicator we observed that 33% from the analyzed period is represented by light, moderate and even severe drought (3%). Again, the driest period it was identified as being 1982-1993.

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42. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

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# MODELING CLIMATE CHANGE IMPACT ON WINTER WHEAT YIELD IN NOVI SAD (VOJVODINA) USING DSSAT CROP MODEL

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## SUMMARY

*DSSAT v. 4.0 is a crop model commonly used to quantify the climate change impacts on agriculture production. The model objective is to predict the duration of growth, the average growth rates and the amount of assimilate partitioned to the economic yield components of the plant. The DSSAT model structure is comprehensively described in this paper. The input data were used from Balkan winter wheat twelve year field experiment from Rimski Sancevi in Novi Sad and climate data were given by Republic Hydrometeorology Service of Serbia for current climate and 2030 and 2050 using three climate models (ECHAM5, HadCM3 and NCAR-PCM). DSSAT 4.0 wheat yield simulations were done for 1971-2000, for 2030 and 2050. In the paper is presented the yield change for 2030 and 2050, calculated relative to 1971-2000, as quantitative indicator of climate change impact on wheat yield and production. The yield analyses shown no changes in 2030 and 2050, except in 2050 a slightly decrease in yield for NCAR-PCM model. The results shown winter wheat benefit in climate change conditions, because its growing season begins during winter months when the climate model ECHAM5, under A1B scenario predicted the favorable climatic conditions in 2030 and 2050.*

*The results analyses from climate and crop models have huge importance in making decisions for adaptation measures in agro technology in expected climate conditions for many important crops in agriculture.*

***Key words**: CERES crop model, climate changes, DSSATv.4.0, yield modeling, winter wheat.*

## INTRODUCTION

Climate changes are changes in statistical properties of climate system for long period (decades or centuries), whatever it caused Houghton, 1996. Climate changes have been monitored on global (Olesen et al., 2011) and regional level (Eitzinger et al., 2009; Lalić et al., 2011; Mihailovic D. 2010). The most vulnerable part of economy is agriculture and key focus of much current research is to predict future changes in climate and suggest how these changes will curtail current agricultural technology at individual locations (Eitzinger et al., 2010). Because of that, every country has obligation to monitor changes in climate and research the adaptation measures, to keep the agriculture production on high and stable level.

Crop models are used to quantify climate change impacts on plant production and testing adaptation measures. It is possible to estimate the limits of some plant production and plant vulnerability in new climate conditions, on the basis of these models results.

The previous climate studies in Vojvodina region included comparative analyses of current climate (1985-2005) and expected for 2040, 2080 and its impacts on agro meteorological conditions for some crops (Lalic et al., 2011). The impact of climate changes on winter wheat yield was quantified with Sirius crop model (Lalic et al., 2007; Lalic et al., 2011). Obtained results gave a possibility in making adaptation measures (Lalic et al., 2011; Mihailović et al., 2010). The followed research was focused on the identification of agro climatic parameters which on the best way can point out on effects of climate change and variability on winter wheat yield change in the Pannonian lowland, with respect of different $CO_2$ concentrations and soil types (Lalic et al., 2012).

The aim of this paper was to introduce and familiarize agriculture experts and scientists with DSSAT crop model possibilities, testing DSSAT model and its genetic coefficients for winter wheat varieties and climate conditions of Vojvodina region. The chosen location, for field experiment, was Rimski Sancevi in Novi Sad, because it represented typical climate and soil conditions in Vojvodina region.

DSSAT was tested and validated for typical winter wheat variety Balkan. The agro technology data were used from twelve year field experiment (1994-2005) from Institute of Field and Vegetable Crops in rain fed conditions and data for current climate were assimilated by Republic Hydrometeorology Service of Serbia. The data describing expected climate, for 2030 and 2050, were obtained from three climate models ECHAM5, HadCM3 and NCAR-PCM and downscaled with Met & Roll weather generator under A1B and A2 scenario.

In the paper are presented (a) the structure and functionality of DSSAT v.4.0. crop model (b) CERES model calibration and validation (c) relative yield change for 2030 and 2050 for Balkan winter wheat. These information will help experts and decision makers in the selection of right adaptation measure and making long term plans in agriculture for high and stable yield.

## MATERIAL AND METHOD

DSSAT 4.0 model is developed as a result of IBSNAT project (International Benchmark Sites Network for Agro technology Transfer project) to simulate biological crop demands and most effective use of current and expected soil and climate resources (Tsuji et al., 1998). Model contains sub modules which describes atmosphere-soil-crop interaction. Functional scheme DSSAT 4.0 model consists of input data, sub modules and output results (fig. 1).

*Input data.* Minimum data set has been defined 1984 and amended till 1988 (IBSNAT 1984; IBSNAT 1986; IBSNAT 1988; IBSNAT 1989). The data refers to meteorological and soil conditions, genetic coefficients and applied agro technology (fig. 1).

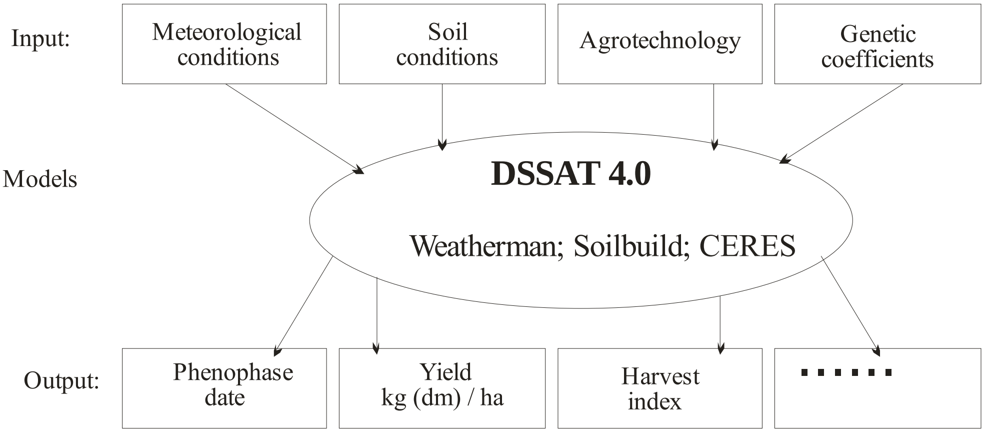


**Fig. 1** DSSAT v. 4.0 functional scheme

*Meteorological conditions.* The daily values of meteorological elements (maximum temperature, minimum temperature, precipitation, solar radiation, evaporation, wind speed) were used in this paper to describe the climate conditions on chosen location. These values were observed on weather station Rimski Sancevi in the period 1971–2000, which are obtained from Republic Hidrometeorological Service of Serbia. For description of expected climate conditions, there were used three climate models: (a) HadCM3 (Gordon et al., 2000), (b) ECHAM5 (Roeckner et al., 2003) and (c) NCAR-PCM (Washington et al., 2000). These models had two scenarios „pessimistic“ (SRES-A2) and „optimistic“ (SRES-A1B) for greenhouse gas emission for 2030 and 2050. The data assimilated from climate models may be used after its downscaling. This is the process of meteorological data regionalization in time and space. In this paper downscaling was done by Met & Roll weather generator (Dubrovsky M., 1996; Dubrovsky M. 1997). Let us note, that in all simulations, $CO_2$ concentration was 330 ppm. This approach is denoted as `climate change only´ in literature.

*Soil conditions.* The soil type, its mechanical and chemical characteristics were assimilated from Ćirić V. 2008. The values used in simulations are presented in Table 1.

**Table 1** Physical and chemical characteristics of chernozem (Ćirić V. 2008)
Particles content (%)

| Depth (cm) | Coarse sand | Fine sand | Silt | Clay | Texture class | pH in $H_2O$ | Org. C (%) | Nitrate (%) |
|---|---|---|---|---|---|---|---|---|
| 0-30 | 0.80 | 35.95 | 35.76 | 27.49 | Loamy clay | 6.96 | 1.51 | 0.19 |
| 30-53 | 1.33 | 37.81 | 34.31 | 26.55 | Loamy clay | 7.97 | 0.98 | 0.15 |
| 53-88 | 10.73 | 44.21 | 28.30 | 16.75 | Clay loam | 8.28 | 0.69 | 0.10 |

*Agro technology*. The experimental field was managed at Rimski Sancevi, Institute of Field and Vegetable Crops in Novi Sad in twelve year period 1994–2005. The crop was Balkan winter wheat variety, sown in the middle of October, a typical time for sowing winter wheat in the Vojvodina region. For all runs, the 10$^{th}$ of October was set as a time of sowing, with 540 pl./m$^2$ density, row space 12 cm and sowing depth at 4 cm. The crop was fertilized with 100 N kg/ha, and 46 kg/ha N in the spring. The harvest, in the first year, was done on the 3$^{rd}$ of July.

*Genetic coefficients* are unique for each variety. These data are necessary for calculation of phenophases and maturity duration and biomass partitioning. There are six coefficients for wheat simulation. The coefficients are: P1V – days at optimum vernalizing temperature required to complete vernalization (days), P5 – grain filling phase duration (C$^0$d), G1 – kernel number per unit canopy weight at anthesis (n/g), G2 – standard kernel size under optimum conditions (mg), G3 – standard, non –stressed dry weight (total, including grain) of a single tiller at maturity (g), PHINT – interval between successive leaf tip appearances (C$^0$d) (Hoogenboom et al., 2003).

The coefficients used in wheat simulations are given as part of DSSAT v. 4.0 crop model for Winter – Europe wheat since Balkan winter wheat has the same genetic characteristics. Standards for coefficient description defined Hunt et al., 1993, Ritchie J. T. 1993.

DSSAT 4.0 model component contains three sub models: meteorological model (Weatherman), soil model (Soilbuild) and crop simulation model (CERES). In meteorological model (Weatherman) observed meteorological element values and values from climate models were input data, where they were classified and saved in special files necessary for further crop simulations. Soil model is model for soil data characteristics where input data were processed. The soil type was defined, on the basis of soil characteristics input. For experimental field it was obtained soil nitrogen quantity and organic carbon fertility.

The cereal crops included in DSSAT 4.0 – CERES crop sub model, are maize, wheat, barley, millet, sorghum and rice. A feature of this model is its capability to include cultivar specific information that make possible prediction of the cultivar variations in plant ontogeny and yield component characteristics and their interaction with weather and soil. CERES calculates phenophase, growth rate and biomass partitioning in plant parts. These processes are dynamic and affected by genetic coefficients and environmental conditions. Biomass growth is calculated using the radiation use efficiency approach; biomass production is partitioned between leaves, stems, roots, ears and grains. The proportion partitioned to each growing organ is determined by the stage of development and general growing conditions. The crop yield is defined as a product of the grain numbers per plant times the average kernel weight at physiological maturity. The grain numbers are calculated from the above ground biomass growth during a critical stage in the plant growth cycle for a fixed thermal time before anthesis. The grain weight is calculated as a function of cultivar specific optimum growth rate multiplied by the duration of grain filling (Tsuji et al., 1998). On the base of genetic coefficients, environmental conditions and field experiment data, it is possible to calibrate crop model.

## RESULTS AND DISCUSSION

*Calibration and validation*. The first step in model use is its calibration and validation. Using input data, model is calibrated for Balkan winter wheat variety in rainfed conditions adjusting genetic coefficients to get the similar simulated yield and maturity duration to observed values from experimental field on Institute of Field and Vegetable Crops on Rimski Sancevi.

In order to quantify ability of crop model to simulate crop yield, the model was validated (Table 2 and fig. 2) and relative deviation between simulated and observed yield was calculated. According to Tsuji et al, 1998, simulation is considered as correct if relative deviation is between 5–10%. Results presented in Table 2. and in fig. 2. show that the relative deviation between observed and simulated winter wheat yield was 7.79 %.

**Table 2** Validation of winter wheat yield (t/ha) for Balkan winter wheat in rain fed conditions for 1994–2005 period.

| Year | Observed | Simulated |
|---|---|---|
| 1994 | 7.50 | 6.38 |
| 1995 | 8.13 | 7.49 |
| 1996 | 7.30 | 5.57 |
| 1997 | 6.56 | 4.70 |
| 1998 | 8.22 | 6.17 |
| 1999 | 5.11 | 5.99 |
| 2000 | 7.58 | 2.94 |
| 2001 | 6.34 | 8.64 |
| 2002 | 6.58 | 5.08 |
| 2003 | 2.80 | 2.59 |
| 2004 | 6.58 | 9.19 |
| 2005 | 2.80 | 4.84 |
| Average | 6.29 | 5.80 |

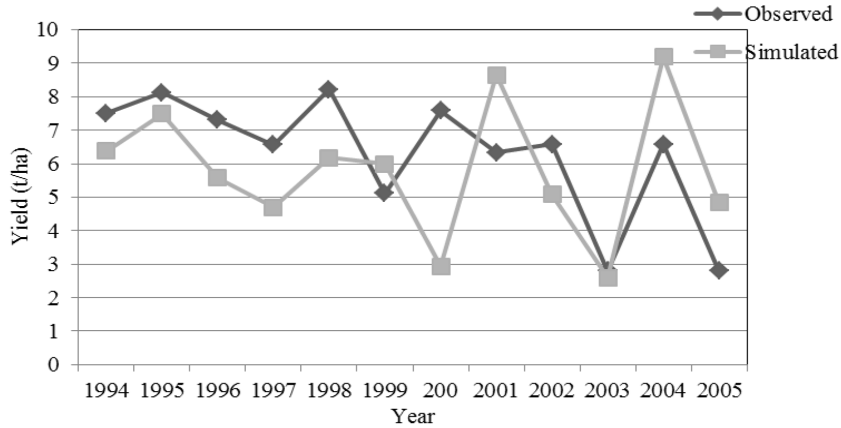


**Fig. 2** Validation of winter wheat yield (t/ha) for Balkan winter wheat in rain fed conditions for 1994–2005 period

*The expected Balkan winter wheat yield for 2030 and 2050*

After model validation, the yield simulations were done for 2030 and 2050 using three climate model outputs (H – ECHAM5, M - HadCM3, N – NCAR-PCM) under two scenarios: A1B, A2 for expected climate conditions. The change in yield for 2030 and 2050 was calculated relative to 1971-2000 baseline yield (Table 3).

According to obtained results, in 2030 Balkan winter wheat yield shown no changes under A1B and A2 scenario. In 2050, there are no expected changes in yield, only with NCAR-PCM climate model under A1B (-4.28%) and A2 (-5.49%) scenario, it is expected a slightly decrease in yield. The yield change between same climate model under different scenario shown no differences in 2030 and 2050. Also, the change in yield between climate models under one scenario did not show did not show changes. In a comparison of yield change between A1B and A2 scenario for 2030 and 2050 there were no differences.

**Table 3** Relative yield change (%) for Balkan winter wheat for 2030 and 2050 (H – ECHAM5, M - HadCM3, N – NCAR PCM)

| 2030 | | | | | | 2050 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| A1B | | | A2 | | | A1B | | | A2 | | |
| H | M | N | H | M | N | H | M | N | H | M | N |
| 0.82 | 1.43 | -2.32 | 1.10 | 1.78 | -2.82 | 1.31 | 1.63 | -4.28 | 0.75 | 1.25 | -5.49 |

## CONCLUSIONS

The successful calibration and validation was shown that DSSAT v. 4.0. is adequate model for winter wheat simulations in Vojvodina region.

The DSSAT v. 4.0. yield simulations gave a description how climate changes impact on winter wheat yield in 2030 and 2050. The change in yield for 2030 and 2050 shown no significant changes in yield for all climate models and both scenarios, except in 2050 it was predicted the slightly decrease in yield for NCAR-PCM under A1B (–4.28%) and A2 (–5.49%) scenario.

It is concluded that winter wheat has only benefit in climate change conditions and it is necessary to mention that Balkan variety is winter wheat and growing season start through autmn and winter months. The results from climate model ECHAM5, under A1B scenario predicted that temperature in 2030 for October – March (OM) period is expected to be 1 °C higher and 1.2 °C higher for December-January-February (DJF), while the precipitation for these periods OM will be 10.38 % and 29.21 % in DJF higher than in 1971-2000. In 2050, ECHAM5 under A1B scenario predicted temperatures for 2 °C higher in OM period and 2.2 °C higher in DJF period. The precipitation is expected to be 12.32 % higher in OM and 38.27 % higher in DJF period.

The higher temperatures and precipitation will provide better soil water reserves and better initial conditions for the beginning of wheat growing season, when the plant (seed and small plant) is the most sensitive on soil temperature level and moisture deficit.

The serious climate change impacts on crops are expected in April-September vegetation, because the high temperatures, heat stress and drought is predicted for June-July-August period.

The model offers opportunities to choose the less vulnerable crop or make adaptation options and long term plans for stable agriculture production.

## ACKNOWLEDGEMENT

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42. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

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# SPRING BARLEY AND WINTER WHEAT PRODUCTION IN NON-CONVENTIONAL SOIL TILLAGE SYSTEMS

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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. Spring barley (*Hordeum vulgare *L.) and winter wheat (*Triticum aestivum *L.) were cultivated on five soil tillage systems. The tillage systems and implements used were: CT – mouldboard plough, disc harrow, multitiller, drill, NcT 1 – chisel plough, disc harrow, multitiller, drill, NcT 2 – chisel plough, rotary harrow integrated with seed drill, NcT 3 – mouldboard plough, rotary harrow integrated with seed drill, NcT 4 – chisel plough, mouldboard plough, rotary harrow integrated with seed drill. The weather conditions had great influence on production of spring barley, and the occurrence of drought periods during the vegetation season could have affected the yields. The highest average yields were obtained by NcT 2 system in spring barley (3.20 t ha$^{-1}$) and NcT 1 in winter wheat production (8.79 t h$^{-1}$). The greatest energy and labour savings in soil tillage, among the lowest total cost of production were achieved by NcT 2 system in which, consequently, the highest economic efficiency of spring barley (coefficient of 1.81) and winter wheat production (coefficient 2.54) was obtained. Therefore, regarding the choice of tillage systems, assuming uniform level of yields, the advantage should be given to systems with lower level of tillage intensity, not only to reduce costs but also because of the possibility of simpler production organization due to less machine and labour requirement.*

***Key words:*** *soil tillage, energy and labour productivity, economic efficiency*

## INTRODUCTION

Soil tillage aims to create favourable conditions for seed germination and plant growth and is considered an indispensable part of arable crop production. The intensification of tillage, along with fertilization, crop protection and selection, has enabled a significant increase in yields, but also caused soil degradation, increased risk of erosion and rise of production costs. Greatest possibility for production rationalization offers tillage reduction, mainly by substitution of mouldboard ploughing as the most energy and time-demanding task with conservation tillage systems.

Barley (*Hordeum vulgare* L.) and wheat (*Triticum aestivum* L.) are the main cereals largely represented in the crop rotation on arable areas in Croatia. The mainly utilised soil tillage system in wheat and barley production is conventional system based on mouldboard ploughing as primary tillage operation, followed by secondary tillage carried out with disc harrow and seed-bed implement. 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 *(Tebrügge et al. 1998, Tebrügge 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 30-50% savings of the energy and human-machine work, and direct sowing as much as 70%, compared with conventional tillage. 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 *(Filipović et al. 2006)*.

*Stroppel (1997)* reported that by the end of the last century about 85% of the arable land of central Europe was under conventional tillage systems. The implementation of reduced tillage systems has not significantly increased to date, and it is estimated that there are still less than 10% *(ECAF, 2013)*. The world leading agricultures in substitution of conventional soil tillage systems with different variations of the reduced tillage and direct sowing are United States and Canada in North America and Brazil, Argentina, Uruguay and Paraguay on the South, where conservation tillage and no-tillage systems applied to more than half of total arable crop area *(Derpsch and Friedrich, 2009)*. Despite the mentioned trends, it is estimated that over 90 percent of the fields in Croatia are still being tilled with the conventional tillage system *(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 *(Vratarić and Sudarić 2000, Pospišil et al. 2002, Špoljar et al. 2009, Kisić et al. 2010)*. While some authors *(Chatskikh and Olesen, 2007)*, have noticed a decrease of yield of spring barley with the degree of tillage reduction (14% lower yield 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 Arrué, 2007)*. Reduction of production costs by applying some of the reduced tillage systems, in conditions where yields were not significantly reduced due to lower tillage intensity, enables a lower profitability threshold *(Stipešević et al. 2007, Košutić et al. 2008, Jug et al. 2010, Kovačev et al. 2011)*.

## MATERIAL 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 was consisted of 15 plots with dimension length 185 m x width 54 m each, organized as randomized blocks with three replications. The tillage with different systems was performed on the Hypogley-vertic type of soil (*Škorić, 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 775 mm and an average annual temperature of 10.8 °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:

1. Conventional tillage – mouldboard plough, disc harrow, multitiller, drill (CT);
2. Non-conventional tillage 1 – chisel plough, disc harrow, multitiller, drill (NcT1);
3. Non-conventional tillage 2 – chisel plough, rotary harrow + drill (NcT2);
4. Non-conventional tillage 3 – mouldboard plough, rotary harrow + drill (NcT3);
5. Non-conventional tillage 4 – chisel plough, mouldboard plough, rotary harrow + drill (NcT4).

Mouldboard plough used in tillage systems CT, NcT3 and NcT4 was Kuhn Multimaster 151 with four bodies, disc harrow was Kuhn Discover XM 44/660, multitiller Lemken Korund 750L, and seed drill Tive 2000. Chisel plough used in NcT1, NcT2 and NcT4 was Agram GeoDec SVD6. In tillage systems NcT2, NcT3 and NcT4 an integrated implement Kuhn Integra 3000 was used, consisted of rotary harrow and seed drill.

Energy requirement of each tillage system was determined based on the tractor's fuel consumption. The amount of fuel consumed was measured for each implement (tillage and sowing) on every single plot. Specific energy consumption is calculated based on the energy equivalent of 38.7 MJ $L^{-1}$ for diesel fuel used. In this experiment 4WD tractor with engine power of 136 kW was used. The working width of the tillage implements was chosen according to the pulling capacity of the tractor. The labour requirement was determined by measuring the time for finishing single tillage operation at each plot of the known area (1 ha). The yields were determined by weighing grain mass of each harvested plot, and recalculated according to storage grain moisture content.

Schedule of field operations (tillage, fertilizing, sowing, crop protection, harvesting) and soil moisture content at the moment of tillage are shown in Table 2. On the experimental field previous crop was soybean. Fertilization and crop protection was uniform in all systems, determined by crop specific requirements. Working conditions regarding soil moisture content, soil compaction and post-harvest residues at the beginning of experiment were equal for all tillage treatments.

**Table 2** Date of field operations and application rates

| Description | Spring Barley | Winter Wheat |
|---|---|---|
| | Tillage & Sowing | |
| Primary tillage | November 14th 2011 | August 7th 2012 |
| Soil moisture (%) at 5; 15; 30 cm depth | 31.8; 39.8; 37.4 | 15.8; 34.2; 38.5 |
| Secondary tillage | March 8th 2012 | September 29th 2012 |
| Soil moisture (%) at 5; 15; 30 cm depth | 25.5; 46.8; 48.6 | 24.7; 43.6; 44.7 |
| Sowing date | March 8th 2012 | October 10th 2012 |
| Crop-cultivar (kg ha$^{-1}$) | Scarllet C1 (220) | Apache C1 (220) |
| | Fertilizing | |
| Application date | November 10th 2011 | September 29th 2012 |
| Fertilizer-rate (kg ha$^{-1}$) | NPK 0:20:30 (350) | NPK 8:26:26 (400) |
| Application date | April 15th 2012 | February 13th 2013 |
| Fertilizer-rate (kg ha$^{-1}$) | CAN 27% (130) | CAN 27% (120) |
| Application date | May 20th 2012 | March 28th 2013 |
| Fertilizer-rate (kg ha$^{-1}$) | CAN 27% (90) | urea 46% (100) |
| | Crop protection | |
| Application date | April 8th 20012 | September 26th 2012 |
| Chemical-rate (l ha$^{-1}$) | izoproturon + diflufenikan (1,70) | glyphosat (2.00) |
| Application date | May 7th 2012 | May 12th 2013 |
| Chemical-rate (l ha$^{-1}$) | metaconazole + azoxystrobin (0.80) | ciprokonazol+propi-konazol (0.50) metiltiofanat+epoksi-konazol (0.50) |
| Application date | May 15th 2012 | June 2th 2013 |
| Chemical-rate (l ha$^{-1}$) | aminopiralid + florasulam (0.033 kg ha$^{-1}$) | alfacipermetrin (0.10) ciprokonazol+propi-konazol (0.50) |
| | Harvest | |
| Harvesting date | July 13th 2012 | July 18th 2013 |

Economic efficiency of different soil tillage systems was calculated based on the natural indicators of barley and wheat production (energy consumptions, labour requirement, raw materials, yields). Statistical analysis of data for all research indicators was done with computer program SAS *(SAS Institute, 1990)* 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

*Climate conditions*

Weather had a major influence in the production of spring barley. During the vegetation season, from March to July, mean monthly air temperature was 1.1 °C higher, while the precipitation was 10 % less than the long-term averages. Although the drought periods in Walter climate diagram (Figure 1) are noticeable only at the time of sowing and harvesting barley, the majority of rainfall consisted of abundant torrential rains followed by high heat due to which there has been a drying out of the topsoil in which the main, relatively shallow, roots of barley is located. These climatic conditions could have affected spring barley yield reduction in the observed season.

During the vegetation season of winter wheat mean monthly air temperatures and overall precipitation were within long-term averages and generally favourable for soil tillage and wheat growth.

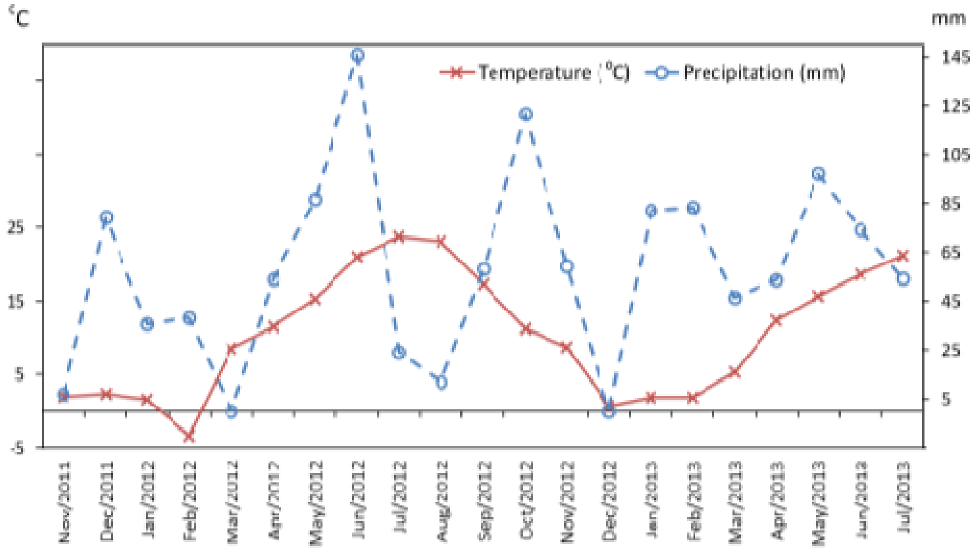


**Figure 1** Walter climate diagram for barley and wheat cropping period

*Yield*

In spring barley production the greatest average yield of 3.20 t $ha^{-1}$ was achieved by NcT2 tillage system followed by NcT1 with average yield of 3.01 t $ha^{-1}$ and NcT4 with 2.88 t $ha^{-1}$. According to ANOVA, differences of average yields obtained in soil tillage systems listed above were not statistically significant. The lowest average yield of spring barley was recorded in CT system with 2.34 t $ha^{-1}$. Along with slightly higher yield of 2.64 t $ha^{-1}$ in NcT3, those two systems have resulted in statistically lower yields than other tillage systems at probability level of $p<0.05$.

Overall yields obtained in the production of spring barley were below expectations for the grown variety, which may be due to the previously mentioned weather conditions and in accordance with the observations of *Žugec et al. (2002)* and *Fallon and Betts (2010)* in whose studies yields have also been susceptible to seasonal climate deviations. It is noticeable, however, that the greatest yields being recorded in variants without plowing, which was probably the cause of better soil percolation and sorptivity.

Yields of winter wheat were high and uniform across all non-conventional soil tillage systems with the highest average yield of 8.79 t $ha^{-1}$ obtained in NcT1 system. The lowest average yield of 7.83 t $ha^{-1}$ was recorded in CT system and has been only one that was statistically lower than yields achieved with other tillage systems. This may be a consequence of cumulative soil degradation caused by consecutively applied conventional tillage *(Birkas 2008)*.

*Energy and labour productivity*

Soil tillage with mouldboard plough was expectedly most energy and labour consuming task, and has largely contributed to high fuel consumption in tillage systems where was applied (Table 3). In spring barley production the greatest fuel consumption in soil tillage was recorded in NcT4 system 62.69 L $ha^{-1}$, or 33.8 % more than with conventional tillage. Due to significantly higher average yields, specific energy consumption of 842.1 MJ $t^{-1}$ in NcT4 was only 8.5 % greater than in CT. NcT3 system enabled 21.0 % less specific energy consumption (613.0 MJ $t^{-1}$) and NcT1 36.6 % (492.3 MJ $t^{-1}$) less compared to conventional tillage. The greatest energy saving per ton of barley produced was obtained in NcT2 system, 402.7 MJ $t^{-1}$ or 48.1 % less than CT.

Similar trends regarding energy consumption were noticed also in winter wheat production where the share of fuel used for ploughing ranged from 51.2% in NcT4 to 68.7 % of total energy used for tillage and sowing in NcT3 system. Given the high yields of winter wheat, specific energy engaged per ton of yield ranged from 129.8 MJ $t^{-1}$ in NcT2 tillage system to 259.3 MJ $t^{-1}$ in NcT4 and remained under one third compared to spring barley production.

The highest productivity regarding labour requirement per hectare and ton of grain yield was achieved with NcT2 tillage system in both spring barley and winter wheat production. Comparing the results with allegations by other authors *(Pellizzi et al. 1988, Hernanz and Ortiz-Canavate 1999)* larger deviations due to soil types, current conditions in the field, depth of tillage and implements used could be expected, but an increase in labour productivity with the degree of reduction of tillage is noticeable.

**Table 3** Energy and labour requirement of different soil tillage systems

| Tillage system | Spring Barley | | | | Winter Wheat | | | |
|---|---|---|---|---|---|---|---|---|
| | 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 = 2.34 t $ha^{-1}$ c(1) | | | | Average yield = 7.83 t $ha^{-1}$ b | | | |
| Plough | 29.39 | 487.1 | 1.30 | 0.56 | 30.05 | 148.5 | 0.97 | 0.13 |
| Disc harrow | 10.25 | 169.9 | 0.31 | 0.13 | 9.89 | 48.9 | 0.31 | 0.04 |
| Multitiller | 4.26 | 70.6 | 0.43 | 0.18 | 4.96 | 24.5 | 0.24 | 0.03 |
| Seed drill | 2.94 | 48.7 | 0.45 | 0.19 | 3.43 | 17.0 | 0.19 | 0.02 |
| Total | 46.84 | 776.3 | 2.49 | 1.06 | 48.33 | 238.9 | 1.71 | 0.22 |
| NcT 1 | Average yield = 3.01 t $ha^{-1}$ a | | | | Average yield = 8.79 t $ha^{-1}$ a | | | |
| Chisel | 20.84 | 267.9 | 0.83 | 0.28 | 14.97 | 65.9 | 0.66 | 0.07 |
| Disc harrow | 10.25 | 131.8 | 0.31 | 0.10 | 9.89 | 43.5 | 0.31 | 0.04 |
| Multitiller | 4.26 | 54.8 | 0.43 | 0.14 | 4.96 | 21.8 | 0.24 | 0.03 |
| Seed drill | 2.94 | 37.8 | 0.45 | 0.15 | 3.43 | 15.1 | 0.19 | 0.02 |
| Total | 38.29 | 492.3 | 2.02 | 0.67 | 33.25 | 146.3 | 1.40 | 0.16 |
| NcT 2 | Average yield = 3.20 t $ha^{-1}$ a | | | | Average yield = 8.54 t $ha^{-1}$ a | | | |
| Chisel | 20.84 | 252.0 | 0.83 | 0.26 | 14.97 | 67.8 | 0.66 | 0.08 |
| Rotary harrow + drill | 12.46 | 150.7 | 0.61 | 0.19 | 13.69 | 62.0 | 0.65 | 0.07 |
| Total | 33.30 | 402.7 | 1.44 | 0.45 | 28.66 | 129.8 | 1.31 | 0.15 |
| NcT 3 | Average yield = 2.64 t $ha^{-1}$ bc | | | | Average yield = 8.71 t $ha^{-1}$ a | | | |
| Plough | 29.39 | 430.5 | 1.30 | 0.49 | 30.05 | 133.5 | 0.97 | 0.12 |
| Rotary harrow + drill | 12.46 | 182.5 | 0.61 | 0.23 | 13.69 | 60.8 | 0.65 | 0.07 |
| Total | 41.85 | 613.0 | 1.91 | 0.72 | 43.74 | 194.3 | 1.62 | 0.19 |
| NcT 4 | Average yield = 2.88 t $ha^{-1}$ ab | | | | Average yield = 8.76 t $ha^{-1}$ a | | | |
| Chisel | 20.84 | 279.9 | 0.83 | 0.29 | 14.97 | 66.1 | 0.66 | 0.08 |
| Plough | 29.39 | 394.8 | 1.30 | 0.45 | 30.05 | 132.7 | 0.97 | 0.11 |
| Rotary harrow + drill | 12.46 | 167.4 | 0.61 | 0.21 | 13.69 | 60.5 | 0.65 | 0.07 |
| Total | 62.69 | 842.1 | 2.74 | 0.95 | 58.71 | 259.3 | 2.28 | 0.26 |

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

*Economic analysis*

Total costs include all the inputs (labour, machine costs, seed, fertiliser and plant protection chemicals) from soil tillage to harvest, including grain transport within field. Storage and handling costs were not taken into account since its great variability.

In both seasons conventional tillage system resulted in the highest costs (Table 4) with 585.00 € $ha^{-1}$ (spring barley) and 787.00 € $ha^{-1}$ (winter wheat) mainly due to great number of field operations and large amount of labour requirement. In spring barley production the highest income was obtained with NcT2 system and that variant also showed the best economic efficiency (coefficient 1.81) together with the highest income due to the highest yield compared to other tillage systems. In winter wheat production the highest income was recorded with NcT1 tillage system, but economic efficiency of that variant has been slightly lower (coefficient 2.50) than the best coefficient 2.54 achieved in NcT2 system that generated the lowest costs. Similar to findings of other authors *(Košutić et al. 2006, Jug et al. 2007)* better economic effects were achieved principally with reduced tillage systems.

**Table 4** Economic efficiency indicators of barley and wheat production

| Tillage | Spring Barley | | | Winter Wheat | | |
|---|---|---|---|---|---|---|
| | Gross income[1] € $ha^{-1}$ | Total costs € $ha^{-1}$ | Income/Costs ratio | Gross income € $ha^{-1}$ | Total costs € $ha^{-1}$ | Income/Costs ratio |
| CT | 744.00 | 585.00 | 1.27 | 1,659.00 | 787.00 | 2.11 |
| NcT 1 | 894.00 | 558.00 | 1.60 | 1,837.00 | 734.00 | 2.50 |
| NcT 2 | 936.00 | 518.00 | 1.81 | 1,791.00 | 704.00 | 2.54 |
| NcT 3 | 812.00 | 545.00 | 1.49 | 1,822.00 | 757.00 | 2.41 |
| NcT 4 | 865.00 | 578.00 | 1.50 | 1,831.00 | 778.00 | 2.35 |

[1]income includes 217 € $ha^{-1}$ of subsidies

## CONCLUSIONS

Summarizing the results together with previously acquired experience it could be concluded that the production of spring barley and winter wheat, as most important cereals largely represented in the crop rotation on arable areas in Croatia, has proven to be economically efficient at all variants of soil tillage. Better economic results were achieved mainly with the reduced tillage systems as a result of higher yields and reduced production costs compared to conventional system. Thus, the best improvement of economic efficiency was 42.5 % in spring barley and 20.4 % in winter wheat production, both obtained with NcT2 tillage system.

The greatest saving regarding specific energy per ton of yield was achieved by NcT2 system, 48.1% in spring barley and 45.6 % in winter wheat production compared to conventional tillage system. The highest productivity regarding labour requirement per hectare and ton of barley and wheat grain was also achieved with NcT2 system, and due to the best economic efficiency in both seasons this tillage system could be recommend in spring barley and winter wheat production.

This short-term experiment showed that non-conventional tillage systems could be economically important tool to decrease production costs. 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, not only to reduce costs, but also because of the simpler production organization due to less machine and human labour requirement.

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# AGGREGATE SIZE DISTRIBUTION OF HUMOGLEY AFTER AN AUTUMN TILLAGE

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## SUMMARY

*This paper presents results of dry aggregate size analysis of non-carbonate Humogley after the autumn tillage for wheat seeding. The 140 soil samples have been taken from square area of 90 m in length and 60 m in width, at depths of 0-5 cm and 5-10 cm. Structural aggregates larger than 9.5 mm were dominant in samples at depth of 0-5 cm, 51.67%. In contrast, the fractions larger than 50 mm have not been evidenced in any of acquired soil samples. This way, the regular conditions of Humogley has been confirmed and, therefore, its applicability for soil aggregate analysis and testing of the appropriate models has been verified too. Among others, presented results also show the large discrepancies of mean weight diameters of structural aggregates at different sample sites over the experimental plot. The analogue difference has been evidenced between the sample sites at depths of 0-5 cm and 5-10 cm. It follows that analysis of the representative distribution of soil structural aggregates of any plot demands analysis of large number of soil samples, acquired over the whole area of the plot.*

***Key words***: *Humogley, dry aggregate size distribution, mean weight diameter, mechanical decomposition.*

## INTRODUCTION

Arable land represents a limited fundamental environmental resource for each country and for the whole civilization. According to the Statistical yearbook of the Republic of Serbia 2011, 3.066.000,00 hectares were seeded by different crops in Serbia during the year of 2010. Plant production and especially the crop yield are directly related to the soil properties. Soil degradation results in the crop yield decreasing. In addition, maintaining the soil quality at desired level is crucial for sustainability and energy efficiency of plant production of any kind, but also for protection of the environment.

Ramazan et al., 2012, emphasized a key role of agricultural mechanization in the contemporary agricultural production: its application may provide many benefits, but only if an adequate mechanization is properly used. Otherwise, a number of different problems that reflect negative influence on the crops growth and yield may arise. They underlined that unnecessary and excessive application of heavy machines should be prevented, because they compact soil causing degradation of its structure.

Therefore, new more efficient, more accurate and more reliable procedures for collecting the soil samples as well as the new methods for measurement, estimation and evaluation of the relevant characterization parameters of soil quality are needed, while the existing approaches of such kind should be improved. It is widely accepted that these methods are also important for further scientific development and advancing of the highly efficient, reliable and predictable methods for management of the soil/crop agricultural production systems (Torbert et al., 2008). Besides application of an appropriate tillage system, it is very important to use it under optimal working conditions (Ponjičan et al., 2011).

Soil tillage by moldboard plough represents the most efficient tilth system for the sandy and loam soils. The advantages of this system are decreased when applied at heavy clay soils, because of increased energy demands caused by high soil resistances of implements of this kind. In addition, high soil resistances demand high pulling power and heavy machines that cause soil compaction.

Tillage assumes a variety of mechanical soil recomposing mechanisms, intended to improve its structure and providing suitable conditions for a crop production. Therefore, quality control of each tillage concept is of key importance. Adequate tillage must provide appropriate size distributions soil aggregates, 0.25-10 mm – most valuable aggregates. Higher percentages of aggregates larger than 5 mm is needed in situations related to irrigated lands. However, higher content of smaller aggregates, which sizes are between 1 mm and 2mm, are appropriate for dry non-irrigated soils. Consequently, soil structure was in the focus of interest of many researchers (Mueller et al., 2010).

Hwang et al., 2002 emphasized the importance of accurate mathematical representation of aggregate size distribution for evaluation of the soil quality. Itoh et al., 2008 formulated an algorithm for aggregate size evaluation, based on real-time digital image analysis. Petrović et al., 2010 analyzed soil aggregate size distribution after tillage and evidenced their strong deviations from the most commonly used normal Gaussian model. Chan et al., 2006 analyzed repeated soil compaction after removing impermeable layers generated by deep ploughing.

Humogley soils are characterized by very unfavourable physical properties: heavy mechanical composition, low total porosity, high penetration resistance, inapropriate water and air flow regimes, bad heat properties, high tillage resistance, etc. Consequently, the tillage timelines are very narrow, causing the managements of Humogley very complicated, as it was reported in Radojević et al., 2010.

## MATERIAL AND METHODS

Presented study is based on the field experiments, which have been conducted at parcel T-9 of farm "Mladost", Jabučki Rit, PKB Corporation – Belgrade. Following Škorić et al., 1985, the soil under reserach is classified as non-carbonate Humogley. After harvesting the forecrop (silage corn) the following autumn tillage operations, specified for soil preparation for wheat seeding, have been performed: stubble cultivation, chisel ploughing, disc harrowing and presowing preparation.

According to classification of the International Society of Soil Science, mechanical soil composition is characterized by low content of coarse sand (1% in average). Fine sand particles are dominant in plowing horizon, 29.8% in average, silt fraction 30.7% and content of clay fraction in A horizon is 38.5% in average. On the basis of International Society of Soil Science classification, analyzed soil is classified as light clay (Baize, 1993).

Monthly average temperatures and rainfalls, in the period between 2004 and 2009 year, in the region of Belgrade (Hydrometeorologic Office of Republic of Serbia, Agrometeorolgy Department, 2010, Statistical Office of Republic of Serbia, 2010), are illustrated in Figs. 1 and 2.

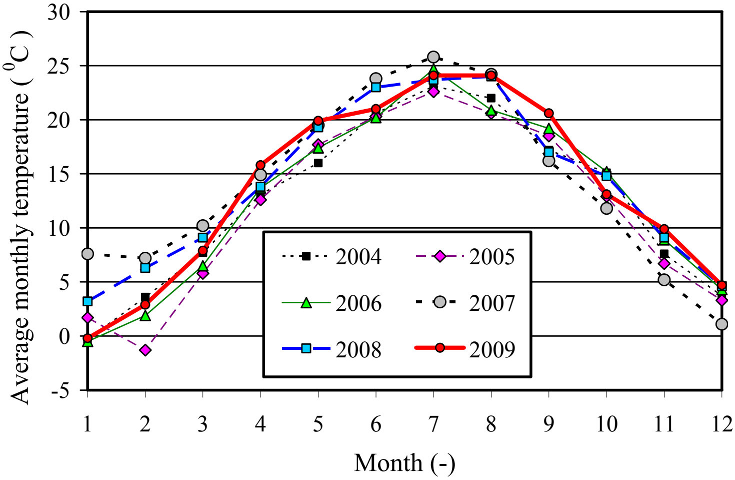


**Figure 1** Average monthly temperatures for the Belgrade region, in the period 2004-2009.

Fig. 1 shows fairly stable tempeartures over the years, with some variations. However, the general trend of temperature rising within this period is evident. In the years 2004-2009, the yearly temperature averages were 12.5°C, 11.9°C, 12.8°C, 14.0°C, 14.0°C and 13.7°C, respectively. This is evidently higher with respect to the average temperature (11.9°C) in the period betwen 1961 and 1990 year, and is in agreement with general belief of global heating of the planet Earth.

The total monthly rainfall values (mm/month) are variable. They expose large variations in time, and are much more unpredictable, as it is illustrated in Fig. 2. The yearly total rainfalls in Belgrade region varied from 586.9 (mm/year) to 839.0 (mm/year) in the period between 2004 and 2009 year. Besides the total rainfall in 2008, having value of 586.9 (mm/year), the total rainfall values for other years in this period are higher with respect to the average total rainfall value for the years between 1961 and 1990, which is 684.3 (mm/year).

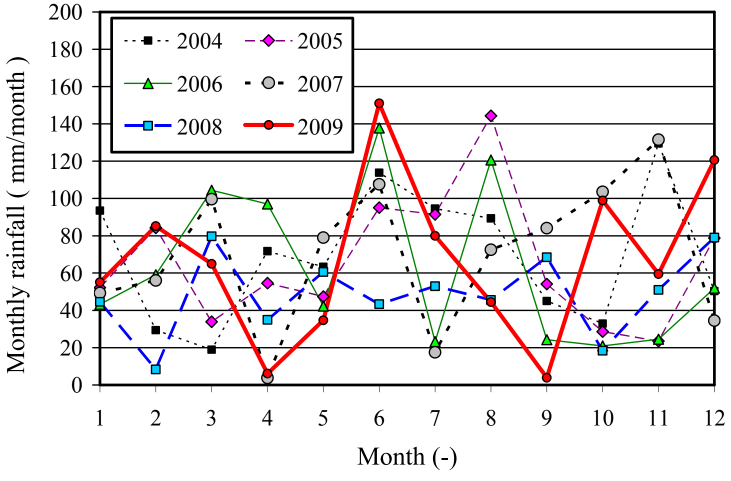


**Figure 2** Monthly rainfalls for the Belgrade region, in the period 2004-2009

The experiment presented in this paper has been conducted in the first half of October 2010, at average air temperature of 14°C and air humidity of 50%. The average temperature for this month, having value of 10.6°C, was lower with respect to the average value of 12.5°C for the October in the years between 1961 and 1990. In the first half of October 2010, the total rainfall value was lower in comparison to the average value for the period 1961-1990.

Tractor "Fendt" 936 Vario, having the engine of 243 kW nominal power and 4x4S driving system has been employed in the autumn tillage of experimental plot together with following implements:

- disc-harrow having the operational width of 4.5 m;
- chisel plough having the operational width of 5.5 m and
- multitiller having the operational width of 6.0 m.

Soil testing has primarily comprehended analysis of the following soil properties: dry aggregate size distribution, penetration resistance and bulk density. Sample sites were equidistantly distributed at 10 m in the longitudinal and lateral direction, as it is shown in Table 1. Sampling zone of the parcel was chosen to be deeply within the inner part of the plot, which was at least 50 m far from the parcel outer borders.

Soil bulk density was measured using the core method (Rowell, 1997). Aggregate size distribution was determined using the dry-sieve modified method of Savinov (Korunović and Stojanović 1989).

**Table 1** Sampling map*

| | | | COLUMNS | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | I | II | III | IV | V | VI | VII | VIII | IX | X |
| | | m | 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 |
| ROWS | I | 0 | * | * | * | * | * | * | * | * | * | * |
| | II | 10 | * | * | * | * | * | * | * | * | * | * |
| | III | 20 | * | * | * | * | * | * | * | * | * | * |
| | IV | 30 | * | * | * | * | * | * | * | * | * | * |
| | V | 40 | * | * | * | * | * | * | * | * | * | * |
| | VI | 50 | * | * | * | * | * | * | * | * | * | * |
| | VII | 60 | * | * | * | * | * | * | * | * | * | * |

***** soil samples were acquired at 70 cross-points of 7 measuring rows and 10 acquisition columns

For aggregate-size distribution, the mean weight diameter of the dry aggregates was calculated by equation described in Hillel, 2004.

In addition, the method of Kachinskiy (Качинский), 1958 is applied for determination of the soil moisture content. Penetration resistance of the soil were measured at depths of 0-5 cm and 5-10 cm by hand penetrometer Eijkelkamp, Set A, having the measuring range up to 10 MPa.

## RESULTS AND DISCUSSION

Average values of bulk density and penetration resistance, are given in Table 2.

**Table 2** The mean values of water content, bulk density and penetration resistance of Humogley (n= 70) after the autumn tillage

| Depth (cm) | Soil water content (% vol.) | Bulk density ($g/cm^3$) | Penetration resistance (MPa) |
|---|---|---|---|
| 0-5 | 15.68 | 1.22 | 0.87 |
| 5-10 | 20.70 | 1.24 | 1.26 |

As it can be seen in Fig. 3, the overall mean percentage of aggregates smaller than 5 mm in size, were 37.74% at depth of 0-5 cm, and 48.61% at soil depth of 5-10 cm. High percentage of small structural aggregates indicates soil dispersion and degradation (Gajić et al., 2010).

At depth of 0-5 cm, content of aggregates fraction 25-50 mm was 20.82%, what can be explained as a consequence of high draught conditions in 2010, which influenced the inappropriate soil conditions for adequate tillage. However, at depth of 5-10 cm, the same fraction was the smaller percentage, only 12.08%.

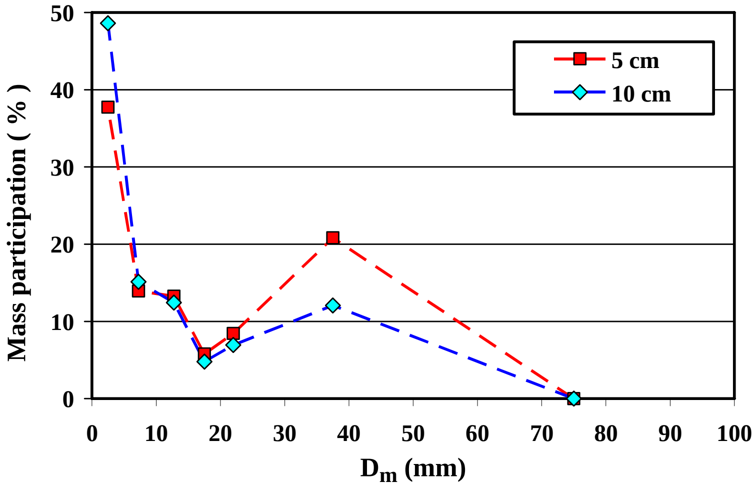


**Figure 3** Overall mean aggregate size distribution obtained by dry-sieving (n=70).

Figures 4 and 5 illustrate distribution of dry mean weight diameters $D_m$ (cm) of soil aggregates taken at depths of 0-5 cm and 5-10 cm with respect to the sampling map shown in Table 1. In these figures, “x” and “y” axes represent longitudinal and lateral coordinates of the square test area of 90 m in length and 60 m in width.

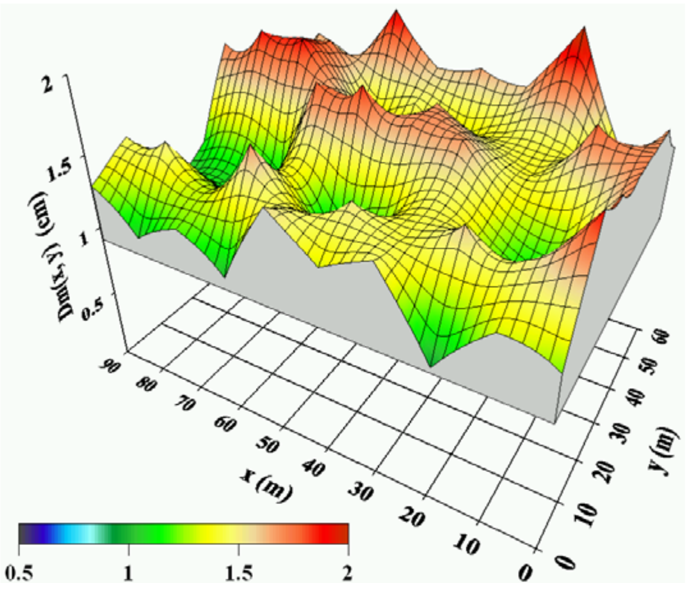


**Figure. 4** Surface map representing the mean diameters of soil aggregates sampled over the experimental parcel at depth of 5 cm.

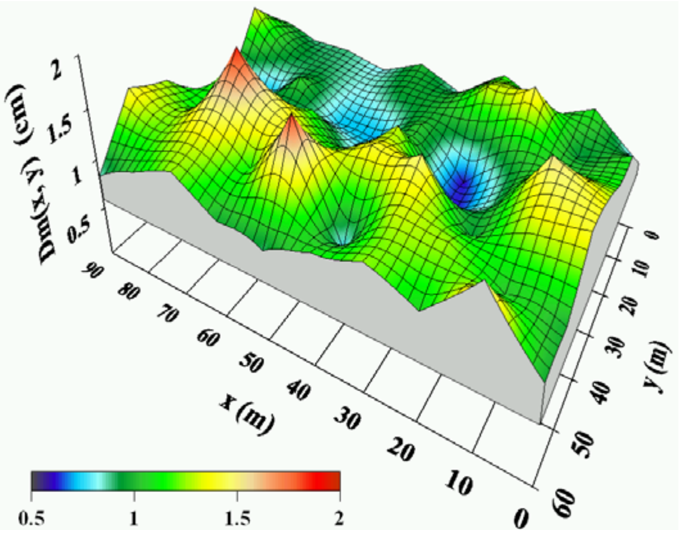


**Figure 5** Surface map representing the mean diameters of soil aggregates sampled over the experimental parcel at depth of 10 cm.

At sampling depth of 0-5 cm, Fig. 4, minimal value of the mean weight diameter was 0.91 cm, the maximum was 2.07 cm, while the overall mean weight diameter (counted using all acquired samples, i.e. for the whole experimental plot) was 1.44 cm. Simultaneously, the coefficient of variation *Cv* of the fraction sizes was in the range between 69.31% and 116.31%.

At depth of 5-10 cm, Fig. 5, the minimum value of the mean weight diameter of aggregates sizes was only 0.59 cm, maximum 1.88 cm, while the overall average (for the whole experimental plot) was 1.09 cm. The variation coefficient *Cv* took also the large values, from 75.67% to 122.51%.

Presented results verify strong non-uniformity of aggregate sizes distribution over the soil area at tested depths, 0-5 cm and 5-10 cm. Among many others, Petrović et al., 2010 analysed similar problem and also reported large dispersion of the mean weight aggregate diameters (0.64 cm and up to 3.69 cm) and variation coefficients of aggregate size distributions (76.18% and 149.79%). However, in contrast to present experiment focused to single specific soil and tillage approach, Petrović et al., 2010 processed 13 soil samples taken during six different experiments related to different soils and tillage techniques.

This way, results of these two studies open again an old question on the sources of evident discrepancies between statistical parameters of soil aggregate size distributions: different soil types, different applied tillage techniques, different weather and irrigation/drainage conditions, or these discrepancies originate from the inadequate (small) number of acquired soil samples used in statistical calculations and analysis. A possible way in resolving the problem is to formulate algorithm for evaluation of the minimum number of soil samples, which provides fairly accurate and reliable measurement results of soil aggregate size distributions.

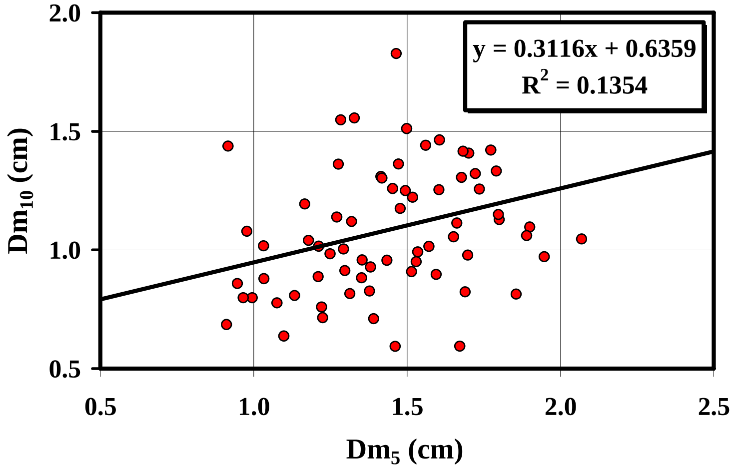


**Figure 6** Relationship between mean diameters of arable soil particles acquired at depths of 5 cm and 10 cm.

The last phase of present study comprehended the analysis of relationships between the mean weight diameters of soil aggregates at depths of 0-5 cm ($Dm_5$) and 5-10 cm ($Dm_{10}$). Literally, as it is shown in Fig.6, we compared the values of mean aggregate diameters $Dm_5$ (abscissa) toward $Dm_{10}$ (ordinate) measured at the same measuring location of the test plot, but at different depths. If the clear and reliable relationship between these two series of Dm values could be found, it could be possible to estimate some statistical parameters of aggregate size distributions at depth of 5-10 cm, using data taken at depth of 0-5 cm. Consequently, measuring and calculation procedure would be simplified, reducing the time required. Unfortunately, the connection between $Dm_5$ and $Dm_{10}$ practically does not exist. It is evident from the Fig. 6, which shows the large dispersion of data points that form some kind of "cloud" in the coordinate system. Therefore, no analytical function that appropriately connects $Dm_5$ and $Dm_{10}$ could be found. To illustrate this finding, Fig. 6 presents the linear trend line, characterized by very low so-called R-square factor reaching the value of only 0.1354.

It follows that mean weight diameters at depths of 0-5 cm and 5-10 cm, are not mutually correlated. Consequently, statistical parameters of soil aggregate sizes distributions must be independently measured for each depth-layer of arable soil.

## CONCLUSIONS

The improvement of conditions for plant production is an imperative for arrable soils characterized by heavy mechanical composition. Literally, it is crucial to improve physical and mechanical soil properties, water and air content and migration, as well as the other soil characteristics. It is verified in present study that autumn tillage of heavy clay soil at the experimental parcel satisfies the common quality criteria for wheat production.

At depth of 0-5 cm, the prevailing portion of 51.67% belongs to structural aggregates smaller than 9.5 mm. The situation is similar at depth of 5-10 cm – the mass content of aggregates smaller than 9.5 mm is 63.75%. Aggregates larger than 50 mm have not been evidenced neither at depth of 0-5 cm, nor at 5-10 cm. Results of analysis clearly show large dispersion of mean weight diameters of soil aggregate, that describe aggregate size distribution over the area of experimental plot. It follows that reliable and accurate measuring results of the relevant soil aggregate size distribution parameters demands processing of large number of soil samples, taken over the whole experimental plot.

## ACKNOWLEDGEMENT

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42. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

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Stručni rad
Expert paper

# WIRED ELECTRICAL EROSION OF HARD AND SUPERHARD METAL COMPONENTS OF AGRICULTURAL EQUIPMENT

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**SUMMARY**

*In the manufacturing technology of various components of the structure of agricultural equipment, especially cutting edge, made by hard and superhard metallic materials, there are many difficulties in using traditional methods, by cutting. This paper presents some processing solutions using wired electrical erosion with the description of some modern integrated systems which can to fulfill a lot of functions which must realized all in real time. It is showed some experiments with Sodick's electrical erosion machine with wire electrode. With the developments in Computer Numerical Control (**CNC**), the versatility of Electrical Discharging Machining (EDM) has reached tremendous heights and has become an indispensable process in modern manufacturing industry because of its ability to produce complex shapes with high degree of accuracy in difficult-to-cut materials.*

*Wire EDM machines always operate with extremely small electrode contact area. Because of this small electrode contact area the average current that may be applied to the Wire is small in comparison. The systems work for 2 axis but can be extended for 4 and 5 axis. In 4 and 5 axis case the personal computer must decompose the complex position for 4 or 5 axes. The precision cutting is now the precision position sensor and mechanical equipment for wire moving. EDM can replace many types of contour grinding operations and eliminate secondary operations such as deburring and polishing.*

*In wire cut process the wire control it's possible even the process speed is high. The differences of necessary times to control the wire in low speed relative to top gear can be short time and the productivity can be the same. It's impossible to touch the high precision and a big productivity for the first step. In first step it's possible to attain a high productivity but with a small precision process.*

***Key words:*** *wired electrical erosion, hard, superhard, metal, agricultural equipment, productivity*

## INTRODUCTION

To achieve a higher productivity, many agricultural machines tools made by hard and superhard metallic materials. Using conventional technologies in their production the costs are very high. Applying some non-conventional technologies it can result a substantial cost reduction, shorter manufacturing and obtaining greater accuracy of processing. This paper presents some studies on the processing of knives from straw and fodder combine harvesters, Romanian and German manufacturing, using wired electrical erosion technology. [6], [2]

## THEORETICAL APPROACH

Electrical discharge machining is a machining method primarily used for hard metals or those that would be very difficult to machine with traditional techniques. EDM typically works with materials that are electrically conductive. In *wire electrical discharge machining* (WEDM), also known as *wire-cut EDM* and *wire cutting*, a thin single-strand metal wire, usually brass, is fed through the workpiece, submerged in a tank of dielectric fluid, typically deionized water. [1] Wire EDM machines always operate with extremely small electrode contact area. Because of this small electrode contact area the average current that may be applied to the wire is small in comparison. The systems work for 2 axis but can be extended for 4 and 5 axis. In 4 and 5 axis case the personal computer must decompose the complex position for 4 or 5 axes. The precision cutting is now the precision position sensor and mechanical equipment for wire moving. EDM can replace many types of contour grinding operations and eliminate secondary operations such as deburring and polishing. [2], [3].

## METHODS

To analyze the processing using WEDM, was chosen processing knives for cutting a straw and forage harvester, whose shape and dimensions are shown in Figure 1.

This serrated edged knife blade (LCZ type, CLAAS, FEPA CODE: 3808 2760), are used for grain and forage harvesters, mounted on support rods specific to these types of blades. Blades are made of alloy tool steel brand 65Mn10 or OSC 8 M and are subject to heat treatment that ensures a hardness of 54÷60 HRC in an area of 7÷12mm and max cutting parallel to the sides, and 35 HRC for the rest.

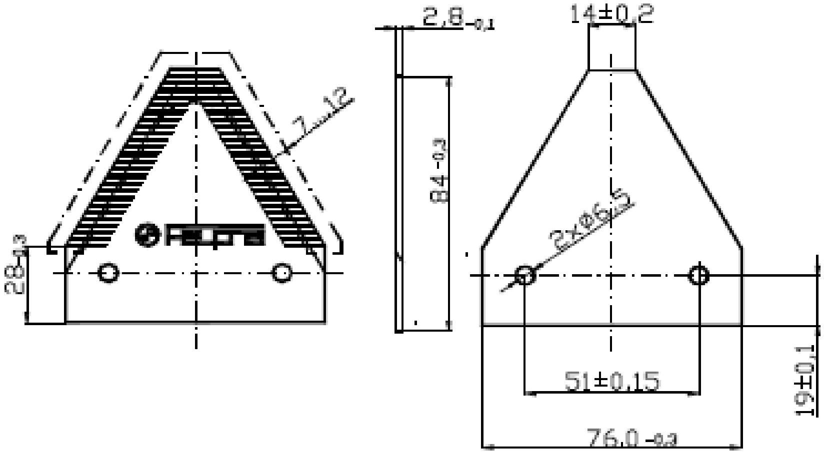


**Figure 1** Serrated edged knife blade type LCZ (CLAAS), for grain and forage harvesters.

Dimensional processing were performed on Ectrical erosion machine Sodick wire AQ300L, equipped on LN1W CNC. (Figure 2).


**Figure 2** Electrical erosion machine Sodick wire AQ300,. equipped on LN1W CNC.

For knife positioning, during processing were made fixtures and appropriate adjustment.

## RESULTS AND DISCUSSION

After experimenting with processing methods were surveyed the potential for increased processing capacity. In the wire cut process the wire control it's possible even the process speed is high. The differences of necessary times to control the wire in low speed relative to top gear can be short time and the productivity can be the same. It's impossible to touch the high precision and a big productivity for the first step. In first step it's possible to attain a high productivity but with a small precision process. [4], [6].

For that it was made some analysis about the influence of the pulses to processing time:

- The increased processing time depends on the decrease during pulse ON time. OFF pulse time is 15μs. ON time drop below 9 μs lead to process instability, resulting the wire breaking.
- When the weight of used wire loss it proves the wear results during the processing.
- The roughness evolution of the surface machined based on the time ON, show that with the increasing of ON time results the roughness increasing. [2], [6].

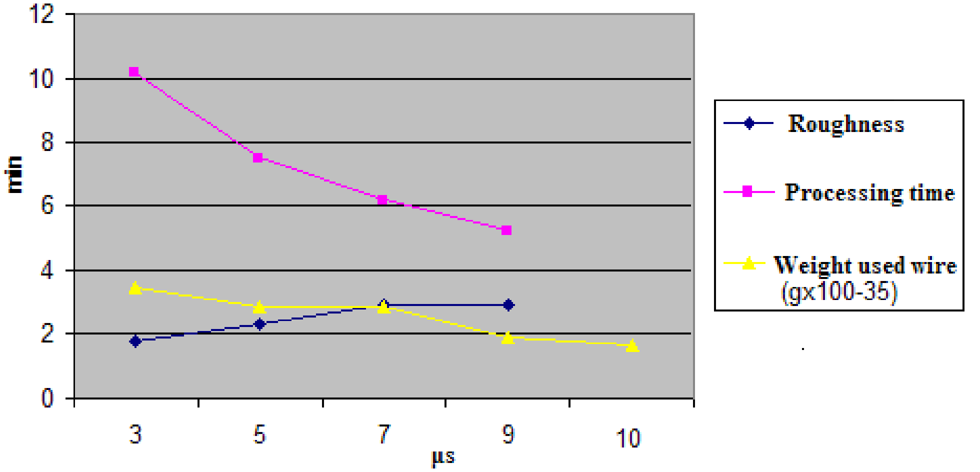


**Figure 3** The evolution of parameters: roughness, processing time and weight of the wire.

Maintaining the voltage and time constant OFF and analyzing the processing in according with the ON time is observed that it can influence processing can greatly compromise processing: by the increasing the time, the wire lose weight as it increases its wear will break. Also the increasing ON time lead to a faster process but also with the influencing of the quality of the piece surface measured by roughness.

If the ON time decreases that leads to a low roughness, low wear of the wire, but also low productivity. One small roughness surface processed with decreasing processing time leads to the conclusion that this system of generators can be used if it want a high dimensional accuracy. By reducing the processing time and for high roughness of work demonstrates that this regime can be successfully used for debits where it are not very interested in surface quality and dimensional accuracy.

For modern automation of electrical erosion machine with wire electrode it can use also an expert system.

Expert systems are used to reach a conclusion, a solution or a recommendation. EXSYS CORVID uses for these conclusions/recommendations term GOALS (alternative-purposes). The execution rules for obtaining conclusions/recommendations are necessary responses to be taken from users through specialized interfaces or interfaces with other external programs. This knowledge of the system are stored and subsequently evaluated by the rules. If permission from the IF of a rule is true knowledge will enable spare part for THEN, otherwise knowledge will enable parts of the ELSE. If the ELSE part will stick to cold the next rule in the decision tree. EXSYS CORVID uses two types of facts (pieces of knowledge) Questions and Variables.

It aim to create a prototype expert system to decide how to set the parameters of cutting machine, the prototype will be called CUTTING given the subject matter knowledge base. From this point it can proceed to create a new knowledge base or the consultation or updating existing ones. After a good experience and respecting general principles of product design information available it recommends that the analysis problem resolved to undertake knowledge that the following parts: goals, questions and specific variables EXSYS CORVID generator. Thus for each processing type it will be possible to use the expert system to make the best decision regarding the setting of pulse generator.

## CONCLUSIONS

In the current improvement of technical systems for processing of hard and superhard metal components from the structure of modern agricultural machinery, choosing the most efficient technological options with the considering all the influence factors.

In the modern system using wire cut process the wire control it's possible even the process speed is high. The differences of necessary times to control the wire in low speed relative to top gear can be short time and the productivity can be the same. To touch the high precision and a big productivity it is necessary to use good and modern equipment with a high level of automation.

For series production it can use artificial intelligence that can be a very effective solution, also for the ensuring quality products.

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42. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

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# PORABA GORIVA PRI DELU Z EKONOMSKO PRIKLJUČNO GREDJO

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## POVZETEK

*Zorana zemlja ni dovolj zdrobljena in poravnana, da bi bila primerna za setev, zato jo moramo dopolnilno obdelati. Uporaba vrtavkaste brane je najbolj razširjena metoda za dopolnilno obdelavo tal. Namen raziskave je ugotoviti kako obdelati tla, da bomo za to porabili čim manj goriva in časa. Zanimalo nas je, kako na porabo goriva vpliva število vrtljajev motorja in priključne gredi. Primerjali smo porabo goriva pri dopolnilni obdelavi tal na jeseni in na spomladi zoranih njivah. Za poskus smo uporabili traktor Case-IH JX90 in vrtavkasto brano VOGEL NOOT Terramat L 250. Povprečna poraba pri brananju na jeseni zorani njivi pri nazivnih vrtljajih motorja 2199 min$^{-1}$ je znašala 10,7 l/ha, pri vrtljajih motorja 1715 min$^{-1}$ pa 7,9 l/ha. Na spomladi zorani njivi je znašala poraba pri 2199 min$^{-1}$ 9,5 l/ha, pri 1715 min$^{-1}$ pa 8,7 l/ha. V obeh primerih je bila hitrost vrtenja priključne gredi 540 min$^{-1}$. Z gotovostjo lahko trdimo, da je uporaba ekonomske priključne gredi smiselna in ekonomsko upravičena.*

***Ključne besede:*** *obdelava tal, vrtavkasta brana, ekonomska priključna gred, poraba goriva*

## UVOD

Zaradi vse slabših ekonomskih razmer v kmetijstvu se kmetje poslužujejo ukrepov, s katerimi lahko privarčujejo gorivo. Gorivo lahko prihranimo z izbiro pravilnega tlaka v pnevmatikah, obtežitvijo traktorja, pravilno tehniko vožnje, usklajenosti traktorja in delovnega priključka, ekonomsko priključno gredju ter rednim vzdrževanjem traktorja.

Tlak v pnevmatikah bistveno vpliva na zdrs koles. Ker je pri nižjem tlaku oprijem pnevmatike s podlogo najboljši, je tudi dejanska pot prevožena pri oranju najkrajša. To pomeni, da je takrat tudi najmanjši zdrs pogonskih koles. Z večanjem tlaka v pnevmatikah se oprijem pnevmatike s podlogo zmanjšuje, zato v povprečju narašča tudi odstotek zdrsa, kar posledično vpliva tudi na porabo goriva. Pri oranju njive s 0,8 barov tlaka v pnevmatikah je bila poraba 21,9 l/ha, pri tlaku 2,4 bara pa 25,8 l/ha. Meritev je bila opravljena s standardnim traktorjem Deutz Fahr K100 in 3-brazdnim plugom PÖTTINGER SERVO 25-302. Delovna širina pluga je znašala 1,2 m (Kacijan, 2010).

Traktor mora biti tako lahek, kot je mogoče in tako težak, kot je potrebno. Velike uteži imajo to pomanjkljivost, da je treba premikati nepotrebne mase, npr. za dela s priključno gredjo ali lahka vlečna dela. Pri lahkih traktorjih lahko obremenitev koles, ki je potrebna za vlečne sile, prilagodimo aktualnim potrebam z dodajanjem uteži zaradi zmanjšanja tveganja zdrsa, ki pomaga prihraniti gorivo. Prednji balast je potreben samo na cesti in na ozarah, ko obdelujemo s težkimi zadnjimi priključki (Uppenkamp, 2006).

Vožnja z izhodno močjo okrog 60 % nazivne moči in okrog 92 % nazivne hitrosti motorja ima za posledico specifično porabo goriva, ki znaša 260 g/kWh. Če vozniku uspe doseči enako izhodno moč pri približno 64 % nazivne hitrosti motorja, npr. z izbiro pravilne prestave ali z upravljanjem na pravilen način brezstopenjskega menjalnika, se specifična poraba goriva zmanjša na 230 g/kWh. V tem primeru lahko prihranimo do 12 % goriva. Upadajoči vrtljaji motorja so uravnoteženi z naraščajočim navorom. Motorji delujejo najbolj učinkovito pri obremenitvi 60–80 % nazivne moči in pri 60–70 % nazivnih vrtljajev motorja (Handur in Nadlinger, 2012).

Moč traktorja je potrebno uskladiti z delovno širino priključka. Na ta način lahko privarčujemo od 5–8 % goriva. Vsakršno pretiravanje s prevelikim ali s premajhnim delovnim priključkom prinaša nepotrebne dodatne stroške (Moitzi, 2006).

Večina novejših traktorjev ima že vgrajeno ekonomsko priključno gred, ki omogoča zelo enostavno varčevanje z gorivom, torej doseganje 540 vrt/min priključne gredi pri 20–25 % nižjem številu vrtljajev motorja, kot so potrebni za doseganje največje moči motorja traktorja. Tako lahko vozimo traktor znotraj območja minimalne specifične porabe goriva (Konečnik, 2013).

Samo s skrbnim vzdrževanjem lahko zagotovimo, da bo učinkovitost pretvorbe energije iz goriva čim boljša. Ko kupujemo traktor, moramo misliti tudi na njegovo čim enostavnejše vzdrževanje. Težave v zvezi z vzdrževanjem lahko privedejo do relativno majhnega ali tudi prevelikega deleža zraka v zgorevalni komori. Optimalno mazanje motorja in prestavnega sistema zmanjšuje izgube zaradi trenja. Olje je potrebno kontrolirati in menjavati v rednih intervalih, ki jih predpiše proizvajalec traktorja (Uppenkamp 2006).

Namen raziskave je ugotoviti, kako ekonomska priključna gred vpliva na porabo goriva pri delu z vrtavkasto brano. Primerjali bomo porabo goriva med jeseni zorano njivo ter njivo zorano po spomladanski košnji. Najti želimo optimalno porabo goriva in čas obdelave, ki bi nam prinesel največji ekonomski učinek (Konecnik, 2013).

## METODE DELA

### *Poskusne parcele in zasnova poskusa*

Meritve porabe goriva z vrtavkasto brano so potekale na dveh parcelah. Prvi poskus je potekal na njivi imenovani »Čez cesto«. Površina njive je 0,7 ha. Drugi poskus je potekal na 2,1 ha veliki njivi, za katero je domače ime »Njiva pod Homcem«. Obe njivi se nahajata v kraju Šmartno pri Slovenj Gradcu ter sta v lasti kmetije Konečnik. Tla so na obeh njivah peščena in lahka za obdelavo.

*Uporabljena mehanizacija*

Pri brananju smo uporabili traktor Case JX 90, ki ima 4,5 l dizelski motor z močjo 65 kW pri 2500 $min^{-1}$. Masa traktorja je 3600 kg brez uteži. Nameščen ima sinhroniziran menjalnik 12/12 z mehanskim spreminjanjem smeri vožnje.

Hidravlični sistem poganja črpalka s pretokom 40,1 l/min. Hidravlična dvigalka in distributerji so krmiljeni mehansko. Nameščena ima dva para hidravličnih ventilov. Na traktorju so nameščene pnevmatike dimenzij, zadnje 420/85 R 34, sprednje 340/85 R 24. Dolžina traktorja je 4244 mm, širina 2100 mm, višina 2620 mm ter medosna razdalja 2312 mm. Traktorska priključna gred ima dve hitrosti in sicer 540 $min^{-1}$ pri 2199 $min^{-1}$ motorja ter 750 $min^{-1}$ (540E) pri 2380 $min^{-1}$ motorja. Doseženа končna hitrost je 40 km/h. Za mešano delo na kmetiji je bila razvita tudi komfortna kabina, ki s svojo prostornostjo omogoča prijetno delo tudi v zahtevnih pogojih.

Za obdelavo tal je bila uporabljena vrtavkasta brana VOGEL NOOT Terramat L 250 (Slika 1). Modeli bran Terramat spadajo med izredno uporabne stroje, saj zajemajo vse od enega do štirih metrov delovne širine. Imajo kratko in lahko konstrukcijo, zato ni večjih težav z razbremenjevanjem prednje traktorske osi na ozarah ali med transportom. Specifičnost teh bran je veliko število rotorjev. Uporabljeni model ima delovno širino 2,5 m ter 11 rotorjev na katerih je nameščenih 22 nožev. Noži so izdelani iz drobnozrnatega mikro-legiranega borovega jekla in so dolgi 300 mm. Na desni in levi strani so nameščene varnostne pločevine zaradi točnosti odmetavanja zemljišča po delovni širini stroja in zaradi varnosti.

**Figure 1** Power harrow VOGEL NOOT Terramat L 250

Da je njiva pred setvijo tudi poravnana, poskrbi ravnalna deska, ki je nameščena za noži. Posebno funkcijo ima valj za drobljenje, premera 500 mm. Njegove naloge so, da :

- dobro drobi zemljo na trdih tleh;
- zemljo utrdi nižje kot nazobčani paker valj;
- zemljo odlično zrahlja.

*Meritev porabe goriva*

Porabo goriva smo merili s pomočjo plastične merilne čaše volumna 1200 ml. Pred brananjem smo rezervoar do vrha napolnili z gorivom. Po vsakem opravljenem poskusu smo z merilno čašo dolili porabljeno gorivo in odčitali količino.

Meritve so potekale na dveh parcelah. Prva parcela, za katero je domače ime »Čez cesto«, je bila zorana jeseni pred snegom, tako da smo opazovali tudi, koliko je zima pripomogla k spomladanski pripravi zemlje in ali je vplivala na porabo goriva.

Druga parcela ni bila zorana jeseni, temveč je bila posejana s travno-deteljno mešanico in smo pred spomladanskim oranjem na njej opravili še en odkos.

Z merilnim metrom smo odmerili posamezne parcele, na katerih smo merili porabo goriva. Vsako meritev smo izvajali v treh ponovitvah. Najprej smo merili porabo goriva na parceli »Čez cesto«, nato pa še na »Njivi pod Homcem«.

## REZULTATI

*Poraba goriva na jeseni zorani njivi (»Čez cesto«)*

Rezultati merjenja porabe goriva pri vrtilni frekvenci motorja 2199 in 1715 min$^{-1}$ na jeseni zorani njivi so prikazani v Preglednici 1. V preglednici sta vidna tudi čas in izračunana je hitrost obdelave, ki smo ju porabili za obdelavo v poskusu. Vse meritve so bile opravljene v treh ponovitvah.

**Table 1** The results of tillage with a rotary harrow on autumn ploughed field

| Measurement | Path or lenght (m) | RPM of PTO (min$^{-1}$) | RPM of engine (min$^{-1}$) | Time (s) | Calculated speed (m/s) | Fuel consumption (L) | Calculated fuel consumtion (L/ha) |
|---|---|---|---|---|---|---|---|
| 1 | 134 | 540 | 2199 | 80 | 1,675 | 0,35 | 10,45 |
| 2 | 134 | 540 | 2199 | 84 | 1,595 | 0,37 | 11,04 |
| 3 | 134 | 540 | 2199 | 82 | 1,635 | 0,35 | 10,74 |
| Average | | | | 82 | 1,635 | 0,36 | 10,745 |
| 1 | 134 | 540 | 1715 | 72 | 1,861 | 0,26 | 7,76 |
| 2 | 134 | 540 | 1715 | 73 | 1,830 | 0,262 | 7,90 |
| 3 | 134 | 540 | 1715 | 74 | 1,810 | 0,27 | 8,05 |
| Average | | | | 73 | 1,833 | 0,264 | 7,904 |

Iz rezultatov je razvidno, da je razlika v porabi med nazivnimi vrtljaji motorja 2199 min$^{-1}$ in 1715 min$^{-1}$ vrtljaji motorja znašala 2,84 litra po hektarju. Cena za liter dizelskega goriva znaša že 1,39 evra, kar pomeni, da bi pri obdelavi 10 ha velike površine lahko privarčevali nekaj manj kot 40 evrov.

Ker je navor traktorja zadosten, da motor brez problema poganja priključno gred pri 540 min$^{-1}$ pri 1715 min$^{-1}$ motorja eno prestavo višje kot pri 2199 min$^{-1}$, pridobimo zaradi večje hitrosti približno 8 minut po hektarju. To pa pri večjih površinah predstavlja kar veliko pridobitev časa.

*Poraba goriva na njivi, zorani spomladi po prvem odkosu*

Rezultati merjenja porabe goriva pri vrtilni frekvenci motorja 2199 in 1715 min$^{-1}$ na spomladi zorani njivi so prikazani v Preglednici 2. Poraba goriva je bila merjena na njivi katera je bila zorani spomladi po prvem odkosu travno deteljne mešanice. Vse meritve so bile opravljene v treh ponovitvah.

**Table 2** The results of tillage with a rotary harrow on spring ploughed field

| Measurement | Path or lenght (m) | RPM of PTO (min$^{-1}$) | RPM of engine (min$^{-1}$) | Time (s) | Calculated speed (m/s) | Fuel consumption (L) | Calculated fuel consumtion (L/ha) |
|---|---|---|---|---|---|---|---|
| 1 | 131 | 540 | 2199 | 75 | 1,746 | 0,29 | 8,85 |
| 2 | 131 | 540 | 2199 | 77 | 1,700 | 0,32 | 9,44 |
| 3 | 131 | 540 | 2199 | 79 | 1,658 | 0,33 | 10,07 |
| Average | | | | 77 | 1,702 | 0,31 | 9,46 |
| 1 | 131 | 540 | 1715 | 70 | 1,871 | 0,28 | 8,54 |
| 2 | 131 | 540 | 1715 | 71 | 1,843 | 0,28 | 8,70 |
| 3 | 131 | 540 | 1715 | 72 | 1,819 | 0,29 | 8,85 |
| Average | | | | 71 | 1,845 | 0,285 | 8,695 |

Po brananju njive, na kateri smo opravili en odkos pred oranjem, je bila posejana koruza. Iz Preglednice 2 vidimo, da se je poraba goriva pri obdelavi z vrtilno frekvenco motorja 2199 min$^{-1}$ nekoliko znižala glede na brananje po jesenskem oranju. Pri brananju z vrtilno frekvenco motorja 1715 min$^{-1}$ pa je poraba nekoliko narasla glede na brananje po jesenskem oranju. Upoštevati je treba tudi to, da smo pripravo njive za setev opravili takoj po oranju. Če bi z brananjem čakali še kakšen dan, bi se zorana površina zasušila in takrat bi bilo zemljo veliko težje tako kvalitetno obdelati.

*Izračun storilnosti*

Storilnost na jeseni orani njivi pri 2199 min$^{-1}$ motorja znaša 1,47 ha na uro, pri 1715 min$^{-1}$ pa znaša 1,65 ha na uro.

Pri pomladnem oranju znaša storilnost pri 2199 min$^{-1}$ 1,53 ha na uro, in pri 1715 min$^{-1}$ 1,66 hektara na uro.

Če bi merili čas brananja celotne njive, bi dobili nekoliko manjšo storilnost, saj pri izračunu nismo upoštevali obračanja na koncu njive.

Oglejmo si še primerjavo, kako čas oranja in zimski mraz vplivata na storilnost pri različnih vrtljajih motorja. To nam prikazuje Grafikon 2.

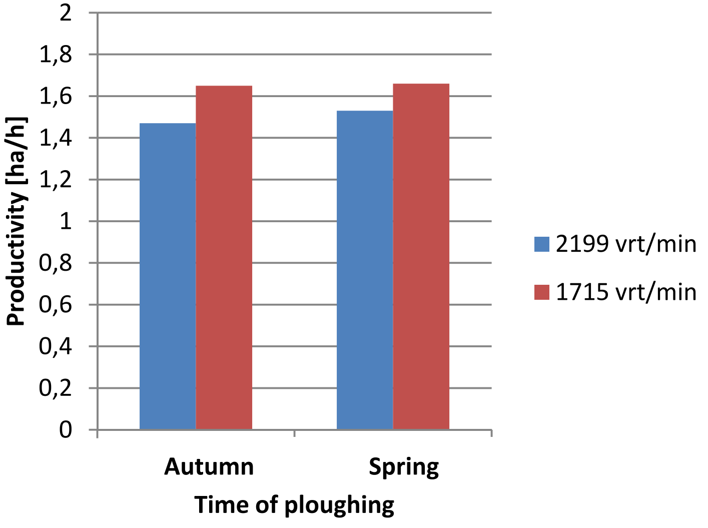


**Figure 2** A comparison of productivity between autumn and spring ploughing

*Primerjava rezultatov porabe goriva med poskusom 1 in poskusom 2*

Ker gre za zelo lahka peščena tla, vidimo, da letni čas oranja bistveno ne vpliva na porabo goriva in so razlike v porabi minimalne.

Ko smo branali z 2199 $min^{-1}$ vrtljaji motorja na njivi zorani jeseni, je poraba znašala 10,7 litra po hektarju, pri enakih vrtljajih na spomladi zorani zemlji pa 9,5 l/ha, kar je za 1,2 l več.

Pri 1715 $min^{-1}$ motorja je na jeseni zorani zemlji znašala poraba 7,9 l/ha, na zemlji orani spomladi pa 8,7 l/ha, kar je za 0,8 l manj.

Iz Grafikona 3 vidimo, da je poraba goriva nižja pri uporabi ekonomske priključne gredi tako po jesenskem oranju kot po spomladanskem. V povprečju smo z uporabo le-te privarčevali 1,8 litra po hektarju. Pri obdelanih desetih hektarjih bi torej privarčevali 18,0 litrov dizelskega goriva. Če to pomnožimo s ceno goriva za liter, ki je takrat (1. 5. 2013) znašala 1,39 evra, dobimo vrednost 25 evrov, ki je pri današnji ekonomski situaciji v kmetijstvu ne gre zanemariti.

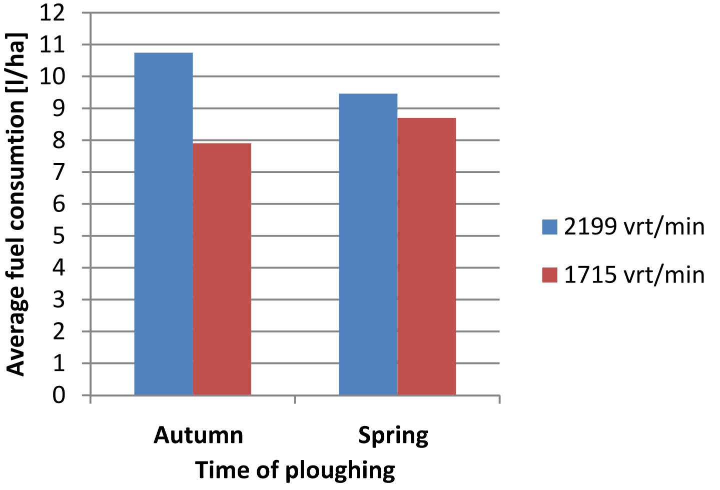


**Figure 3** Comparison of fuel consumption in litres per hectare

## ZAKLJUČKI

V raziskavi smo primerjali porabo goriva pri delu z vrtavkasto brano pri vrtljajih motorja 2199 $min^{-1}$ in 1715 $min^{-1}$ in enaki vrtilni frekvenci priključne gredi (540 $min^{-1}$). Porabo smo merili na dveh parcelah; prva je bila zorana jeseni in druga spomladi po opravljenem odkosu travno-deteljne mešanice.

Ugotovili smo, da je na jeseni zorani njivi povprečna poraba goriva pri 2199 $min^{-1}$ motorja znašala 10,7 l/ha in pri 1715 $min^{-1}$ 7,9 l/ha. Na spomladi zorani njivi je povprečna poraba goriva pri 2199 $min^{-1}$ vrtljajih motorja znašala 9,5 l/ha in pri 1715 $min^{-1}$ 8,7 l/ha.

Iz dobljenih rezultatov lahko sklepamo, da je uporaba ekonomske priključne gredi smiselna v primeru, da njivo zorjemo jeseni, saj k razgradnji oziroma pripravi zemlje doda tudi zimski mraz.

Največja storilnost je bila dosežena pri uporabi ekonomske priključne gredi, saj lahko z njo obdelamo v eni uri 15 arov več kot pri uporabi standardne priključne gredi.

Iz rezultatov meritev vsem uporabnikom traktorja in delovnih strojev priporočamo uporabo ekonomske priključne gredi. Tako bodo privarčevali na gorivu in hkrati manj obremenjevali traktor.

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# FUEL CONSUMPTION WORKING WITH ECONOMY PTO

PETER VINDIS, DENIS STAJNKO AND MIRAN LAKOTA

*Plough soil is not enough crushed and levelled to be appropriate for sowing, so it needs to be cultivated. The use of power harrow is the most common method for soil cultivation. The main purpose of the research was to find out, how to cultivate soil with the lowest fuel and time consumption. The effect of the number of revolutions on the fuel consumption and PTO was investegated. Fuel and time consumption in soil cultivation of autumn and spring ploughing field was compared. Tractor Case-IH JX90 and power harrow VOGEL NOOT Terramat L 250 was used for our experiment. Average fuel consumtion for soil cultivation on autumn plough field was 10.7 l/ha by 2199 min$^{-1}$ rated number of revolutions and 7.9 l/ha by 1715 min$^{-1}$. Average fuel consumption for soil cultivation on spring ploughed field was up to 9.5 l/ha by 2199 min$^{-1}$ and 8.7 l/ha by 1715 min$^{-1}$. In both cases the rotation speed of power harrow was 540 min$^{-1}$. We can definitely assert that the consumption of economy PTO is reasonable and economically justifiable.*

**Key words:** *soil cultivation, power harrow, economy PTO, fuel consumption.*

42. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

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Prethodno priopćenje
Preliminary communication

# ANALYSIS OF TRANSVERSE DISTRIBUTION OF FERTILIZERS GRANULES SPREAD BY USING SOME SPREADERS

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## SUMMARY

*The quality of fertilizer spreader work is reflected primarily in the equitable fertilizer distribution by working width and maintains standards scattering. Bearing in mind that the production of fertilizers still consumes the most energy in agricultural production, it is desirable and necessary that the distribution of mineral fertilizer is preferably smooth and perfect the entire surface to be treated. The aim of this study was to determine the effects of different types of fertilizer spreaders, in agro ecological conditions of central Serbia. Method included the application of standard procedures for the study and testing of centrifugal spreaders prescribed by standards of which the ASAE S341.2, which is adapted to local test conditions and in addition of required assessments. The test conditions were specified in the first phase and work quality of spreader and uniformity of distribution, mineral fertilizers, the theoretical norm of 250 kg ha$^{-1}$. In all tested fertilizer spreaders were noted that approaching the limits of tolerance of 15 % compared to standard fertilization with theoretical working width of 12 m. On the overlap in the measured amounts of fertilizer were higher than the allowable 15% deviation. At lower standards in all tested fertilizer spreader recorded higher imprecision than at higher standards of fertilization. With the fertilizer type B (SF400) in setting standards of 250 kg ha$^{-1}$ average deviations were 17.31% (206.72 kg ha$^{-1}$), while with the other two fertilizer the deviations were a bit smaller. The lowest average deviations defined in comparison to the projected (theoretical) dose of the fertilizing were written down with the fertilizer type C (TG402) and they were 12.10%, or 219.76 kg ha$^{-1}$.*

***Key words**: fertilizer spreader, distributions, work quality, granules*

## INTRODUCTION

Contemporary designs of centrifugal granular fertilizer spreaders should ensure fairly uniform fertilizer mass dispersion across the whole working width/area at different machine speeds. In the situations characterized by uneven fertilizer distribution, deviations greater than 15% may significantly affect the expected crop yields, Persson (2000), Srivastava et al, (2006). This is in full agreement with Malinović et al 2011, who claimed that maximal acceptable value of variation coefficient of fertilizer transversal distribution is 15%. Therefore, application of high quality fertilizer spreaders represents an important prerequisite of modern agricultural plant production of any kind.

Companies and cooperatives in Serbia own 707 fertilizer spreaders of various types, while for private farmers there are no precise data (Statistical Yearbook of Serbia, 2012). Following the source, 482.878 t of nitrogen fertilizers, 5.703 t of phosphates, 36.000 t of complex and 226.463 t of mixed fertilizers have been produced in Serbia during the last year. In the central region of Republic of Serbia, where the experiments presented in this paper have been conducted, centrifugal spreaders equipped with the disc apparatus are most commonly used for spreading the mineral fertilizers.

Nowadays, most of competitive agricultural strategies demands/assumes the best possible transversal mass distribution of specified fertilizers by using centrifugal machine spreaders at different tractors' paths. Most of proposed methods of this kind are based on the optimal setup of fertilizer spreaders depending on the performance and the possible defects, Fulton (2001).

Fulton et al, (2003) analyzed different types of fertilizer spreaders, focusing their attention to design and operation of the spreading mechanisms. They pointed out that contemporary fertilizer spreaders require carefully prepared granular fertilizers, which has pretty uniform physical and mechanical properties. More precisely, only such kind of fertilizer can assure the uniformity of deposition over the treated soil area.

Palmer et al, (2003) reported that fertilizer deposition errors can reach extremely high values, close to 95%, which can result in serious environmental and economic problems. The authors concluded that, among other possible approaches, the application accuracy can be simply increased by detailed pre-planning of the tractor/spreader trajectories over the surface of interest. This kind of approach results in defining the optimal paths for the implement, which guarantee fertilizer distribution within specified limits around the norm.

Under-application of fertilizer generally results in yield losses, while the over-application causes ground-waters and watercourses pollution by fertilization. Consequently, European and American governments have accepted general agreement to impose strict rules, in accordance to Bruxelles (2005). Following such kind of requirements, experimentalists and engineers have intensified their activities in order to improve the quality of the fertilizer distribution achieved by centrifugal machine spreaders.

Optimal surface distribution of applied fertilizer assumes that the actual amount of distributed fertilizer mass per square unit of soil area is equal to the prescribed value at any point over a treated field. Furthermore, this specified optimal amount has to be determined on the basis of agronomic and soil (pedologic) assessments, which provide balancing the needs of the crops optimal growing.

Virin et al, (2005, 2006) claimed that, nowadays, centrifugal machine spreading represents the most commonly used technique that enables accurate distribution of mineral fertilizers with respect to desired doses. In general, this kind of machine spreaders design may provide satisfying results under simple operational condition, which demands regularly spaced and parallel tractor trajectories during the process of fertilizer distribution over the whole treated soil area. Unfortunately, the employment of spreaders of this kind still suffers from some imperfectness: geometrical irregularities in the tractor/spreader motion, like non-parallel paths, start and end of spreading, etc. lead to over-application or under-application with respect to the specified fertilizer's mass amount per soil area. However, this goal can be achieved only through careful applying of sophisticated machine spreader set-up and control procedures.

The quality of fertilizer transverse distribution can be evaluated, among others, by fitting the empirical field data. Perfect distribution of fertilizer assumes the fitted curve of experimental data "points" having the form of horizontal straight line, distanced from the abscissa at the level of specified fertilizer dosing norm. This means that distribution is as good as the fitted curve is closer to a straight line up to the pre-set standard dose value, Turan and Findura (2009).

Đević et al, (2009) analyzed the impact of physical characteristics on the efficiency of centrifugal fertilizer spreaders applications and point out that analysis of the results, especially the coefficient of variation ranges between 35 and 40% indicating a worse quality of centrifugal type spreader manufacturers VICON compared to fertilizer RCW, with similar defined parameters

Fertilization represents a crucial stage of any agricultural plant production system, specified to supply the soil with necessary nutritional elements needed for optimal crop growth. More precisely, all mineral soil components that has been spent for growing the cultivated crop during a previous season must be compensated by fertilizing to provide optimal growing conditions for a new plant generation in the next season. This process is especially is important in the area of so-called "precision farming", where fertilization significantly affect yield in crop production, economic effectiveness of farming in general, but also so the environment preservation. Proper and accurate application of fertilizers is affected not only by machine parameters, and natural conditions, but also by the properties of applied fertilizers, Macak and Nozdrovicky (2010).

## MATERIAL AND METHOD

This paper presents results of operational field testing of three types of carried fertilizer spreaders, equipped with centrifugal disc-type distribution mechanisms: Agromehnika AG400 (labeled as "type A"), Ferti SF400 (marked as "type B"), and Tehnos TG402 (labeled as "type C"). Basic technical data of tested mineral fertilization spreaders are listed in Table 1. Spreaders worked in aggregate with tractors of 45; 47 and 52 kW, respectively. The experiments have been conducted in 2012, according to ASAE standard S341.2. The horizontal experimental parcel was placed in the region of central Serbia (Šumadija district, Cerovac field $44^0$ 06′ 00" N, $20^0$ 51′ 00" E).

**Table 1** Technical data for tested mineral fertilizer spreaders

| Parameter | Spreader type | | |
|---|---|---|---|
| | AG400 (type A) | SF400 (typeB) | TG402 (typeC) |
| Tank capacity (l) | 320 | 320 | 400 |
| Working width (m) | 12-14 | 6-18 | 10-12 |
| Spreader weight (kg) | 63 | 58 | 92 |
| Required power (kW) | Max. 18 | Max. 18 | Max. 18 |
| Apparatus type / | Centrifugal disc | Centrifugal disc -2 | Centrifugal disc-2 |
| Number of blades / | 4 | 6 | 6 |
| Maximal capacity (kg) | 450 | 450 | 550 |
| Rpm $min^{-1}$ | 540 | 540 | 540 |

In the focus of interest was the accuracy of spreaders work, which have been evaluated on the base of the achieved uniformity of fertilizer transversal distribution with respect to the norm – preset nominal value of fertilizer mass per soil area of 250 kg $ha^{-1}$ (control). All three spreaders were examined during presowing preparation for planting corn crop. The working width was 12 m in all cases.

Data sampling has been performed using collecting vessels, accurately positioned in the three successive parallel lines, positioned orthogonally with respect to the walking directions of tractor/spreader aggregates under evaluation. However, the need to provide a free walking area for a tractor/spreader aggregate, resulted in a gap of empirical data, positioned in the central part of the measuring width. After passing the aggregate, fertilizer granules fell into the marked "measuring" cups of 40x50 cm in width and 10 cm in height. Each cup was equipped with an internal honeycomb network, which prevents deflection of acquired granules. Consequently, a sample from one measuring vessel represents a mass of fertilizer deposited per soil surface of 0.20 $m^2$ (in grams), which was then mathematically recalculated toward the norm of fertilizer mass per hectare (kg $ha^{-1}$). In investigation used granulated fertilizer NPK 15:15:15. Wind speed was measured by the anemometer and not higher than 1,7 m $s^{-1}$, while a test track was measured by ribbon of 50 m in length. All spreaders under investigation have been tested under three runs of aggregates. Operating speed, amounted to 10.90 km $h^{-1}$, 11.45 km $h^{-1}$ and 11.76 km $h^{-1}$, was evaluated by measuring the aggregate walking time over distance of 20 m, defined by appropriate markers.


**Figure 1** The satellite snapshot of the field of the research

## RESULTS AND DISCUSSION

Table 2 presents the transversal mass distribution of mineral fertilizer per unit of treated soil areas, deposited by three tested machine spreaders, which were preset to the norm of 250 kg $h^{-1}$ (control).

These results it can be noted that the distribution of fertilizers to all three spreader reaching the threshold of tolerance deviations up to 15% compared to the projected norm of fertilization in the zone up to 8 m working width.

The extended work-mesh overlap, it can be seen that the measured amounts of fertilizer were ejected above the tolerable deviation of 15% compared to controls, in all investigated spreaders, looking across the working width to the left and right sides.

Analyzing the results of the transverse distribution of mineral fertilizers which are shown in Table 2 for each individual spreader, it is observed that the measured ejected quantities of fertilizers vary in the breadth of the project in relation to the projected norm (control).

Deviations are particularly pronounced at 10, 11 and 12 m working width of the left and right of the center line of engine (tractor + fertilizer) and were thrown out significantly less fertilizer compared to the projected norm. By 8m of working width to the left and right of the center line of aggregate amounts of fertilizer were removed were tolerant of variations in the level of 15%.

Spreader with type B (SF400) was the largest deviation measured ejected quantities of fertilizers, with the amount of fertilizer was ejected 206.72 kg $ha^{-1}$ (Average**)** , which is the standard fertilizer shortfall recorded in relation to the projected 17.31%.

The lowest standard deviation was at fertilizer spreader C (TG 402), which has launched an average of 219.76 kg $ha^{-1}$(Average**)** , which is a deviation of 12.10% compared to the projected norm (control).

**Table 2** Transverse distribution of fertilizers

| Ejected fertilizer quantity (Spreader AG400 -Type A) ($kg\ ha^{-1}$) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | The position of cups ← | | | | | | Course motion ↑ | | | | |
| Num. of samples | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | Average |
| Dose ($kg\ ha^{-1}$) | 164.60 | 178.83 | 195.92 | 210.86 | 211.87 | 223.74 | 226.32 | 229.58 | 234.41 | 238.20 | 211.43 |
| Deviation (%) | 34.10 | 28.68 | 21.63 | 15.66 | 15.25 | 10.50 | 9.47 | 8.17 | 6.24 | 4.72 | 15.43 |
| | The position of cups → | | | | | | Course motion ↑ | | | | |
| Num. of samples | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Average |
| Dose ($kg\ ha^{-1}$) | 237.10 | 236.97 | 231.00 | 228.13 | 225.20 | 216.10 | 206.84 | 191.98 | 176.97 | 165.17 | 211.54 |
| Deviation (%) | 5.16 | 5.21 | 7.60 | 8.75 | 9.92 | 13.56 | 17.26 | 23.21 | 29.21 | 33.93 | 15.38 |
| Ejected fertilizer quantity (Spreader SF400 -Typ B) ($kg\ ha^{-1}$) | | | | | | | | | | | |
| | The position of cups ← | | | | | | Course motion ↑ | | | | |
| Num. of samples | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | Average |
| Dose ($kg\ ha^{-1}$) | 152.31 | 174.55 | 183.86 | 209.96 | 210.96 | 218.54 | 224.73 | 227.96 | 230.11 | 234.24 | 206.72 |
| Deviation (%) | 33.00 | 30.18 | 26.46 | 16.00 | 15.62 | 12.58 | 10.11 | 8.82 | 7.95 | 6.30 | 17.31 |
| | The position of cups → | | | | | | Course motion ↑ | | | | |
| Num. of samples | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Average |
| Dose ($kg\ ha^{-1}$) | 238.29 | 234.89 | 230.27 | 226.20 | 222.18 | 210.23 | 203.91 | 182.77 | 169.86 | 150.97 | 206.96 |
| Deviation (%) | 4.68 | 6.04 | 7.89 | 9.48 | 11.13 | 15.90 | 18.44 | 26.89 | 32.01 | 39.61 | 17.22 |
| Ejected fertilizer quantity (Spreader TG402- tip C) ($kg\ ha^{-1}$) | | | | | | | | | | | |
| | The position of cups ← | | | | | | Course motion ↑ | | | | |
| Num. of samples | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | Average |
| Dose ($kg\ ha^{-1}$) | 178.69 | 195.91 | 210.98 | 215.63 | 218.95 | 225.68 | 228.19 | 233.62 | 236.57 | 243.14 | 218.74 |
| Deviation (%) | 28.54 | 21.64 | 15.61 | 13.75 | 12.42 | 9.73 | 8.72 | 6.55 | 5.37 | 2.74 | 12.51 |
| | The position of cups → | | | | | | Course motion ↑ | | | | |
| Num. of samples | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Average |
| Dose ($kg\ ha^{-1}$) | 245.87 | 238.41 | 236.00 | 230.12 | 226.17 | 217.89 | 214.86 | 211.27 | 197.84 | 179.17 | 219.76 |
| Deviation (%) | 1.65 | 4.64 | 5.60 | 7.95 | 9.53 | 12.84 | 14.06 | 15.49 | 20.86 | 28.33 | 12.10 |

Analyzing the results of the transverse distribution of mineral fertilizers which are shown in Table 2 for each individual spreader, it is observed that the measured ejected quantities of fertilizers vary in the breadth of the project in relation to the projected norm (control).

Fertilizer type C (TG402) achieved the best cross over the distribution of fertilizer on all the spreaders, bearing in mind that with this spreader was highest accuracy of distribution, and the left and right side of the working procedure in relation to the center line of aggregates up to 10 m working width and 5 m to the left and 5 m from the right.

Standard deviation achieved in comparison to the projected (control) was below 15%. In the central part of the spreader working width variations were smaller and more varied in the range of 1.65% (245.87 kg $ha^{-1}$) up to 9.73% (225.68 kg $ha^{-1}$), which can be considered satisfactory given that under the tolerant values so that when the spreader no additional settings, which is important because it achieves high quality work at a greater working width, where the deviation from the values within tolerance so extended zone or zones overlap.

A spreader (AG400) reported a lower quality of work in relation to fertilizer C (TG402), since it was less accurate transverse distribution of fertilizers. In relation to the centerline engine was not designed to standard fertilization 5 m to the left and to the right, so that the standard deviation achieved in comparison to the projected tolerance values were above 15%, and varied in the range of 15.66-17.26%, or 206.84-210.86 kg $ha^{-1}$.

When working with the spreader in the central part of fertilization was the norm of 4.72% (238.20 kg $ha^{-1}$) and 10.50% (223.74 kg $ha^{-1}$) compared to the projected (control, 250 kg $ha^{-1}$).

Based on the results set forth in Table 2 it can be seen that the fertilizer B (SF400) worked well at least in relation to all three spreaders, having achieved the minimum accuracy of the transversal distribution of fertilizers to the left and right of the center line in relation to the engine.

Deviation was the 5m working width on the left and right sides of the tolerance values are exceeded by 15% the projected standard (control), so that the shortfall was thrown fertilizer norm 16.00% or 209.96 kg $ha^{-1}$, or 18.44%, or 203.91 kg $ha^{-1}$.

In the middle of the spreader working width shortfall standards achieved in comparison to the projected 250 kg $ha^{-1}$ varied in the range of 6.30% to 12.58%.

Some other authors have reached the similar results in their researches (Persson,2000; Fulton, 2001; Virin et al. 2005; Srivastava et al., 2006; Turan and Findura, 2009; Đević et al., 2009; Malinović et al.,2011).

Figure 2 clearly shows similar behavior of fertilizers under investigation. Distributions of raw material are symmetric. However, besides the narrow central part of soil area around the tractor axis of symmetry (± 0.7 m), deposition is weak. Percentage deviations of deposited values (kg $ha^{-1}$) from the fertilizing norm (250 kg $ha^{-1}$) tightly follows the parabolic trend lines for all three tested devices – R-square factors are over 0.95 in all cases.

Besides improving the design of these machines, the problem can be resolved by fertilizers resetting, decreasing the operational speed of the tractor and overlapping the fertilizing tracks.

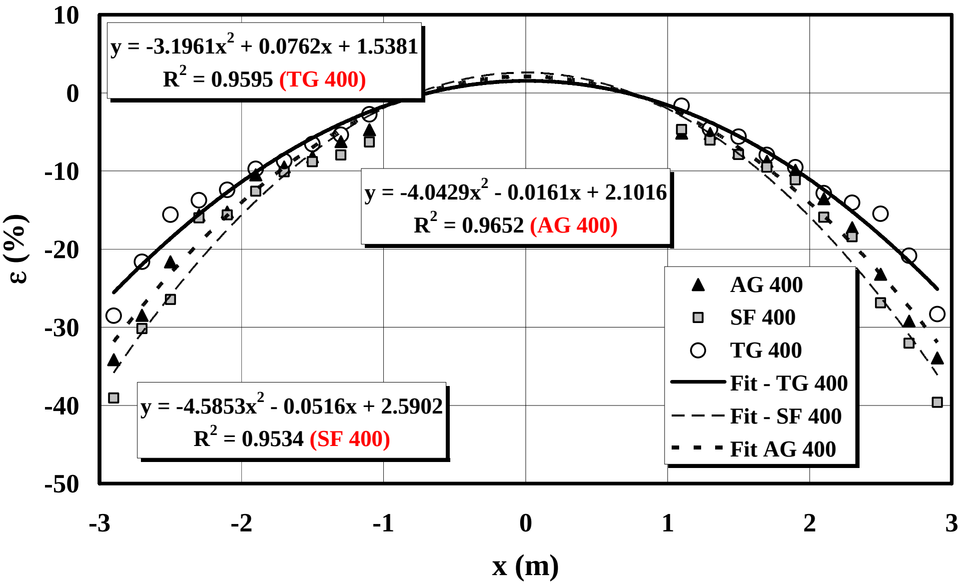


**Figure 2** Lateral distribution of deposition variations from the fertilizing norm

## CONCLUSIONS

Based on the results of the quality of the studied mineral fertilizer spreaders the following can be concluded that with all tested spreader reached the threshold standard deviation achieved up to 15% compared to the projected norm of fertilization in the zone up to 8 m working width. C-type spreader (TG402) achieved the highest accuracy of transverse distribution of fertilizer since the average standard deviation achieved in relation to the projected (control, 250 kg ha$^{-1}$) was less than 15% and amounted to 12.10% or 219.76 kg ha$^{-1}$. A-type spreader (AG400) achieved a lower accuracy of distribution, fertilizer spreader compared to C (TG402), considering that the average deviation was greater than 15% compared to controls and amounted to 15.43% or 211.43 kg ha$^{-1}$. Spreader B (SF400) achieved the lowest accuracy of the transversal distribution of fertilizers in relation to all test spreaders. The average standard deviation achieved in comparison to the projected (control) was greater than 15% and amounted to 17.31% or 206.72 kg ha$^{-1}$. On the overlap (extended working width), measured ejected quantities of fertilizers were above tolerable deviation of 15% compared to control in all tested spreader. Deviations are particularly pronounced at 10.11 and 12 m working width of the left and right of the center line of engine (tractor + fertilizer), with significantly less thrown fertilizer compared to the projected norm. Besides improving the design of these machines, the problem can be resolved by fertilizers resetting, decreasing the operational speed of the tractor and overlapping the fertilizing tracks.

The general conclusion of our study is that the investigated mineral fertilizer spreaders could be successfully used as fertilizer in crop production in the study area and beyond, along with better training and optimization of the operator can come to the fore.

## ACKNOWLEDGEMENT

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42. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

UDC 631.333
Pregledni rad
Review paper

# MOTION OF A GRANULE ON FERTILIZER SPREADING DISC

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## ABSTRACT

*This paper reviews the studies on the motion of fertilizer granules on a planar spreading disc in the structure a fertilizer spreader and presents the mathematical model for studying this motion. This model is used to study the dependence of outlet velocity of a fertilizer granule on the coefficient of friction and on adjusting angle. The trajectories of fertilizer granules on the spreading disc are visualized by figures. Video clips are used to simulate the motion of granules on four trajectories. Derived formulae and numerical results of this present paper can be used by the engineers studying discs of fertiliser spreaders. These formulae can also be used for teaching the operation of fertilizer spreader to the students.*

***Key words:*** *Agricultural machinery, fertilizer spreader, spreading disk, visualization, Mathcad.*

## INTRODUCTION

The first works on modelling the spreading process were carried out nearly half a century ago: Patterson and Reece (1962); Inns and Reece (1962). Modelling of the spreading process has been re-activated during the last years, the models have been enhanced, new methodologies have been introduced, the parameters of the spinning disc of spreader have been optimized and a series of articles has been published. Hofstee (1995) offers many differential equations to describe the motion of a particle. This equations where deduced for various shapes of vanes and discs. Reintam (1995) has presented the differential equation, modelling the motion of a fertilizer particle on the planar spreading disk of a fertilizer spreader with pitched straight vanes at adjusting angle of 60$^{o}$. Later non-linear differential equation, with numerical solutions for a conical disc with pitched vanes, where presented (Olieslagers, 1997; Dintwa et al., 2004a). In 2005, Villette, Cointault, Piron and Chopinet reported analytical model of fertiliser particle motion. This mathematical model is derived for a concave disc equipped with pitched straight vanes. Villette et al. 2008 showed that outlet velocity of three-dimensional components in the case of a concave disc could be deduced from the measurement of the horizontal outlet angle. In 2010, Villette et al. introduced the friction coefficient referred to as “equivalent friction coefficient”. This parameter is deduced from a mechanical model of the fertiliser motion on a spinning disc and from the measurement of the outlet angle of the particles.

Van Liedekerke et all. 2006 presented discrete element method (DEM) to simulate particle motion on flat disc with radial vanes. This model took into account interactions between the particles. A new approach consists in investigating entire particle flow by using discrete element method (Van Liedekerke et al., 2009, 2009b; Coetzee and Lombard, 2011). Technical solutions for measuring the speed and direction of fertilizer particles when they leave the disc are used to develop more precise mathematical models according to measurements (García-Ramos, Boné, Serreta and Vidal, 2012). For example, during recent years, the most common technology has been based on the use of different types of optical sensors (Grift, Hofstee, 2002; Swisher, Borgelt and Sudduth, 2002; Villette, Cointault, Chopinet and Paindavoine, 2006). Most studies are focused on particles, but there are also works focusing on the measurement of surface distribution of fertilizer particles (Lawrence, Yule and Coetzee 2007; García-Ramos, Boné, Serreta and Vidal, 2012).

Based on the equations by Reintam (1995), Heinloo (2010) have visualized the motion of fertilizer granules on the planar spreading disc with different contours and with the vanes at adjusting angle of $60^{o}$. Olt, Heinloo (2011) have reviewed the studies on spreading discs and studied the motion of fertilizer particles, directed by the vane at adjusting angle of $-90^{0}$. The first objective of this paper is to apply the results of papers by Reintam (1995), Heinloo (2010) and Olt, Heinloo (2011) to arbitrary adjusting angle, frictional coefficient and the initial distance of a fertilizer granule from the centre of the spreading disc. The second goal of this paper is to compare the trajectories of the motion of fertilizer granules on the planar spinning spreading disc at adjusting angles of $60^{o}$ and $-90^{0}$. The third purpose of this paper is to study the influence of friction coefficient of the fertilizer granule (against the vane and the disc) and location of the vane (determined by the initial location of fertiliser granules and by the adjusting angle of the vane) on the outlet time and outlet velocity when granules leave the disc.

## MATERIALS AND METHODS

*Mathematical model for spreading disc of a disc spreader*

Let us consider the scheme of a spreading disc in figure 1 according to Reintam (1995).

In figure 1, $R$ is the radius of the spreading disc; bold intercept denotes the vane for directing the fertilizer granules on the disk, $\psi_0$ is the adjusting angle of the vane, $r$ – the distance between the centre of the disc and fertilizer granule in the current position $A$, $r_0$ - the distance between the centre of the disc and fertilizer granule in the initial position $A_0$, $\psi$ – angle between the polar radii of fertilizer granule and the direction of the vane.

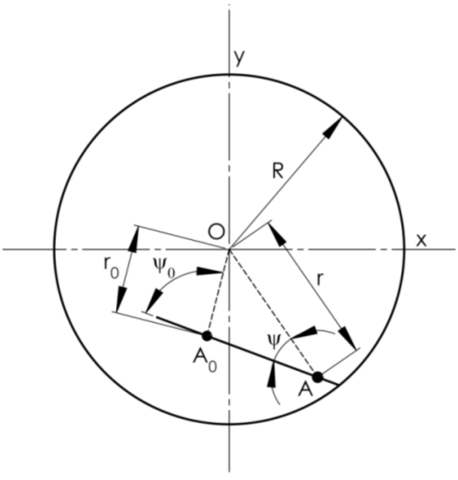


**Figure 1** The scheme of a spreading disk. *R* - spreading disc radius, $\psi_0$ - adjusting angle of the vane, $\psi$ – angle between the polar radii of a fertilizer granule and the direction of the vane, *r* - distance between the centre of the disc and fertilizer granule in the current position *A*, $r_0$ - distance between the centre of the disc and fertilizer granule in the initial position $A_0$.

Fertilizer granule on the spreading disk (fig. 1) is in complex motion. It rotates together with the spreading disk (translation motion) and moves along the vane (relative motion). The projection of equation of relative motion of fertilizer granule on the axis $\xi$, directed from the initial position $A_0$ of fertilizer granule along the vane to the border of the spreading disk, can be presented in the form below (Reintam, 1995):

$$m\frac{d^2}{dt^2}\xi(t) = F_1 + F_2 + F_3 + F_4\,, \tag{1}$$

where $\xi(t) = A_0A$ is the distance between initial and current positions of fertilizer granule; $F_1$ is the friction force projection on axis $\xi$ between the spreading disc and the vane; $F_2$ is the translation inertial force projection on axis $\xi$; $F_3$ is the friction force projection on axis $\xi$, caused by the translation inertial force; $F_4$ the projection of Coriolis inertial force. The equations for these forces are given below:

$$F_1 = -fmg\,,\ F_2 = m\omega^2 r\cos\psi\,,\ F_3 = -fm\omega^2 r\sin\psi\,,\ F_4 = -2fm\omega\frac{d}{dt}\xi(t)\,.$$

Here $m$ is the mass of the fertilizer granule and $\omega$ is constant angular velocity of the spreading disc; $f$ – coefficient of friction between the fertilizer granule and the vane and the spreading disc, $g$ – acceleration of gravity. Placing forces $F_1$, $F_2$, $F_3$, $F_4$ in the equation (1) and dividing them by $m$ gives the ordinary differential equation with constant coefficients (Reintam, 1995)

$$\frac{d^2}{dt^2}\xi(t)+2f\omega\frac{d}{dt}\xi(t)-\omega^2(r\cos\psi-fr\sin\psi)+fg=0\,. \tag{2}$$

From figure 1 it follows that

$$r\cos\psi = AA_0 + r_0\cos\psi_0 = \xi(t)+r_0\cos\psi_0\,, \qquad r\sin\psi = r_0\sin\psi_0\,. \tag{3}$$

The adjusting angle $\psi_0$ of the vane is $\psi_0>0$, if it is measured from the vector $OA_0$ counter clockwise and $\psi_0<0$ – if measured clockwise.

Taking into account equations (3), the equation (2) can be written in the following form

$$\frac{d^2}{dt^2}\xi(t)+2f\omega\frac{d}{dt}\xi(t)-\omega^2\xi(t)=A\,, \tag{4}$$

where

$A=\omega^2 r_0[\cos(\psi_0)-f\sin(\psi_0)]-fg$ .

Differential equation (4) modelling the motion of fertilizer granule on the planar spreading disc with pitched vanes was composed by Reintam (1995).

Let us suppose that fertilizer granule starts motion from its initial position $A_0$. In that case, the initial conditions are:

$$\xi(0)=0\,, \qquad \xi'(0)=0\,, \tag{5}$$

where

$\xi'(0)=\frac{d}{dt}\xi(t)$ .

The equation (4) can be solved by standard technique and its solution is

$$\xi(t)=C\left(1-\frac{\lambda_2 e^{\lambda_1 t}-\lambda_1 e^{\lambda_2 t}}{\lambda_2-\lambda_1}\right), \tag{6}$$

where $e$=2.718... and

$$C=\frac{fg}{\omega^2}-r_0[\cos\psi_0-f\sin\psi_0],\ \lambda_1=\omega\left(-f+\sqrt{1+f^2}\right),\ \lambda_2=\omega\left(-f-\sqrt{1+f^2}\right).$$

From figure 1 one can find the relations

$$AA_0=\xi(t)=\sqrt{r(t)^2-r_0{}^2\sin\psi_0{}^2}-r_0\cos\psi_0\,. \tag{7}$$

From equation (7) and the second equation of (3), we get the following equations

$$r(t)=\sqrt{r_0^{\,2}+2r_0\cos\psi_0\cdot\xi(t)+\xi(t)^2}\ , \tag{8}$$

$$\psi(t)=\arcsin\left[\frac{r_0\sin(\psi_0)}{r(t)}\right], \tag{9}$$

where $\xi$ and $r$ are functions of the time $t$: $\xi = \xi\ (t)$ and $r = r(t)$. In equation (8), the function $\xi\ (t)$ is determined by the solution (6) of the differential equation (1). The outlet time $t_e$ can be found out from the equation

$$\xi(t_e)=\sqrt{R^2-r_0^{\,2}\sin\psi_0^{\,2}}-r_0\cos\psi_0\,. \tag{10}$$

Equation (10) was solved numerically similar to $t_e$ by using the solve block on Mathcad worksheet. The angle between vectors $OA_0$ and $OA$ (fig. 1) can be found out from the equation

$$\alpha(t)=\psi_0-\psi(t)\,. \tag{11}$$

The rectangular co-ordinates of the current position $A$ of fertilizer granule can be found out by the equations

$$x(t,\varphi_0)=r(t)\cdot\cos[\varphi_0+\alpha(t)+\omega\ t],\ \ y(t,\varphi_0)=r(t)\cdot\sin[\varphi_0+\alpha(t)+\omega\ t], \tag{12}$$

where $\omega$ is the angular velocity of the spreading disc and the angle $\varphi_0$ determines the initial position of the granule. The projections of the velocity and the module of the fertilizer granule is determined by the following equations

$$v_x(t,\varphi_0)=\frac{d}{dt}x(t,\varphi_0),\ \ v_y(t,\varphi_0)=\frac{d}{dt}y(t,\varphi_0),$$

$$v(t,\varphi_0)=\sqrt{v_x(t,\varphi_0)^2+v_y(t,\varphi_0)^2}\ . \tag{13}$$

For given parameters of the spreading disc and the fertilizer granule, the velocities (13) were found out by using numerical differentiation on Mathcad worksheet.

## RESULTS AND DISCUSSION

*Visualization of the motion of fertilizer granules on the planar spinning spreading disc of a disc spreader*

By using the mathematical model presented in material and methods of this paper, the computed trajectories of fertilizer granule have been visualized on the spreading disc of fertilizer spreader. The conditions for computations included the following: R = 0.4 m; f = 0.47; $\omega$= 57.6 s-1; $r_0$ = 0.04 m, $\varphi_0$ -900. Figure 2a shows the initial position of the vane and the granule. Figure 2b shows the trajectory of fertilizer granule and the direction of outlet velocity, when $\psi_0 = 60^o$.

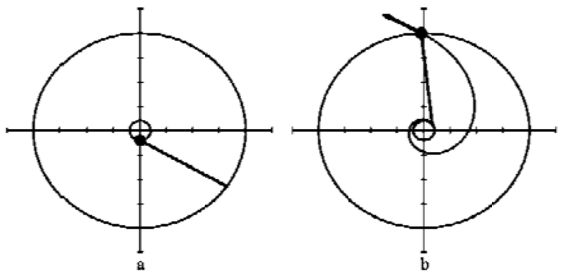

**Figure 2** The initial position of the vane and the granule (a), the trajectory of the granule and the outlet velocity (arrow) (b), when $\varphi_0 = -90^0$, $\psi_0 = 60^o$.

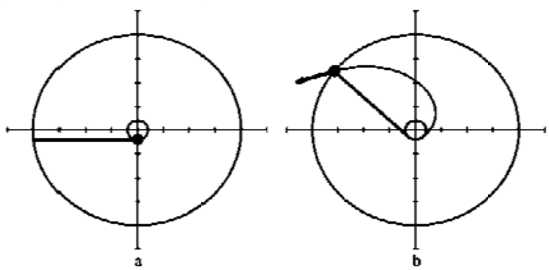

**Figure 3** The initial position of the vane and the granule (a), the trajectory of the granule and the outlet velocity (arrow) (b), when $\varphi_0 = -90^0$; $\psi_0 = -90^o$.

Figure 3a shows the initial position of the vane and the granule. Figure 3b shows the trajectory of fertilizer granule and the direction of outlet velocity, when $\varphi_0 = -90^0$; $\psi_0 = -90^o$. From Figures 2 and 3 it follows that the trajectory of the granule in the case, where $\psi_0 = -90^o$, is shorter than in the case, where $\psi_0 = 60^o$.

Figure 4 shows the initial positions, the trajectories and the outlet velocities of granules in the case of four vanes and granules, when $\varphi_0 = 60^o, 150^o, 240^o, 330^o$; $\psi_0 = 60^o$; relevant angles in Figure 5 are $\varphi_0 = -90^o, 0^o, 90^o, 180^o$; $\psi_0 = 60^o$.

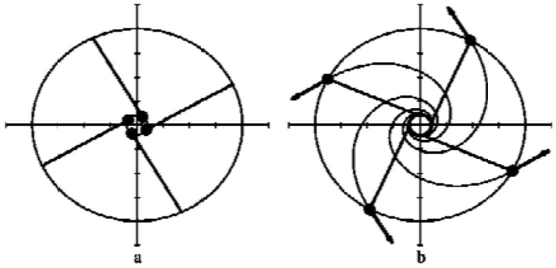


**Figure 4** The initial positions (a), the trajectories and the outlet velocities of granules in the case of four vanes (b), when $\varphi_0 = 60^o$, $150^o$, $240^o$, $330^o$; $\psi_0 = 60^o$.

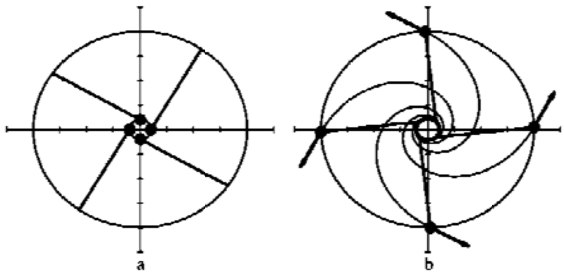


**Figure 5** The initial positions (a), the trajectories and the outlet velocities of granules in the case of four vanes (b), when $\varphi_0 = -90^o$, $0^o$, $90^o$, $180^o$; $\psi_0 = 60^o$.

Heinloo (2010) has shown that polygonal spreading discs may also be used instead of circular spreading discs.

*The dependence of the outlet time and outlet velocity of fertilizer granule on the coefficient of friction*

Let us assume that $g = 9.807$ m s$^{-2}$; $r_0 = 0.04$ m; $R = 0.4$ m; $\omega = 60$ s$^{-1}$, $\varphi_0 = -90^o$

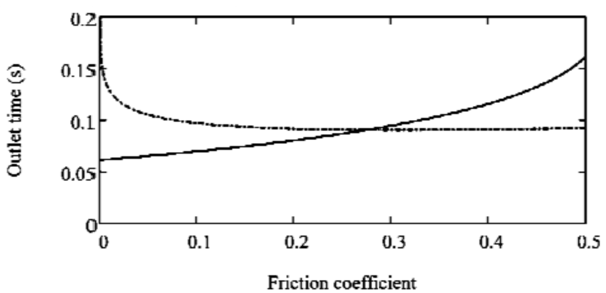


**Figure 6** The dependence of the outlet time $t_e$ on friction coefficient $f$ at $\psi_0 = 60^o$ (continuous line) and at $\psi_0 = -90^o$ (dotted line).

Figures 6 and 7 show the dependence of outlet time (the time, when a fertilizer particle leaves the spreading disc) and the outlet velocity $v_e$ (the velocity of fertilizer granule leaving the spreading disc) on friction coefficient $f$. The continuous lines in Figures 6 and 7 correspond to $\psi_0 = 60^o$ and the dotted line to $\psi_0 = -90^o$. It appears from Figure 6 that in case of $\psi_0 = -90^o$ along with the increase of friction coefficient $f$, the outlet time $t_e$ decreases quickly to the constant value, while in the case of $\psi_0 = 60^o$ this time increases evenly. Figure 7 indicates that the outlet velocity $v_e$ of the granule in the case, where $\psi_0 = -90^o$ is lower than in the case, where $\psi_0 = 60^o$.

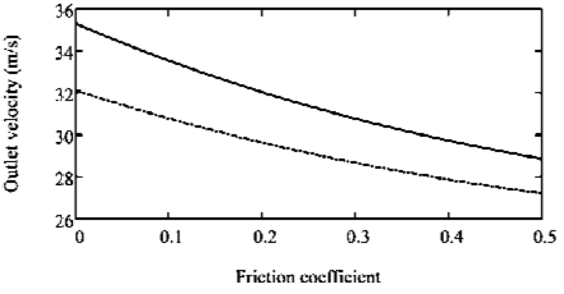


**Figure 7** The dependence of outlet velocity $v_e$ on friction coefficient $f$ at $\psi_0 = 60^o$ and at $\psi_0 = -90^o$ (dotted line).

*The dependence of the outlet time and velocity of fertilizer granule on the adjusting angle*

Let us assume that $f = 0.3$ (according to Dintwa, et al., 2004b) and $r_0 = 0.04$ m, $R = 0.4$ m, $\omega = 60$ s$^{-1}$; $\varphi_0 = -90°$. Figures 8 and 9 show the dependence of outlet time $t_e$ and velocity $v_e$ on adjusting angle $\psi_0$. Figures 8 and 9 show that outlet time $t_e$ and outlet velocity $v_e$ are determined only when $-90^o \leq \psi_0 \leq 72^o$. Interestingly, it appears from Figure 8 that the outlet time $t_e$ has minimal value at approximately $\psi_0 = -10^o$. Figure 9 shows that the outlet velocity $v_e$ increases evenly along with the increase of the adjusting angle $\psi_0$ and it may be in the following range: 28.67 m s$^{-1}$ $\leq v_0 \leq$ 30.85 m s$^{-1}$. Figure 8 shows that the outlet time $t_e$ is subject to the following range: 0.061 s $\leq t_e \leq$ 0.188 s.

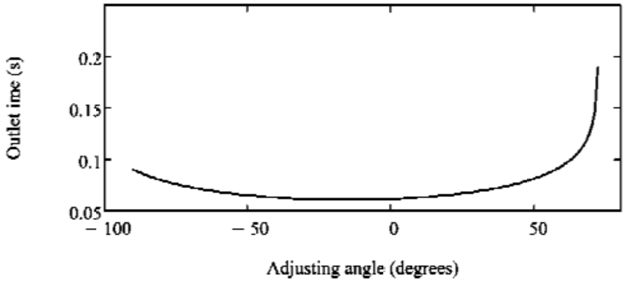


**Figure 8** The dependence of outlet time $t_e$ on adjusting angle $\psi_0$.

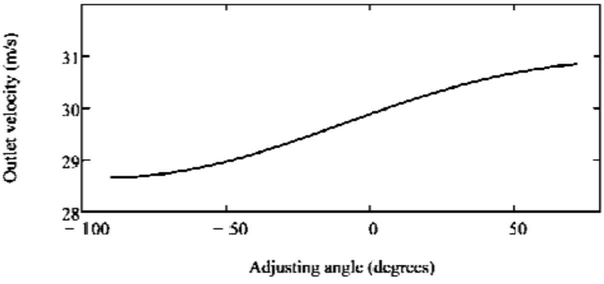


**Figure 9** The dependence of outlet velocity $v_e$ on adjusting angle $\psi_0$.

*The dependence of the outlet time and velocity of fertilizer granule on its initial distance from the centre of the spreading disc*

Let us assume that $f = 0.3$, $\omega = 60\ s^{-1}$, $R = 0.4$ m $\varphi_0 = -90^o$. Figures 10 and 11 show the dependence of outlet time $t_e$ and velocity $v_e$ on the distance $r_0$ of fertilizer particle from the centre of the spreading disc at the initial time, when $\psi_0 = 60^o$ (continuous line) and $\psi_0 = -90^o$ (dotted line).

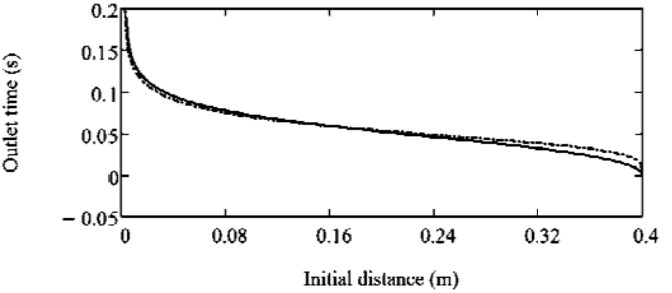


**Figure 10** The dependence of outlet time $t_e$ on the initial distance $r_0$ of fertilizer particle from the centre of the spreading disc at the initial time at $\psi_0 = 60^o$ (continuous line) and $\psi_0 = -90^o$ (dotted line)

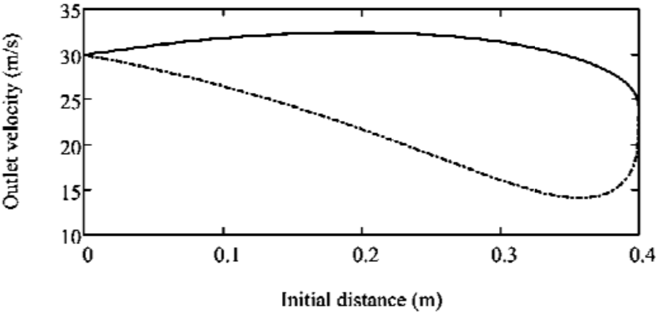


**Figure 11** The dependence of outlet velocity $v_e$ on the distance $r_0$ of fertilizer particle from the centre of the spreading disc at the initial time at $\psi_0 = 60^o$ and $\psi_0 = -90^o$ (dotted line)

Figure 10 shows that the outlet time $t_e$ dependencies on initial distance $r_0$ in the case of $\psi_0 = 60^o$ and $\psi_0 = -90^o$ approximately coincide and decrease along with increasing the values of $r_0$. Figure 11 shows that the dependencies of outlet velocity $v_e$ on initial distance $r_0$ are very different in the cases of $\psi_0 = 60^o$, and $\psi_0 = -90^o$. In the case of $\psi_0 = 60^o$, the outlet velocity $v_e$ has maximum value of 32.5 m $s^{-1}$ approximately at $r_0 = 0.2$ m, while in the case of $\psi_0 = -90^o$, this velocity has minimum value approximately at $r_0 = 0.36$ $s^{-1}$.

This present paper provides a mathematical model for flat spreading disc equipped with pitched straight vanes. This model describes pure sliding motion of the fertilizer particle between disc and vane. With this mathematical model, it was possible to determine fertilizer particle velocity, which depends on five initial variables: $f$ – friction, $r_0$ –initial position of the particle on the vane (vane pitch), $\psi_0$ – adjusting angle of the vane, $R$ – spreading disc radius, and ω - angular velocity of the spreading disc. Comparatively, the study by Villette, Cointault, Piron, Chopiner (2005) uses three variables for flat disc: friction coefficient, disc angular velocity and vane pitch.

The video clips by Aan, Heinloo (2013) on simulation of the motion of the fertilizer granules represent a very good visualisation of the motion of the granules on the spreading disk of a fertilizer spreader. These video clips were composed on Mathcad worksheet by using the methodology presented by Heinloo (2010) and Olt, Heinloo (2011).

## CONCLUSIONS

This paper shows the use of the features of the computer program Mathcad in the study of the spreading disc of fertilizer spreader.

According to the results of this paper, in order to ensure maximum outlet velocity of fertilizer granules, it is reasonable to use adjusting angle equal to $72^o$ as possible minimum value of friction coefficient and vane pitch approximately equal to 0.17 m.

The outlet times and velocities can be used to study the motion of fertilizer granules after leaving the spreading disc of the fertilizer spreader, and the virtual sowing of the fertilizer spreader, and to determine the virtual distribution of virtual granules on a virtual field.

The results of this present paper and the corresponding video clips can be used in the process of teaching the students agricultural machinery and by the engineers studying the disc fertiliser spreader.

The scientists, wishing to compose visualizations of motions of the elements involved in agricultural machinery, can consider this paper as an example of visualization of machine elements on Mathcad worksheet and simulation of their motion.

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42. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

UDC 631.331.5:633.63
Originalni znanstveni rad
Original scientific paper

# TEST OF QUALITY OF PRECISION SEEDERS FOR SUGAR BEETS UNDER FIELD CONDITIONS

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## ABSTRACT

*In a three years program (2009-2011) 5 precise seeder were tested on fields around Würzburg/Germany, (luvisol from loess). The 12 row seeders were equipped with mulch tools and worked on a mechanic basis, whereas one worked on a pneumatic basis. In addition to field emergence, spacing accuracy on the field at different speeds (6, 8, 10 km/h) was tested. Additionally, the impact of various clamping tools (rear packers) was evaluated.*

*"Vicon Unicorn synchro-drive" (with finger-pressure roller) convinced with respect to emergence and spacing accuracy despite slightly higher numbers of doubles. All other seeders followed on a comparatively high level. With increasing speed "Schmotzer UD 3012" could only work with slightly poorer working quality. The pneumatic based "Amazone ED Contour ZR" only fell off regarding spacing accuracy.*

***Key words**: Precision seeder, field testing, sugar beet*

## INTRODUCTION

Since the early 1980s the ideal number and distribution of plants without singling cultivation is determined by sowing (Schmitz, 2011). Sugar beet cultivation needs to consolidate quantity and quality. Especially the latter does not only refer to substances but also include harvest with low-loss. Homogenous crop stand with the least possible misses or doubles is heavily dependent upon the choice and adjustment of the right sowing machine (Kromer, 1998).

A three-year field test with five different single grain seeders has been carried in the region of Würzburg (type of soil: luvisol from loess) with typical soil conditions for sugar beet cultivation. After straw mulch and tine cultivation in autumn, the seedbed preparation with standard cultivator (Lemken Kompaktor) was undertaken in spring. Between 2009 and 2011 field emergence, distance accuracy with straw mulching method and the effect of various rear packers were investigated.

In Europe a considerable part of the sugar beet acreage is sawn by seeders with mechanical or pneumatic singling device. This basic technology for seed placement has hardly changed in the last 30 years. The technical progress and mission extension of the seeders took place by implementing mulch tools, electric drives for the single unit, new rear packers, tram lining control etc. The traditional mechanic devices have been joined by pneumatic ones due to their wide-ranging applicability.

The aim of this test series was to state the precision of the seeders under field conditions to provide a genuine comparison between existing products with a wide application rate in sugar beet cultivation.

## MATERIAL AND METHODS

The five sowing machines *(table 1*) were adjusted for seed distance of 20 cm and operated with 6, 8 und 10 km/h forward speed and were equipped with different rear packers (e.g. conical or finger pressure roller…)

For each variation emergence was calculated at two different dates: an earlier date with approximately 50% emergence and a later date (final).

By means of a distance meter (Heier, 1997) optimum crop placement was determined. The definition thereof is described in the IIRB standard (Vandergeten et al., 2004) for single grain sowing machines. Accordingly, optimum placement is achieved if plants do not fall below or above the legitimate threshold of the required seed in distance (+/- 2,5 cm) or of a multiple thereof. This parameter is more wide-ranging than the accuracy of placement (tested in the laboratory) since the pill is subject to rolling and other effects occurring in the seed furrow. The dates of sowing represent those of local practice in the respective years.

Data regarding the emergence and accuracy of placement was always collected of all six rows (same rear packer) on a distance of at least 50 m – and repeated four times. The results were backed by statistics SPSS (Tukey test for significance), the respective thresholds (GD-value) are indicated in the tables 3, 4 and Figures 3, 4.

*Field emergence*

Differences between required and the actual seed placement distance occurred as a result of device-specific peculiarities and slip effects. In order to calculate the emergences only the most frequent seed distance in the field was taken into account. Having a look at the years 2009, 2010 and 2011 (figure 1), the potential difference between various years can be recognizes.

*Seed placement*

Data was collected by means of the Distance-Measurement-System which was developed by the Institute for Agricultural Engineering at the University of Bonn (Heier, 1997). All variants were recorded four times with six rows. At the moment of measurement plants were in four to six leaf stages.

**Table 1** Data and test setting of the tested machines

| **Manufacturer** | **Accord** | **Amazone** | **Becker*** | **Schmotzer** | **Vicon** |
|---|---|---|---|---|---|
| Type | Monopill SE | ED Contour ZR | Centra | UD 3012 PH | Unicorn synchro-drive |
| |  |  |  |  |  |
| Rows | 12 | 12 | 12 | 12 | 12 |
| Drive | Electronic | mechanic | mechanic | mechanic | electronic |
| Filling | Inside | Suction air | Inside | Inside | Inside |
| Press roller (PR) | Finger-PR Monoflex-PW | V-PR narrow V-PR broad | Finger-PR Whorl | Finger-PRnub circle | Gum-V-PR Finger-PR |
| Mass | 1640 kg | 2144 kg | 1500 kg | 1340 kg | 1560 kg |
| Placement distance | 20,3 cm | 19,9 cm | 20,4 cm | 19,8 cm | 19,6 cm |
| Placement depth | 2,5-3,0 cm | 2,5-3,0 cm | 2,5-3,0 cm | 2,5-3,0 cm | 2,5-3,0 cm |
| Particularities | 2009 no Finger-PR and too deep placement | | 2011 no participation in tests | | 2009 lack of 10 km/h sowing speed and Gum-V-PR |
| Homepage | de.kvernelandgroup.com | www.amazone.de | www.becker-lt.de | www.schmotzer.de | de.kvernelandgroup.com |

*Becker only 2 years

## RESULTS

The plant density (figure 1) was high in all three test years. Out of between 98.300 and 103.400 sown seeds about 86.6 % to 90.5 % emerged. This indicates the final plant number at harvest was between 85.200 and 93.400 per hectare. Differences regarding the seed rate are the result of varying placement targets as recommended by the manufacturers in the different years.

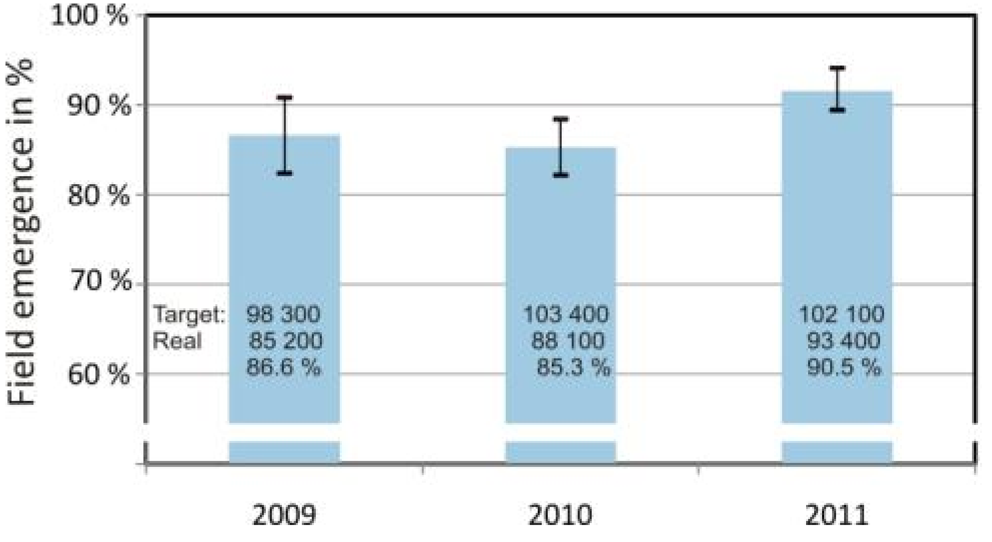



**Figure 1** Field emergence and plant population in the 3 test years

## RESULTS OF WORKING QUALITY

Figure 2 demonstrates the results of the working quality of the 3 years test at three different speeds (6, 8 und 10 km/h). The relative proportion of the individual classes (represents the distance between 2 plants) is outlined.

Placement accuracy is stated as relative data and indicates the percentage of plants which are placed in the range of +/- 2.5 cm around the actual distance. The significant difference (GD), calculated for an error level of 5%, enables the reader to judge whether the differences are the result of natural scatter or of technical differences. If the difference between two machines is higher than the GD, they are statistically significant different.

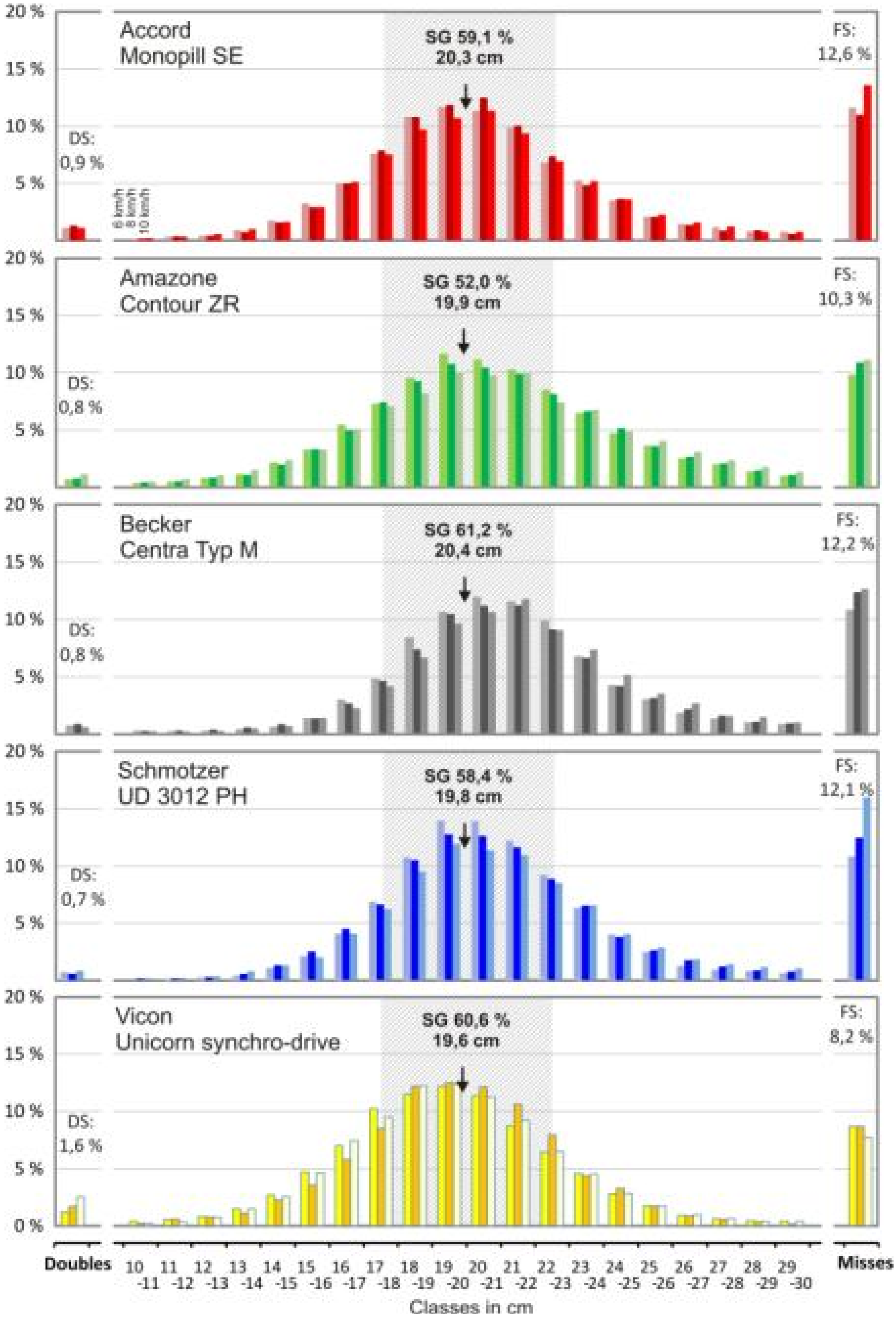



**Figure 2** Comparison of the tested precision seeders regarding their spacing accuracy (SG), doubles (DS) and misses (FS), 3 years (Becker: 2 years)

**Table 2** Numbers and thresholds of quality determination, 3 years (Becker: 2 years)

| | | | Accord | Amazone | Becker | Schmotzer | Vicon |
|---|---|---|---|---|---|---|---|
| | | *GD* | *Monopill SE* | *Contour ZR* | *Centra* | *UD 3012 PH* | *Unicorn Syn.-drive* |
| **Average** | | | | | | | |
| Emergence | % | *0.8* | 86.0 | 88.4 | 88.2 | 86.5 | 92.4 |
| Spacing accuracy | % | *0.8* | 59.1 | 52.0 | 61.2 | 58.4 | 60.6 |
| Targets | % | *0.6* | 86.5 | 88.9 | 87.0 | 87.2 | 90.2 |
| Doubles | % | *0.1* | 0.9 | 0.8 | 0.8 | 0.7 | 1.6 |
| Misses | % | *0.6* | 12.6 | 10.3 | 12.2 | 12.1 | 8.2 |
| **6 km/h** | | | | | | | |
| Emergence | % | *1.3* | 86.2 | 88.9 | 89.4 | 88.4 | 92.1 |
| Spacing accuracy | % | *1.4* | 58.7 | 53.1 | 62.7 | 61.9 | 60.0 |
| Targets | % | *1.0* | 86.8 | 89.6 | 88.0 | 88.9 | 90.3 |
| Doubles | % | *0.3* | 0.7 | 0.6 | 0.8 | 0.7 | 1.3 |
| Misses | % | *1.0* | 10.2 | 9.7 | 11.2 | 10.4 | 8.4 |
| **8 km/h** | | | | | | | |
| Emergence | % | *1.3* | 87.6 | 87.2 | 87.5 | 87.5 | 92.2 |
| Spacing accuracy | % | *1.3* | 60.7 | 51.9 | 60.9 | 57.6 | 59.6 |
| Targets | % | *1.0* | 87.3 | 88.5 | 86.6 | 88.1 | 90.2 |
| Doubles | % | *0.2* | 1.1 | 10.8 | 0.9 | 0.6 | 1.6 |
| Misses | % | *1.0* | 11.6 | 10.7 | 12.5 | 11.3 | 8.2 |
| **10 km/h** | | | | | | | |
| Emergence | % | *1.6* | 84.4 | 89.1 | 87.7 | 83.5 | 93.3 |
| Spacing accuracy | % | *1.5* | 58.1 | 50.7 | 60.0 | 55.6 | 64.0 |
| Targets | % | *1.0* | 85.4 | 88.3 | 86.5 | 84.6 | 90.0 |
| Doubles | % | *0.3* | 0.9 | 1.0 | 0.7 | 0.8 | 2.4 |
| Misses | % | *1.1* | 13.7 | 10.7 | 11.2 | 14.6 | 7.6 |

*Becker, only 2 years

*Field emergence*

Vicon produced the highest emergence, followed by Amazone. Accord, Becker and Schmotzer are ranked slightly below. It was not possible to observe a general impact of the sowing speed on the emergence although Schmotzer's UD reacted negatively on increasing speed. Accord had best results at 8 km/h.

*Spacing accuracy*

Spacing accuracy embraces various disturbances: technical ones pointing to variations of the throw-off point of the beet pill and their respective trajectories, but also interactions such as rolling or erectophile vegetation (Kam et al. 2010).

As expected Amazone ED (52.0 %), the only machine usable for sugar beets and maize, achieved the worst results. These results were significantly worse than those of Becker, Schmotzer and Vicon. All four remaining machines ranged between 58.4 and 61.2 %.

Spacing accuracy fell slightly at a speed of more than 8 km/h.

*Doubles*

In general doubles are the result of multiple occupancy of cells. According to the definition, each placement with a smaller distance of 0.5 times the target distance to the neighboring plant is counted as a double. Thus, distances between 0 and 10 cm are considered as doubles.

Four groups which differ significantly can be build up. Schmotzer – with 0.7 % - achieved the best result. The second group is composed of Becker and Amazone followed by Accord. With 1.6 % Vicon has the highest percentage of doubles.

At a lower speed (6 km/h) the number of doubles was significantly smaller than at 8 or 10 km/h, with had been on a comparable level.

*Misses*

In case of a spacing distance higher than 1.5 times the target distance, one can speak of a missing spot. According to testing standards there is no difference between a simple and multiple missing.

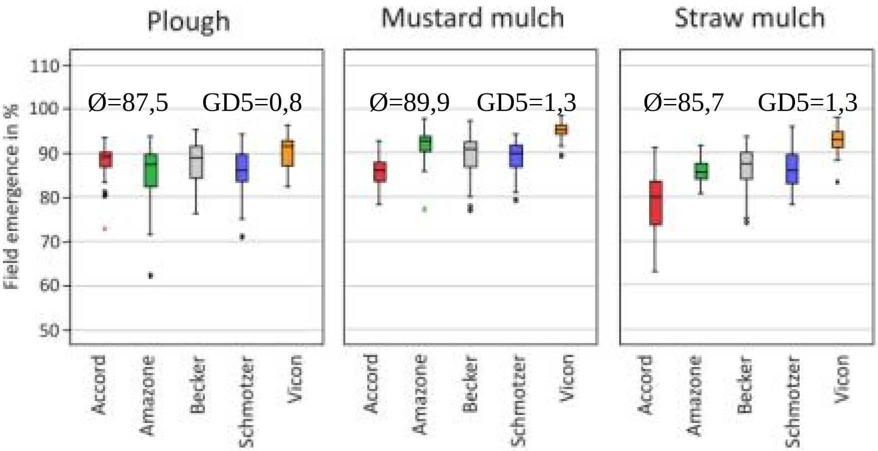
In contrast to the spacing accuracy measured, vacant spots do not only arise due to technical reasons but also as a result of the germination of the seeds and if already emerged plants die back.

While the Vicon-Machine left a higher number of doubles, it had a great result regarding misses (with significantly fewest misses) Amazone follows on second rank. Accord, Becker and Schmotzer share the third position.

A higher speed influences the number of misses in a negative way. Thus, there is a significant difference between the 6 and 8 km/h and the 10 km/h variant. Obviously, the filling of the cell wheel is affected.

*Comparison of tilling systems*

In 2009 the working quality of the tested machines was examined with three different tilling systems. Figure 3 shows field emergence and figure 4 shows spacing accuracy with respect to the different manufacturers.




Plough:

| | Accord | Amazone | Becker | Schmotzer | Vicon |
|---|---|---|---|---|---|
| A | 88,2 | | 87,7 | | 90,3 |
| B | 88,2 | 85,6 | 87,7 | 86,2 | |

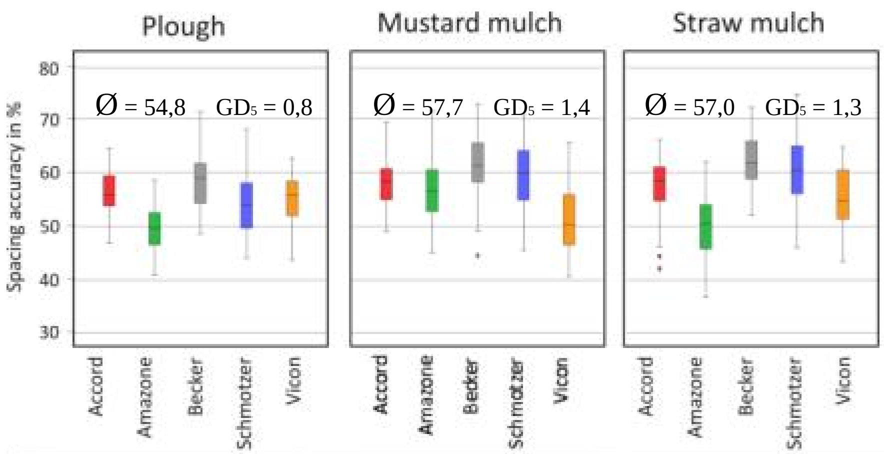
Mustard mulch:

| | Accord | Amazone | Becker | Schmotzer | Vicon |
|---|---|---|---|---|---|
| A | | | | | 95,0 |
| B | | 91,5 | 89,4 | | |
| C | | | 89,4 | 89,0 | |
| D | 86,0 | | | | |

Straw mulch:

| | Accord | Amazone | Becker | Schmotzer | Vicon |
|---|---|---|---|---|---|
| A | | | | | 92,9 |
| B | | 85,9 | 86,4 | 86,6 | |
| C | 79,1 | | | | |

**Figure 3** Field emergence (%) of the tested seeders with the variants plough, mustard and straw mulch (A to D = significance groups; if two or more machines are part of one group, it means that they do not differ significantly)




Plough:

| | Accord | Amazone | Becker | Schmotzer | Vicon |
|---|---|---|---|---|---|
| A | 56,2 | | 58,5 | | |
| B | 56,2 | | | 54,2 | 55,3 |
| C | | 49,7 | | | |

Mustard mulch:

| | Accord | Amazone | Becker | Schmotzer | Vicon |
|---|---|---|---|---|---|
| A | 57,9 | | 61,1 | 59,2 | |
| B | 57,9 | 57,1 | | 59,2 | |
| C | | | | | 51,1 |

Straw mulch:

| | Accord | Amazone | Becker | Schmotzer | Vicon |
|---|---|---|---|---|---|
| A | | | 62,1 | 59,9 | |
| B | 57,7 | | | 59,9 | |
| C | 57,7 | | | | 55,4 |
| D | | 49,5 | | | |

**Figure 4** Placement accuracy (%) of the tested machines with the variants plough, mustard and straw mulch (A to D = significance groups; if two or more machines are part of one group, it means that they do not differ significantly)

**Table 3** Comparison of different cultivation variants

| | | *GD* | **Plough** | **Mustard mulch** | **Straw mulch** |
|---|---|---|---|---|---|
| Final emergence | % | *1,3* | 87,5 | 89,9 | 85,7 |
| Spacing accuracy | % | *1,2* | 54,8 | 57,7 | 57,0 |
| Targets | % | *1,3* | 87,4 | 89,3 | 85,1 |
| Doubles | % | *0,1* | 0,7 | 0,4 | 0,8 |
| Misses | % | *0,9* | 11,9 | 10,3 | 14,1 |

**Table 4** Comparison of the tested seeder with the variants plough, mustard and straw mulch (Becker: 2 years)

| | | *GD* | **Accord** *Monopill SE* | **Amazone** *Contour ZR M* | **Becker** *Centra* | **Schmotzer** *UD 3012 PH* | **Vicon** *Unicorn Syn.-drive* |
|---|---|---|---|---|---|---|---|
| Plough | | | | | | | |
| Final emergence | % | 0.8 | 86.0 | 88.4 | 88.2 | 86.5 | 92.4 |
| Spacing accuracy | % | 0.8 | 59.1 | 52.0 | 61.2 | 58.4 | 60.6 |
| Targets | % | 0.6 | 86.5 | 88.9 | 87.0 | 87.2 | 90.2 |
| Doubles | % | 0.1 | 0.9 | 0.8 | 0.8 | 0.7 | 1.6 |
| Misses | % | 0.6 | 12.6 | 10.3 | 12.2 | 12.1 | 8.2 |
| Mustard mulch | | | | | | | |
| Final emergence | % | *1.3* | 86.2 | 88.9 | 89.4 | 88.4 | 92.1 |
| Spacing accuracy | % | *1.4* | 58.7 | 53.1 | 62.7 | 61.9 | 60.0 |
| Targets | % | *1.0* | 86.8 | 89.6 | 88.0 | 88.9 | 90.3 |
| Doubles | % | *0.3* | 0.7 | 0.6 | 0.8 | 0.7 | 1.3 |
| Misses | % | *1.0* | 10.2 | 9.7 | 11.2 | 10.4 | 8.4 |
| Straw mulch | | | | | | | |
| Final emergence | % | *1.3* | 87.6 | 87.2 | 87.5 | 87.5 | 92.2 |
| Spacing accuracy | % | *1.3* | 60.7 | 51.9 | 60.9 | 57.6 | 59.6 |
| Targets | % | *1.0* | 87.3 | 88.5 | 86.6 | 88.1 | 90.2 |
| Doubles | % | *0.2* | 1.1 | 10.8 | 0.9 | 0.6 | 1.6 |
| Misses | % | *1.0* | 11.6 | 10.7 | 12.5 | 11.3 | 8.2 |

*Final field emergence*

Field emergence depends to a great extent on the choice of the right placement depth and re-compaction (pressure device and pressure magnitude). Vicon achieved the best results out of all variants. Also Amazone achieved remarkable result. Accord showed weak points in 2009 (placement too deep); Becker and Schmotzer are midrange.

*Spacing accuracy*

With respect to spacing accuracy hardly any difference can be discerned between the variants. The fewest misses could be observed in straw mulch and the most misses were observed in mustard mulch. Amazone fell off slightly.

In principal the order of the machines remains the same for all cultivation methods. The only difference is that value scatter with mulch variants is bigger than with the plough.

*Comparison of different press roller*

The choice of pressure devices has a strong influence on the emergence speed. Emergence was counted 11 and 39 days after sowing (= final emergence). Since the placement depths as chosen by the manufacturers were not identical, field emergence varied correspondingly (table 3., 4. and figure 5.. The emergence at times of the first screening differed remarkable from the second screening. Each machine was equipped with two different pressure devices – each six rows – which allows a direct objective evaluation. In general it can be observed that differences existing at the first screening were hardly compensated until the second screening.

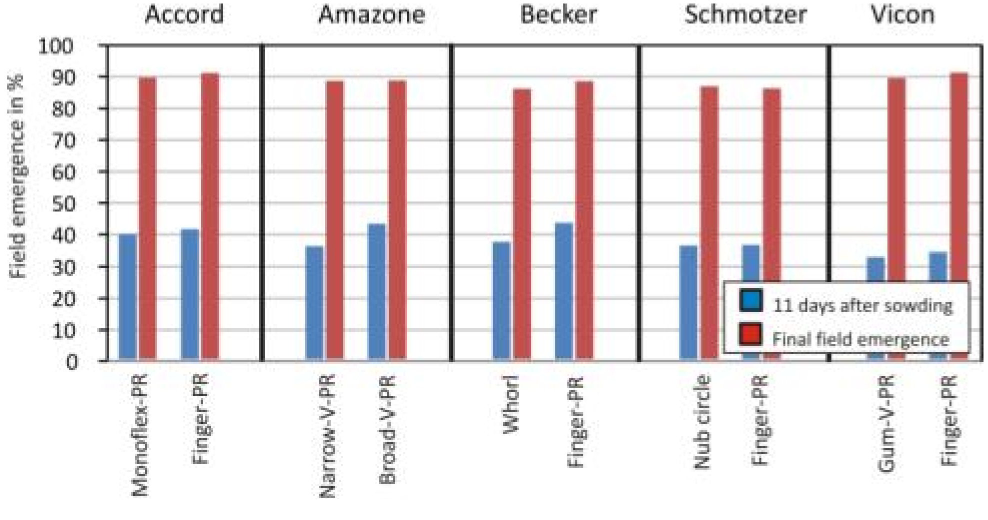



**Figure 5** Field emergence and press rollers (PR)

With the exception of Amazone each machine was also equipped with finger press rolls. In comparison with Monoflex-press rolls (Accord), whorl (Becker) und Rubber-V-press rolls (Vicon), the Finger-press roll performs better. The nub circle press roll achieves slightly better results only with Schmotzer. However, it needs to be considered that the experiments lasted for 2 or 3 years and weather conditions can strongly influence the test results.

## CONCLUSION

The tests compared five precise seeders by means of standardized methods. Experimental facilities allowed for equal conditions for all variants. Statistical evaluation ensures that random effects are not misinterpreted. One needs to consider, however, that working quality is not only influenced by technology but also by the operator. Thus, the choice of placement depth can lead to greater differences in the emergence than technology. Also the impact of re-compaction depends on the choice of contact pressure devices (pressure rolls/ rear packers) and the weather.

All machines work on a high quality level. Spacing accuracy is at 60%. With respect to increased working speed, working quality diminishes slightly for all devices. Nonetheless, one needs to weigh area efficiency and quality loss on an individual basis.

Another factor is soil conditions. Machines react differently to ploughed or cultivated soils.

The tests also showed that contact pressure devices have a great impact on field emergence pace, and ultimately field emergence.

Sowing quality is only one criterion which influences the purchase decision of farmers. Other aspects, such as operation comfort, attrition, customer service and costs are equally important.

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42. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

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# SADNJA VINOVE LOZE SUSTAVOM NAVOĐENJA LASEROM I GPS-OM

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## SAŽETAK

*U radu su prezentirani rezultati strojne sadnje vinove loze pomoću različitih sustava održavanja pravca (laser i GPS) i pogona sadnog aparata (žica i elektro-hidro pogon). Istraživanje usporedbe navedenih strojeva provedene su tijekom sadnje maslina, sorte Oblica, na području Ninskih stanova (Zadar) 2012. godine. Utvrđene su značajne razlike u efektivnom učinku, tako je kod primjene lasera ostvaren učinak sadnje od 0,41 ha/h, dok je kod GPS metode učinak sadnje bio 0.60 ha/h. Utvrđeno je da nema značajnih razlika u kvaliteti rada obje sadilice. Kompjuterskim programima moguće je na temelju uzetih točaka na terenu pomoću GPS-a, definirati konfiguraciju terena i nacrtati budući nasad u 3D obliku.*

***Ključne riječi**: sadilica, vinova loza, laser, GPS*

## UVOD

Podizanje novih vinograda skup je i zahtjevan posao, te je potrebno posvetiti mnogo pažnje kako bi se kvalitetno obavio. Priprema tla, prvi je korak u uspješnoj realizaciji podizanja novih vinograda i predstavlja jednu povezanu cjelinu zahvata i aktivnosti koje kao konačni cilj imaju stvaranje najboljih uvjeta za rast i razvoj biljaka tijekom eksploatacije vinograda. Osnovni preduvjet za uspješan uzgoj vinove loze je dobro pripremljeno tlo za sadnju. Obzirom da je prosječni vijek trajanja vinograda 30 godina, pripremi tla potrebno je posvetiti posebnu pažnju. Nakon ravnanja terena, preporučljivo je provesti meliorativnu gnojidbu stajskim i mineralnim gnojivom širom, koje se rigolanjem ili podrivanjem unosi u tlo. Vinova loza, u našim klimatskim uvjetima, sadi se u proljeće zbog opasnosti od proljetnih mrazova, i iz razloga što tlo ima bolju strukturu pa je i sadnja kvalitetnija. Dubina sadnje ovisi o ekološkim uvjetima, tipu tla i vrsti sadnica (Mirošević, 2008). Način sadnje vinove loze ovisi o veličinu parcele, količine sadnica, konfiguraciji terena, prisutnost skeleta, raspoloživost radne snage, itd (Štefanović, 2012). Za kvalitetnu i uspješnu sadnju potrebno je saditi samo certificirane lozne cijepove visoke kvalitete. To podrazumijeva da cijep ima dobro razvijen korijenov sustav, dobro sraslo spojno mjesto te dobro sazrele plemke. Osim kvalitete cijepa, pažnju treba posvetiti i njihovom pravilnom prijevozu i čuvanju do trenutka sadnje (Mirošević, 2012). Primjena klasičnih metoda sadnje će biti zastupljena samo kod nasada koje se sade sa najvećim rednim razmacima (npr. nasada oraha, šumski nasadi i sl.) kao i na veoma teškim i sabijenim tlima. Primjena sadilica ima prednost kod guste sadnje višegodišnjih nasada pogotovo na dobro pripremljenom zemljištu (Žiković i sur., 2008). Za potpuniju komparativnu analizu ekonomskih pokazatelja neophodno je daljnjim istraživanjima obuhvatiti produktivnost u sadnji.

Mehanizirana sadnja višegodišnjih nasada omogućila je bržu sadnju i uz manje potrebne radne snage osiguravajući veći postotak primljenih sadnica. Spezia (2007) navodi da je najveći napredak u takvom načinu sadnje omogućen primjenom laserskog sustava 80-tih godina. Sadnja navođenjem laserom omogućila je preciznost od ± 3 centimetara između redova. Dva su tipa sadilica najviše zastupljena 90-tih godina, obje njemačke proizvodnje; Wagner, sa rotirajućim sadnim aparatom, i Clemens, sa sadnim aparatom sa jednom hvataljkom. Ova dva tipa sadilica su i danas najzastupljenije na tržištu (Spezia, 2007). Prednost sadilice Wagner je u tome što omogućuje sadnju svih višegodišnjih nasada; loznih cijepova, maslina, i svih ostalih voćnih vrsta.

**Slika 1** Prikaz laserskog i GPS sustava održavanja pravca

Općenito, sadilice za sadnju loznih cijepova sastoje se od noseće konstrukcije na kojoj se nalaze sjedala za saditelje i nosači sadnog materijala, sustav za održavanje pravca sadnje i razmak unutar reda. Sadilice možemo podijeliti i s obzirom na sustav za održavanje pravca između redova i sustava za pogon sadnog aparata. Sustav za održavanje pravca između redova može biti laserski i pomoću GPS sustava. Laserski sustav zahtjeva više rada, i veći su gubitci vremena potrebni za sadnju u odnosu na GPS sustav. Potrebno je razmjeriti parcelu i označiti početke i krajeve redova. Najveći problemi se javljaju kod sadnje na neravnom terenu, onda su moguća i veća odstupanja. Kod takve sadnje potrebno je pažljivo odabrati položaj laserskog odašiljača tako da cijelom dužinom reda laserski prijemnik na sadilici nesmetano prima signal.

Laserski sistem održavanja pravca i pogon sadnog aparata pomoću žice je limitiran dužinom reda, do 300 metara, te reljefom terena za sadnju. Neravan teren sa prisustvom uzvisina i depresija može predstavljati probleme u primanju laserskog signala. Isto tako javlja se problem sa žicom koja pogoni sadni aparat.

GPS (Global Positioning System) sustav za održavanje pravca predstavlja pravu revoluciju u sadnji višegodišnjih nasada. Sadnja se odvija brže i uz veću preciznost, te omogućuje precizniju sadnju i na neravnom terenu. Prednost u odnosu na laserski sustav je u tome što nema ograničenja u dužini redova za sadnju, bez obzira na konfiguraciju terena (Sartori i Rota, 2006).

GPS sustavi mogu biti različitih proizvođača (Wagner IPS-Drive, Leica Geosystems Smartwine, Arvatec). Svi GPS sustavi imaju jednake komponente;

- GPS baza (prijemnik GPS/GLONASS, tronožac, radio modem),
- GPS sustav na sadilici (prijemnik GPS/GLONASS, antena, radio modem),
- Sustav na sadilici (računalo, balans, industrijski kompjuter, automatski
- sadni aparat),
- Kontroler (monitor u traktoru, miš),
- Programski sustav za projektiranje nasada i vožnju (D`Antonio, 2011)

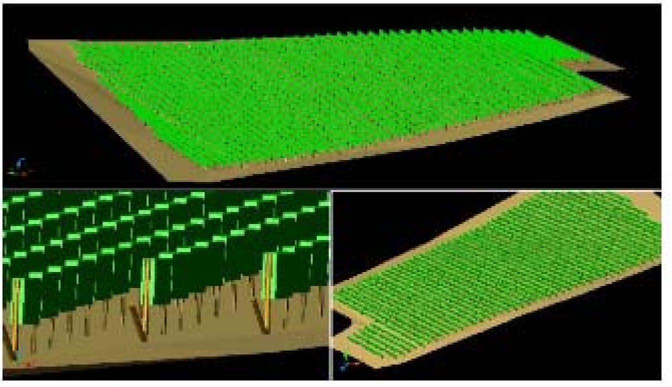
Sadni aparat može biti pogonjen sustavom zupčanika na stražnjem kotaču za podešavanje i održavanje dubine ulaganja sadnica, pomoću žice, i pomoću hidro-elektromotora.

Sustav pogona na stražnjem kotaču se najčešće ne primjenjuje zbog mogućeg klizanja kotača i time netočnog razmaka sadnica unutar redova.

Sustav pogona pomoću žice omogućuje preciznost do 300 metara dužine. Nedostatak takvog pogona što zahtjeva namatanje na početku reda, na kraju reda motanje žice. Najveći problem se javlja na neravnom terenu gdje ako žica takve tlo razmaci unutar redova se poremete, i nastavlja se netočna sadnja do kraja reda. Kako bi se dobila maksimalna preciznost i dijagonale potrebno je saditi samo u jednom smjeru.

Pogon pomoću hidro-elektromotora omogućuje najprecizniju sadnju, jer ako se kojim slučajem dogodi da se jedna sadnica ne postavi na točan razmak, odmah sljedeća se ispravlja i nastavlja se sadnja na zadani razmak. Omogućena je maksimalna preciznost u oba smjera sadnje. Takav sustav je sinkroniziran s GPS sustavom za održavanje pravca (Bellomo, 2009; Calcante, 2009).

Pomoću programa AUTOCAD može se dobiti trodimenzionalna slika budućeg nasada i time detaljnije vidjeti izgled budućeg nasada. Na taj način moguće je detaljnije procijeniti potrebne zahvate za sprječavanje erozije, što je od velike važnosti na nagnutim terenima. Pošto višegodišnji nasadi mijenjaju izgled krajolika, na taj način može se detaljno isplanirati budući nasad tako da uklopi u okolinu i ne naruši prirodni okoliš (Vieri, 2007).



**Slika 1** Prikaz budućeg nasada (Izvor: Vieri, 2007)

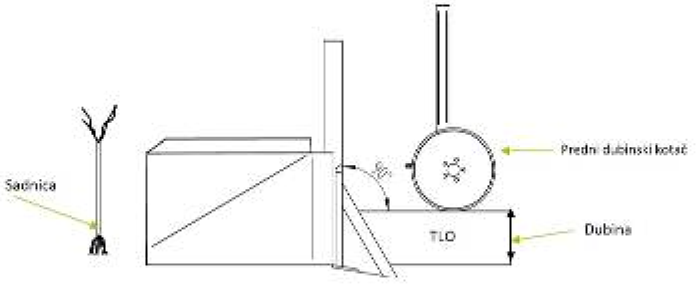
Najnovija istraživanja su usmjerena tome da jedan GPS sustav omogućuje upravljanje svim strojevima za podizanje nasada; moguće postavljanje na grejder pri ravnanju površine, pa na sadilicu, i na kraju na na postavljač stupova (Calcante i Lazarri, 2013).

**Slika 3** Sadilica Wagner Champion Balance

Uređaj za sadnju sastoji se od:

- radnog tijela za izradu brazdice,
- sustava za umetanje sadnica u sadno mjesto,
- sustava za zbijanje zemlje u području korijena sadnice,
- sustava za zatrpavanje brazdice.

Radno tijelo za izradu brazdice je raonik koji otvara brazdu u koju se polažu sadnice. Raonik sadilice je masivan i izuzetno otporan na trošenje. Izrađen je od visoko kvalitetnog čelika, i može izdržati veći otpor u zemljištima sa većim udjelom skeleta.



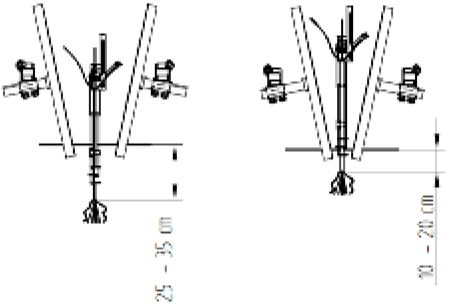

**Slika 2** Prikaz raonika sadilice

Sustav za prihvat sadnica sastoji se od šest do osam hvataljki koje radijalno raspoređene na vertikalnom disku, koluta sa žicom, i različitih lančanika za pogon koji su ujedno i regulatori razmaka unutar redova.

U osnovnoj izvedbi sadni aparat dobiva pogon odmatanjem čelične žice koja se učvršćuje na početku svakog reda. Na kraju reda vrši se namotavanje čelične žice pomoću hidraulične pumpe koja je postavljena na sadilici. Reguliranje razmaka sadnica unutar reda izvodi se kombinacijom različitih lančanika za pogon diska.

Pogon sadnog aparata moguć je i pomoću stražnjeg dubinskog kotača, te elektro-hidro motora kojeg kontrolira GPS sustav.

Sustav za učvršćivanje sadnica sastoji se od dva nazubljena metalna kotača (potiskivača) postavljenih pod određenim kutom. Oni učvršćuju sadnicu potiskujući korijen sadnice.




**Slika 4** Prikaz potiskivača

Na kraju nalazi se sustav za zatrpavanje brazdice koji se sastoji od dva diska ili dvije ravne ploče koji zagrču sadnicu. Pri sadnji u tlima sa više skeleta postavljaju se diskovi, a u tlima sa manjim udjelom skeleta postavljaju se ravne ploče. Sustav za automatsko niveliranje sadilice sastoji se od senzora nagiba i hidraulike na sadilici koji održavaju sadilicu uvijek u horizontalnom položaju. Senzor nagiba šalje signal i sadilica se uz pomoć hidrauličnog cilindra ispravlja i održava sadni aparat u vertikalnom položaju.

**Slika 3** Prikaz sadilice na nagnutom terenu

Kod sadilice sa laserskim uređajem nužne su određene korekcije lasera i razmjeravanje terena kako bi sadnja bila kvalitetno obavljena na nagnutom terenu, dok kod GPS sustava to nije slučaj, već sustav sam sve kontrolira uzimajući u obzir nagnutost terena.

## MATERIJAL I METODE ISTRAŽIVANJA

Ispitivanja sadnje vinove loze, sorte Plavac mali, obavljena su u svibnju 2012. godine na proizvodnim površinama u okloci Zadra (Ninski stanovi). Tvrtka Vigens d.o.o. je 2006. krenula u projekt podizanja trajnih nasada vinove loze, masline, smokve, i trešnje na zapuštenim šumskim zemljištima u državnom vlasništvu na ukupnoj površini od oko 250 hektara. Tlo na spomenutoj lokaciji je pretežito crvenica, plitka i srednje duboka. Crvenica (terra rossa) je kambično tlo mediteranskog podneblja sa izraženom crvenom bojom. Crvenica je tlo koje dolazi na prostorima veće stjenovitosti, a manje kamenitosti i prvenstveno je rezultat kemijskog trošenja čistih mezozojskih vapnenaca i dolomita. Crvenica je plodno tlo, posebno ako su segmenti tla duboki i široki. Pored toga, crvenica je i glinasto tlo, zbog čega je kapacitet držanja vode dosta visok.

Istraživanje je provedeno na dvije sadilice WAGNER CHAMPION BALANCE sa različitim sustavima održavanja pravca i pogona sadnog aparata. Tijekom istraživanja navedene sadilice su bile prikopčane na traktor MASSEY FERGUSON 7480 Dyna-VT, snage 110 kW, opremljenog CVT (Continuously variable transmission) mjenjačem. Sadilice su bile u tvorničkoj izvedbi i uobičajeno pripremljene za sadnju. Dubina sadnje vinove loze bila je u prosjeku oko 30 cm, a zadani razmak sadnje bio je 1,37 m x 2,80 m. Mjerenja za utvrđivanje kvalitete sadnje su obavljena pomoću ručnog metra neposredno nakon sadnje, dok su kronometrijska mjerenja obavljena ručnom štopericom tijekom sadnje.

Parametri koji su uzeti u obzir za ocjenu kvalitete sadnje:

- razmak između redova,
- razmak u redu.

Kronografska "snimanja" rada agregata sastojala su se u utvrđivanju vremena rada pojedinih radnih operacija:

- vrijeme postavljanja sadnica na platformu,
- vrijeme prohoda agregata na dužini redova od 100 metara,
- vrijeme zastoja agregata u radu,
- vrijeme okretanja agregata na uvratini,
- vrijeme povratka agregata,
- utvrđivanje broja praznih mjesta na dužini rada.

## REZULTATI I RASPRAVA

U tablici 1 prikazani su izmjerene vrijednosti razmaka između sadnica vinove loze u redu i između redova.

**Tablica 1** Rezultati mjerenja kvalitete sadnje loznih cijepova

| | Razmak unutar reda | | Razmak između redi | |
|---|---|---|---|---|
| | GPS | LASER | GPS | LASER |
| n | 40 | 40 | 40 | 40 |
| $\sum$ x (cm) | 5.493 | 5.486 | 11.207 | 11.199 |
| X (cm) | 137,3 | 137,2 | 280,2 | 278,0 |
| St. dev. | ±1,89 | ±1,59 | ±1,26 | ±1,44 |
| c.v. (%) | 1,38% | 1,16% | 0,45% | 0,51% |

U tablici 2 prikazane su kronografske vrijednosti tijekom sadnje vinove loze za obje izvedbe sadilica.

**Tablica 2** Kronometrijska mjerenja sadilica primjenom laser i GPS metode

| | Vrijeme sadnje | Utovar sadnica | Okretanje agregata | Prazni hod | Podešavanje agregata | Ukupno vrijeme |
|---|---|---|---|---|---|---|
| Vrijeme (s) | $t_1$ | $t_2$ | $t_3$ | $t_4$ | $t_5$ | $t_{uk}$ |
| Laser | 128,2 | 15,7 | 25,1 | 47,1 | 53,4 | 244.4 |
| GPS | 128,5 | 15,7 | 25,0 | 0 | 0 | 169.2 |

Ispitivanja sadilica u sadnji loznih cijepova su obavljena na dužini redova od 100 m. Na osnovu razmaka loznih cijepova u redu (1,37 m) i razmaka između redova (2,8 m), dobije se 2.597 posađenih loznih cijepova na površini od jednog hektara. Prosječna radna brzina tijekom sadnje je iznosila 2,8 km/h. Mjerenja su izvršena u 10 ponavljanja.

*Sadilica-Laser*

Ukupno vrijeme agregata ($\mathbf{t_{uk}}$) na dužini reda od 100 metara iznosi :

$$\mathbf{t_{uk} = t_1+t_2+t_3+ t_4+ t_5 = 244.4\ (s)}$$

Efektivno iskorištenje radnog vremena sadnje ($\boldsymbol{\tau}$) iznosi:

$$\boldsymbol{\tau} = \mathbf{t_1 / t_{uk} = 0.52}$$

Učinak sadnje loznih cjepova $W_L$ (ha/h) iznosi:

$$\mathbf{W_L} = \mathbf{0.1} \cdot \mathbf{B}\ (m) \cdot \mathbf{v}\ (km/h) \cdot \boldsymbol{\tau}$$
$$\mathbf{W_L} = 0.1 \cdot 2.8 \cdot 2.8 \cdot 0.52$$
$$\mathbf{W_L} = 0.41\ (ha/h)$$

Dnevni učinak sadnje (8 sati) iznosi: **3.28 ha**

U radu agregata na ispitivanoj parceli broj praznih mjesta iznosio je 2 lozna cijepa na ukupnoj dužini od 1000 m.

*Sadilica GPS*

Ukupno vrijeme agregata ($\mathbf{t_{uk}}$) na dužini reda od 100 metara iznosi:

$$\mathbf{t_{uk} = t_1+t_2+t_3+ t_4+ t_5 = 169.2\ (s)}$$

Efektivno iskorištenje radnog vremena sadnje ($\boldsymbol{\tau}$) iznosi:

$$\boldsymbol{\tau} = \mathbf{t_1 / t_{uk} = 0.76}$$

Učinak sadnje loznih cjepova $W_{GPS}$ (ha/h) iznosi:

$$\mathbf{W_L} = \mathbf{0.1} \cdot \mathbf{B}\ (m) \cdot \mathbf{v}\ (km/h) \cdot \boldsymbol{\tau}$$
$$\mathbf{W_L} = 0.1 \cdot 2.8 \cdot 2.8 \cdot 0.76$$
$$\mathbf{W_L} = 0.60\ (ha/h)$$

Dnevni učinak sadnje (8 sati) iznosi: **4.80 ha**

U radu agregata na ispitivanoj parceli broj praznih mjesta iznosio je 1 lozni cijep na ukupnoj dužini od 1000 m.

Laserki sustav navođenja agregata omogućuje sadnju samo u jednom smjeru i zahtijeva više vremena za podešavanje, pa je stoga i učinak sadnje za oko 32% manji u odnosu na GPS sustav koji sadnju obavlja u oba smjera.

Rezultati istraživanja ukazuju da je efektivni učinak za 8 sati rada, u optimalnim uvjetima sadnje i podešenosti agregata, od 8.500 kod laserskog, pa do 12.500 loznih sadnica kod GPS sustava. Istraživanjem došlo se do zaključka da mehanizirana sadnja sadilicama povećava produktivnost rada, te značajno smanjuje troškove sadnje, što potvrđuje i Salvatore et al. (2010).

Neki autori (Mirošević, 2008) ukazuju na upitnost kvalitete sadnje vinove loze pomoću sadilica, te se zalaže za ručnu sadnju vinove loze. Sartori (2004) napominje da je mehanizirana sadnja primjerena i opravdana u podizanju nasada vinove loze, što je potvrđeno i ovim istraživanjem, te da pozitivno utječe na kasniji rast i razvoj vinove loze. Osim primjene suvremene tehnike za postizanje optimalnih učinaka i kvalitetne sadnje vinove loze, bitno utječu i drugi parametri; stanje tla tijekom sadnje (vlažnost i rahlost), tip tla, klimatska obilježja podneblja, specifičnosti lokacije, itd. Tijekom sadnje poželjno je da je tlo rahlo, i sipko, jer na taj način se osigurava dobra fluidnost tla između raonika i potiskivača na sadilici.

Rezultati istraživanja dokazuju da sadilica Wagner, sa sustavom održavanja pravca pomoću GPS-a i pogona sadnog aparata pomoću hidro-elektromotora, može osigurati; kvalitetnu i preciznu sadnju, te visoku produktivnost rada.

## ZAKLJUČAK

Rezultati istraživanja se temelje na usporedbi dviju sadilica Wagner s različitim sustavima održavanja pravca-navođenja (laserski i GPS sustav), i dva različita pogona sadnog aparata (pogon pomoću žice i elektromotora) u kvaliteti sadnje i učinka sadnje vinove loze. Nasad je predviđen za ekološki uzgoj vinove loze, stoga su razmaci veći od uobičajenih kod konvencionalne proizvodnje.

Pri izvođenju istraživanja međuredni razmak kod sadnje vinove loze iznosio je 2,80 m a razmak sadnje u redu 1,37 m. Razmaci sadnje osiguravaju sklop od 2.597 sadnica po hektaru. Odstupanja između redova nisu značajna i iznose najviše do 3 cm, u teškim uvjetima rada. Prosječna vrijednost odstupanja redova za sadilicu primjenom Lasera iznosi 1,84 cm, dok za sadilicu primjenom GPS iznosi 1,80 cm. Značajne razlike u sadnji loznih cijepova pokazala su kronografska mjerenja. Efektivni učinak sadilice primjenom laserskon sustava navođenja agregata je 0.41 (ha/h), dok sadilica primjenom GPS ima efektivni učinak 0.60 (ha/h).Temeljem navedenog nameće se zaključak da kvalitetna sadnja višegodišnjih nasada traži novi, integralni pristup. Također, se može zaključiti da se već danas podizanje višegodišnjih nasada obavlja precizno i učinkovito, uz primjenu suvremene tehnike i tehnologije u svim fazama pripreme terena, sadnje, te održavanje tijekom svih godina iskorištavanja nasada.

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# GRAPEVINE PLANTING BY LASER AND GPS NAVIGATION SYSTEM

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## SUMMARY

*The main goal of this researsh is to tackle with planting perennial crops using planters WAGNER with different systems maintenance directions (laser and GPS) and plant propagating apparatus (wire and electro-hydro plant). Research comparing of these machines were carried out during the planting grapevine slips in Ninski stanovi (Zadar) apartments in the year 2012. Conducted research revealed significant differences in productivity between the planters with laser* *guidance system and the ones with a GPS system. The planters with laser guidance system had 0,41 ha/h planting productivity while planters with GPS system had 0.60 ha/h planting productivity. There were significant differences in the quality of planting out. Application of high technology makes implantation procedures easier and faster. Planting computer programs can be taken on the basis of points in the field using GPS , find the configuration of the terrain and then draw the matching in 3D.*

***Key words**: planting machine, grapevine, laser, GPS*

42. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

UDC 582.542:631.543
Stručni rad
Expert paper

# THEORETICAL MODELING OF WORKING PROCESS OF COVERING DEVICES TO MISCANTHUS RHIZOMES PLANTERS

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## ABSTRACT

*Miscanthus rhizomes planters are composed besides furrow opening devices, by covering disks and press wheels. It requires a certain firmness between soil and rhizomes because they can germinate and the plant to rise and grow.*

*Rhizomes coverage is done generally using two metallic disks inclined in the form of spherical calottes. In order for this to displacing the cut soil and left on the channel by the coulter, it is necessary for them to have a certain inclination, both towards the forward direction and the surface of the soil.*

*In the present paper we are trying to achieve a theoretical modelling of working process of these disks and estimating the soil area displaced and moved laterally in order to cover the channel, depending on the angles of inclination of the disks. There are presented the work process scheme and mathematical relationships for estimating the volume of soil displaced.*

*Also, is presented theoretical modelling of press wheel working process for this to achieve the degree of compaction required to ensure the link between the rhizomes and soil.*

*The mathematical models proposed in this paper can help specialists in construction, design and operation of planters for choosing optimal parameters of the working regime.*

***Key words:*** *miscanthus rhizomes planters, coating disks, press wheel, working process, mathematical modelling*

## INTRODUCTION AND LITERATURE REVIEW

Miscanthus rhizomes planters have as destination planting of seedlings (rhizomes) for setting up the crops which are spread by this method. These planters can work both in tillage field and in unprocessed field and are based on the planter machines principle. They can be equipped with mechanical distribution device of rhizomes or can be with manually distribution, the planting material of the highest quality being directed through a leading tube to the open furrow by the coulter.

The operations of planting rhizomes process carried out by a regular planter machine are: opening the furrow, placing the rhizomes in the furrow, covering the planted rhizomes with vegetative soil and soil compaction after planting.

Considering these remarks, a section of the planter machine is composed of: the coulter for open furrow, before whom could be placed, possibly a disk, a mechanical distribution device for rhizomes that are taken from a storage bin through an elastic claw chain system and a leading system to the open furrow or a leading tube, a rack for rhizomes box and a seat for the operator, in the case of manual distribution of rhizomes (possibly a warning system - sound and / or visual – for when the rhizomes are placed in the leading tube), a coating system with metal disks inclined after two directions and a soil press wheel, Sorica et al., 2009. The section can be completed by a system of soil irrigation at the location of rhizomes in the furrow.

Also, the system of the rhizomes covering and the system of soil compaction with two different working devices can be replaced through a system with two metal wheels with spurs transversely inclined, that executes both covering and soil compaction after placing the rhizomes in the furrow.

Due to the perennial character, miscanthus crop is not included in crop rotation, but is cultivated extensively on specific soils less suitable for other crops where can remain 15-20 years, (Sorica et al., 2009).

Preparing the soil for miscanthus crop involves a deeper loosening that allows proper development of the root system and microorganisms, but also the accumulation of water reserve for driest regions, (Abernathy et al., 1969).

The rhizomes intended for planting have irregular shapes with pronounced ramifications and protuberances. It is used young rhizomes (picked up in the third year of culture), healthy, no mechanical damage, as uniform, with a length of 7-15 cm, thickness of 7-12 mm, weight 40-60 g, with at least 3 - 4 viable buds, (*Abernathy et al., 1969, Poenaru et al.,2012, Sorica et al., 2009).*

The planting distance is influenced by soil fertility, so the density ranging between 10000-20000 plants / ha.

The furrow depth opened by the coulters must be in the range 8-10 cm, depending on the nature of the soil and the degree of compaction.

The researches on miscanthus rhizomes planters are sporadic, but many researches have been carried out regarding the working process of various working devices of planter machines that are very similar to those of rhizomes planters, (Bahri et al.,1992, Benjaphragairat et al.,2010, Cochran et al.,1974, Collins et al.,1996).

There were performed studies and experimental researches on the coulters of planter machines and were evaluated the effects of different types of coulters on traction force and energy consumed to movement, but also on the soil penetration resistance, (Seidi et al.,2012, Solhjou al.,2012).

It was found that the nose and blade addition coulters have the lowest penetration resistance in soil, as well as the lower traction force, at low speed working less than 3 km/h.

Also, the angle of sharpening and shape of the cutting blade of soil have great influence on the energy consumption and fuels for planting tubers, bulbs, rhizomes and seedlings, (*Altuntas et al.,2006, Godwin et al.,2007)*.

From the performed researches Collins et al. (1996*)*, it was found that the double disk coulters recorded the lowest traction force (approximately 1427 N / m), mainly due to the narrow cross section in soil penetration.

The traction force is influenced by planting depth, regardless of soil type: sandy, loamy or clayey, although the average of traction force had values about 3179 N / m for loamy soil and only 2567 N / m for sandy – clay soils (for 9 types of coulter used), (Collins et al., 1996).

Regarding the theoretical studies conducted on the coulters of sewing and planter machines mathematical relations have been developed in which cutting force of soil is a function of many parameters, among them: angles of inclination of the coulter disk, the working width of the disk on the surface soil, the soil resistance at tillage, so on, (Godwin et al.,2007, Godwin et al.,1987, Poenaru et al.,2011, Poenaru et al.,2012[a]).

In the paper (Poenaru et al.,2012[b]) is analysed the soil interaction with the coulter and are determined the forces acting on coulter according to its form and soil characteristics.

## GENERAL ASPECTS REGARDING THE MISCANTHUS RHIZOMES PLANTERS

A miscanthus rhizomes planter, on four-rows is equipped with four work sections, having as component parts all working devices able to open furrow, to place the rhizomes in the furrow, to cover the planted rhizomes with vegetative soil from the edge of the furrow and to compact the loose soil over the rhizomes in order to create the conditions so that they can germinate and spring.

In figure 1 there is presented a schematic diagram of a planter machine and the overview of it.

The main device of work of the section is the coulter 3, where the operator allowed to fall through the leading tube 5, at equal time intervals, each rhizome ready for planting.

After the coulter, the section has following this, a pair of concave disks 7 (in the form of spherical dom having a large radius of curvature), inclined by two directions in the vertical plane which are intended to cover the rhizome already deposited in the furrow.

Due to machine displacement and contact with soil, the disks are rotating in the direction of travel and direct the shredding soil from the edge of the furrow, depositing it back in the furrow, covering the planted rhizome.

Behind the covering disks, the press wheel 8, which can be metallic or rubber tyre type, presses the soil over the rhizome allowing a intimity between these elements, so that the rhizome can germinate and spring, due to soil moisture.

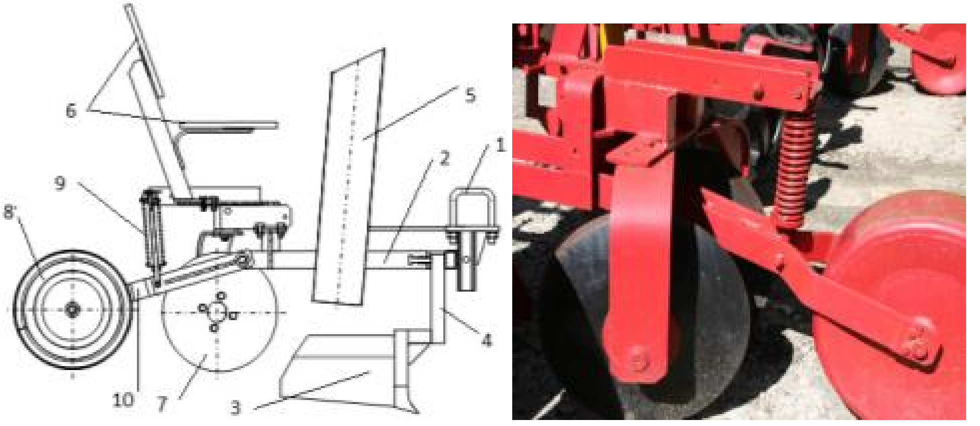


**Fig. 1** The miscanthus rhizomes planter section MPM-4, (Sorica et al., 2009); 1. bridle for mounting on framework car; 2. the framework section; 3. coulter; 4. coulter support; 5. rhizomes leading tube; 6. operator's seat; 7. cover disks; 8. press wheel; 9. coil spring

For the study of working process of the covering disks and press wheels, in the present paper there are presented, firstly, some theoretical aspects about the volume of soil dislocated by the two disks of the miscanthus rhizomes planter section, depending on their rake angles as well the degree of the soil compaction by the press wheel.

In order to determine the soil volume dislocated and displaced laterally by the cover isks it was proceeded to a projection method from descriptive geometry, the inclined disk being designed in both the vertical planes (frontal and lateral) and the horizontal plane.

For a given working depth, $a$, is established the angle of the action area of the disk and the surface in vertical frontal plane of this area.

If it is known the travel speed of machine then the volume of displaced soil can be estimated as a flow rate of material flowing through a unit area in the unit time.

For the press wheel on which presses the load $G_t$, composed of its own weight together with a part of the framework weight, as well as the tension force of the coil spring for adjusting pressing (see fig. 1), were written the traction force equations, the depth of compaction equations and the relative deformation of the soil equations.

The experimental tests have been performed regarding the fuel consumption, the traction force and the working process of the two working devices analyzed, for a miscanthus rhizomes planter on four-rows but that was equipped so that it is possible to estimate (by difference) the indices values recall.

Thus, from the planter machine were initially removed the press wheels and the cover disks and were carried out tests only with coulters sections, for more planting depth, recording the consumption, slip and traction force using a strain frame, with sensors located on the laterally tie rod and the central one of the tractor clamping mechanism.

Then, were added to the machine the cover disks, and in the end the press wheels, recording each time the listed parameters.

**Fig. 2**The working process carried out by the miscanthus rhizomes planter section

## THEORETICAL ASPECTS ON WORK PROCESS OF THE COVERAGE DISKS

The two coverage disks are presented in perspective, in fig. 3, a, being mounted on a support frame that is attached with screws to the planter section. The geometrical characteristics of the disks and the angles disposal on the frame influences the way of taking soil and the degree of covering planted rhizomes.

For the analysis of the coverage disks working process, it is supposed the general case, when these are inclined by two directions: in the vertical transversal plane (that is, towards the direction of advance with the γ angle) and in the vertical plane (that is, π/2-β angle to the horizontal), (Scripnic &Babiciu, 1979).

If the soil processed in front of disks has horizontal surface, by moving in soil, a disk cuts the soil layer *mecn* whose width is $b_a$ (working width of the disk).

Taking into account the rake angles of the disk on both directions, sectional area of the soil layer is:

$$S_o = S_o' \cdot \cos\beta \cdot \sin\gamma \tag{1}$$

where: $S_o$' is the surface of a circle segment *MCN*, from the disk natural size.

The surface of a circle segment *MCN* is given by the relation (see fig.):

$$S_o' = \frac{\pi D^2}{4} \cdot \frac{\varphi_a}{2\pi} - \frac{D}{2}\sin\frac{\varphi_a}{2} \cdot \frac{D}{2}\cos\frac{\varphi_a}{2} = \frac{1}{8} D^2 (\varphi_a - \sin\varphi_a), \tag{2}$$

from which it follows, (Scripnic&Babiciu, 1979):

$$S_o = \frac{1}{8} D^2 (\varphi_a - \sin\varphi_a)\cos\beta \cdot \sin\gamma. \tag{3}$$

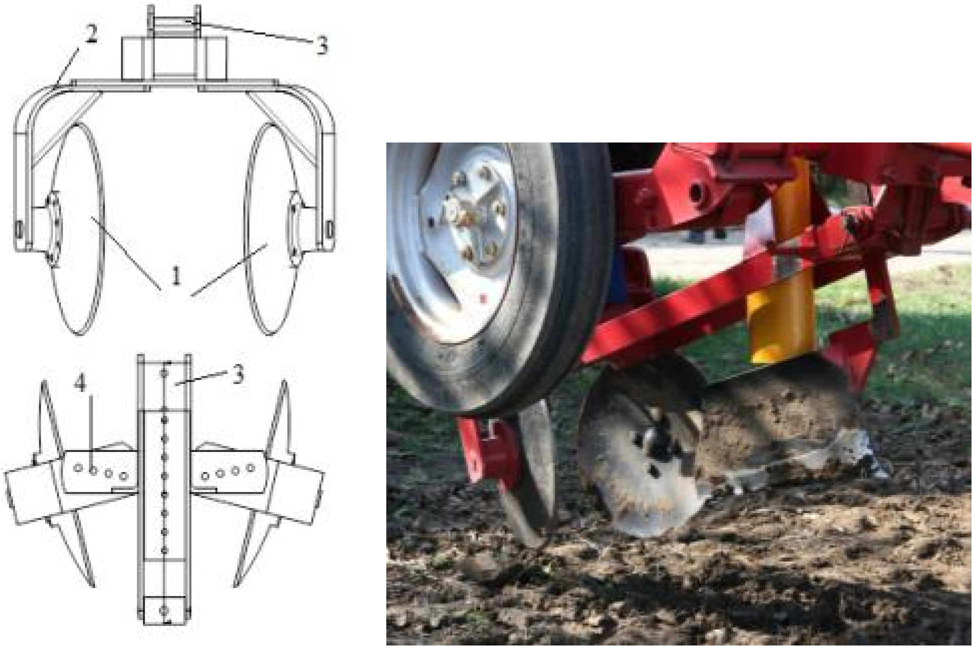


**Fig. 3** Coverage disks of the miscanthus rhizomes planter section (appearance from the time of experimental tests in which the press wheels have been removed); 1. concave disks; 2. the disks framework; 3. holder grip; 4. inclination adjustment hole

The surface of a circle segment *MCN* is given by the relation (see fig.):

$$S_o' = \frac{\pi D^2}{4} \cdot \frac{\varphi_a}{2\pi} - \frac{D}{2}\sin\frac{\varphi_a}{2} \cdot \frac{D}{2}\cos\frac{\varphi_a}{2} = \frac{1}{8}D^2\left(\varphi_a - \sin\varphi_a\right), \qquad (2)$$

from which it follows, (Scripnic&Babiciu, 1979):

$$S_o = \frac{1}{8}D^2\left(\varphi_a - \sin\varphi_a\right)\cos\beta \cdot \sin\gamma. \qquad (3)$$

If it is known the working depth of the disks then it can be determined the angle of each disks working section, from the relation:

$$\cos\frac{\varphi_a}{2} = \frac{D/2 - d/\cos\beta}{D/2}, \qquad (4)$$

resulting:

$$\varphi_a = 2\arccos\left(1 - \frac{2a}{D\cos\beta}\right). \quad (5)$$

Working width of a disk is:

$$b_a = D_a \sin\gamma \quad (6)$$

where: $D_a$ the circle chord length with the $D$, in depth $a/\cos\beta$.

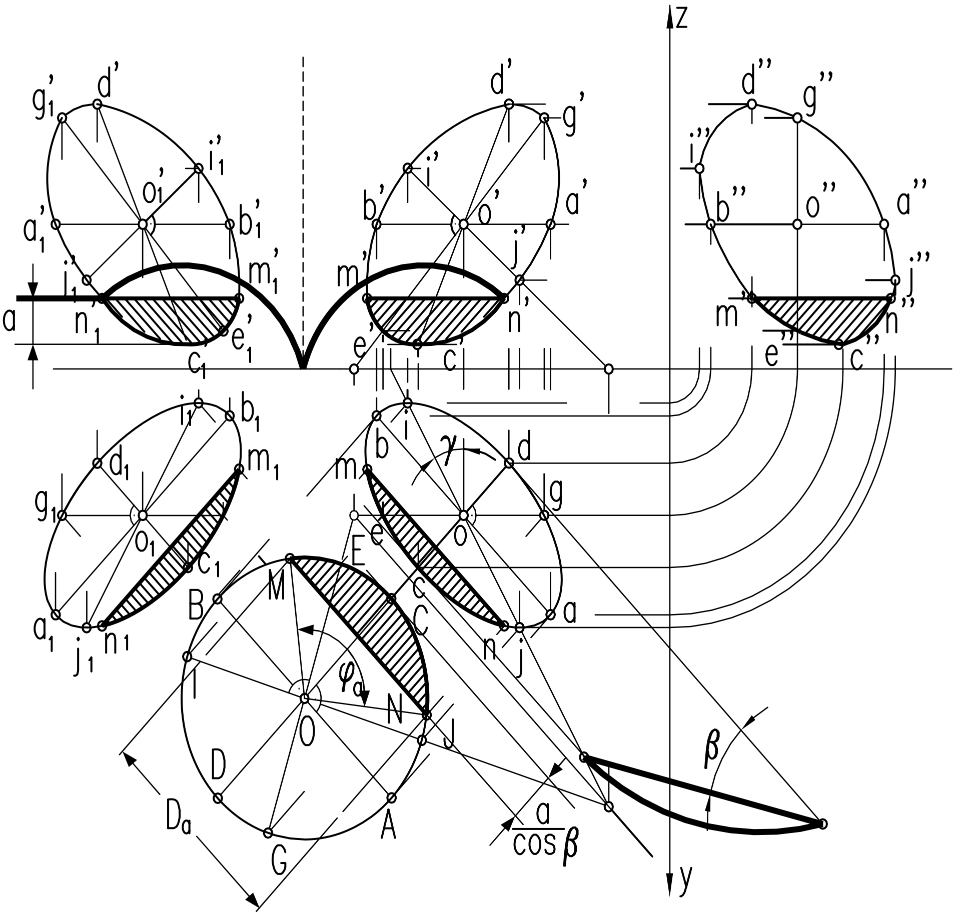


**Fig. 4** Schematic working process of coverage disks and the processed area projections in the three planes (horizontal, vertical frontal and vertical lateral)

The chord length $D_a$ results from the relation:

$$\left(\frac{D_a}{2}\right)^2 = \left(\frac{D}{2}\right)^2 - \left(\frac{D}{2} - \frac{a}{\cos\beta}\right)^2, \tag{7}$$

from which it follows:

$$D_a = 2\sqrt{\left(\frac{D}{2}\right)^2 - \left(\frac{D}{2} - \frac{a}{\cos\beta}\right)^2}, \tag{8}$$

and $b_a$:

$$b_a = 2\sin\gamma\sqrt{\left(\frac{D}{2}\right)^2 - \left(\frac{D}{2} - \frac{a}{\cos\beta}\right)^2}, \tag{9}$$

During work, the cut soil layer by a disk from the field on which it is moving is climbed on the inner surface of the disk, moved laterally and partially reversed. When the concave disk is moving on the soil, the forces resultant that soil reacts on the disk achieve it's rotation, favouring overturning and lateral movement of the already cut soil.

Taking into account that, in the open furrow by the coulter the soil is not, but, horizontal, the soil volume displaced by a disk has a curved upper surface, with the maximum depth in the middle of the furrow (between the two disks), because the two sides of the coulter work as two plow mouldboards placed back to back. By construction, the coulter is located below and working at a depth greater than the coverage disks. If the coulter working depth is 8-12 cm, the disks are working with at least 5 cm above, framing complete the coulter.

It can be assumed that the point around which the soil volume driven by coulter overturns, is the deepest point of the disk, a part of the soil entering into the furrow and the other part returning to the place from which it was taken.

## THEORETICAL ASPECTS ON WORK PROCESS OF THE PRESS WHEEL

The press wheel of each section is designed to perform pressing deposited soil above the rhizomes from furrow covered by coverage disks. The main purpose is to achieve an intimacy between the cut soil and miscanthus rhizome buds for sprout, appearance of roots and plants spring.

Under the action of traction force, $F_t$,, press wheel in weight, $G_t$ , runs on the loose soil surface, compressing the upper layer of soil to a depth *h*.

Compression of the soil is produced on AC zone, soil particles being moved towards the direction of advancement and pressed down, in front of wheel compaction forming a bump.

In the working process on the press wheel following forces and moments are acting: $G_t$ – press wheel weight; $R_s$ - soil reaction (the forces resultant that are opposed to compressing the soil); $M_f$ – the friction moment that appears in press wheel shaft bearings and $F_t$ - traction force.

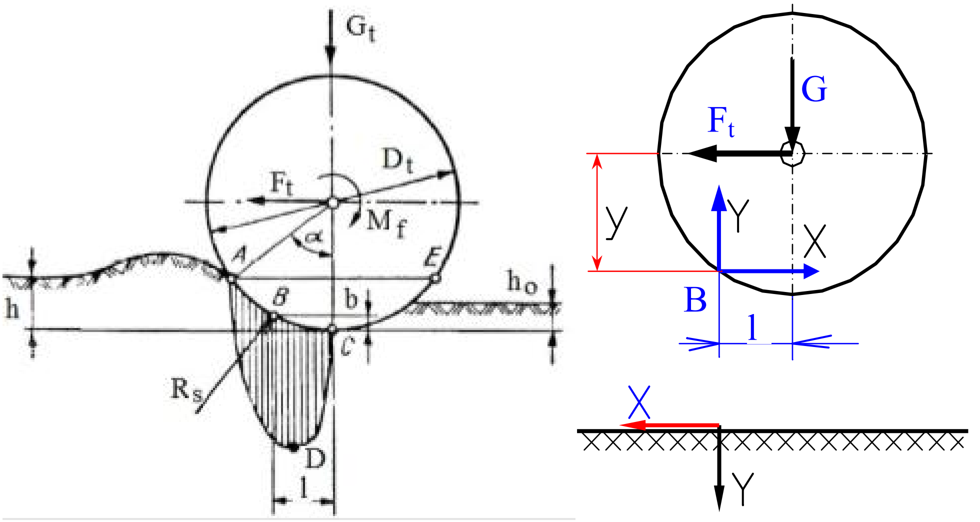


**Fig 5** The working process carried out by press wheel, (Scripnic&Babiciu, 1979)

If ignored $M_f$, applying the isolation bodies theory from technical mechanics, then the traction force, for a considered nominal mode of operation, is determined from the sum of the moments acting on the wheel, (Scripnic&Babiciu, 1979):

$$X = F_t = \frac{x}{y} \cdot Y = f \cdot Y \rightarrow F_t = G_t \frac{2l}{D_t} = f \cdot G_t = W_r \tag{10}$$

where: X and Y are reactions, tangential and normal of the tread surface on press wheel (X – rolling resistance force); x - coefficient of rolling friction, expressed in units of length (point *B* is the point of application of drag forces); $f = x/y$ – rolling resistance coefficient; $W_r$ - rolling resistance roll.

If it is considered $b = 0$, then $f = 2l/D_t$. According to the literature $f$ has the values: $f = 0.15 \ldots 0.20$, for processed fields.

Among the technological parameters of press wheel we can mention: the depth of compaction, wheel dimensions and the pulling force.

The compaction depth *h*, for non-cohesive fields, as the soil is after processing and passing the coverage disks, depending on the humidity of the soil, the specific load on wheel $q = G_t/B$ (*B* – wheel width) and radius of the press wheel, (Voicu, 2007).

$$h = 0.35 \cdot \frac{w}{w_o} \cdot \sqrt{q \cdot R} \ \text{(m)} \tag{11}$$

where: $w$ and $w_o$ represents the real humidity, respectively optimal humidity of the land (the material).

Also, the relative deformation ε after passing the press wheel is influenced by specific load on the wheel $q$ (N/m), on layer thickness of loose soil $H_a$ (considered approximately 0.20-0.25 m), but also the modulus of deformation of loose soil $E_o$ (Pa), (Voicu, 2007):

$$\varepsilon = \frac{20 \cdot q \cdot \alpha}{E_o \cdot R^{0.5} \cdot H_a} \tag{12}$$

in which: α is a coefficient of proportionality.

## FINAL DISCUSSION AND CONCLUSIONS

During the experimental tests were followed energy indices and appreciation indices of work carried out by each working device, and the whole section of planting. It was determined fuel consumption, the traction force, the travel speed with tractor wheel slippage and degree of covering the furrow by the coverage disks and the degree of soil compaction achieved by the press wheels by determining the density of the soil before and after their transition.

Measurements were carried out on the penetration resistance of the soil but also soil moisture.

All these experiments and the results obtained will be the subject of another paper, but we want to present in this paper only physical aspect of soil after passing each working device of miscanthus rhizomes planter section.

Over the working process of coverage disks and press wheel from planters are few references, though its effectiveness on the mode of springing of the plants and on crop production has been studied.

The coverage disks of planters are disposed behind the coulters, but we believe that the coverage is only effective if they work and take over the cut soil from the bumps area produced by the coulter, so after the overturning and moving sideways, the soil surface to remain approximately horizontal. This involves the study of mutual position of coverage disks in relation to the coulter

The press wheel, located behind the coverage disks, should ensure the intimacy of planted material with soil, which is ensured by proper adjustment of the coil spring that presses on the framework wheel.

**Fig. 6** The way how the soil show after passing each working device of planter section.

## AKNOWLEGEMENT

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42. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

UDC 631.17:631.3
Prethodno priopćenje
Preliminary communication

# RESEARCHES REGARDING EXPERIMENTAL VALIDATION OF STRUCTURAL ANALYSIS PERFORMED ON RESISTANCE STRUCTURES OF AGRICULTURAL MACHINERY

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## SUMMARY

*Resistance structures, further called frame or chassis, are designed and dimensioned according with a safety coefficient which assures their good activity performing. These primary structures are subjected to a process of structural analysis for an improved or even optimal dimensioning. This process of structural analysis includes several stages: structural modeling, static analysis, resonance frequencies analysis, dynamic simulation, fatigue analysis. After performing all or only some of these stages, the theoretical dimensioning can be finished. After manufacturing the experimental model, according to the data from the theoretical process, follows the validation stage through testing. There are two types of such tests: in field, in various working regimes, respectively in laboratory conditions. Field tests aim for the quality of the performed work, and also for determining some favorable working regimes and their mechanical behavior (strains, stresses, vibrations, resonance and fatigue). Mechanical tests are performed in detail on specialized stands, in simulated and eventually accelerated regime. In this paper we compare the obtained results through finite element modeling, static analysis, carried out for Miscanthus Planting Machine, with the experimental results.*

**Key words**: *structural analysis, experimental validation, resistance structure, agricultural machinery, loading*

## INTRODUCTION

The design of agricultural machinery at modern and functional parameters that render its viability on the international market, contains several mandatory steps [2]. The conception of the machine is intimately linked to the agronomical requirements which it must meet. In this stage the designer conceives the machine part performing both the agricultural work (soil, harvesting, sorting, planting, plant protection treatments, etc.) and the bearing structure that supports the organs or the working installations, additional energy sources, the annexes, etc. It all starts from a concept sketch without an algorithm, but by the free creation of the designer, perhaps inspired by similar devices. The structure thus generated is then subjected to a simulation process, which means creating one or more mathematical models among which the structural model, [4], it is particularly important as it will serve both to determining the initial characteristics and will be subsequent to verifying the resistance in the final stage, as well as in the eventual stage of optimization. With the results obtained from this theoretical stage, a first structure is built, which then is tested in order to study primarily the quality of the performed work and secondly the assessment of structure response in field conditions. In this testing stage there is gathered information on a number of operating parameters of the machine. Among those, the following ones are important for the mechanical behavior of the structure: required traction force, energy consumption, strains in the essential points of the structure (specified by simulation in the previous stage), accelerations in the same types of locations, etc. After data recording, if the machine meets the agronomical and mechanical requirements according to the current standards, it will move to the optimization stage (fatigue studies of the structure, vibrations, etc.), and then proceed to manufacturing. However, if one of the essential working parameters is not within the limits required by standards, then the structure is sent back to the first stage and the designing process is resumed.

## METHOD

*The structural model and structural analysis*

Miscanthus (Miscanthus) is a complex of about 15 species of perennial grass, native to subtropical regions of Africa and Southeast Asia, [6]. The sterile hybrid Miscanthus sinensis and Miscanthus sacchariflorus, Miscanthus giganteus, was tried as a biofuel in Europe since the 1980s. It may grow at a rate of 3.5 m in the season and can achieve a production of 25 t/ha. The rapid growth and the low content in mineral, as well as the appreciable crop have made of Miscanthus a favorite choice for biofuel production.

For the above reasons, since 2000, in Romania has been raised the question of the development of some Miscanthus crops. The Miscanthus planting machine for which in this paper has been constructed a structural model, is the response of INMA to the requirements of the Romanian biofuel market.

The 3D (three dimensional) drawing of the assembly of Miscanthus planting machine, MPM-4, created with the SolidWorks software, is illustrated in Figure 1. The structural geometrical model of the assembly of the Miscanthus planting machine, MPM-4, is three dimensional constructed exclusively with 1D bars, a spatial truss-type structure. This model is presented in Figure 2.

The purpose of the paper is to assess the behavior of the machine’s resistance structure, mainly composed of a resistance beam on which are mounted the working stations, the holders for planting material and the markers.

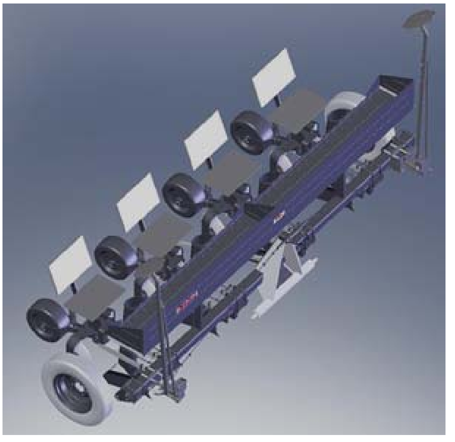

**Fig. 1** Spatial drawing (3D) of the assembly of the Miscanthus planting machine, MPM-4

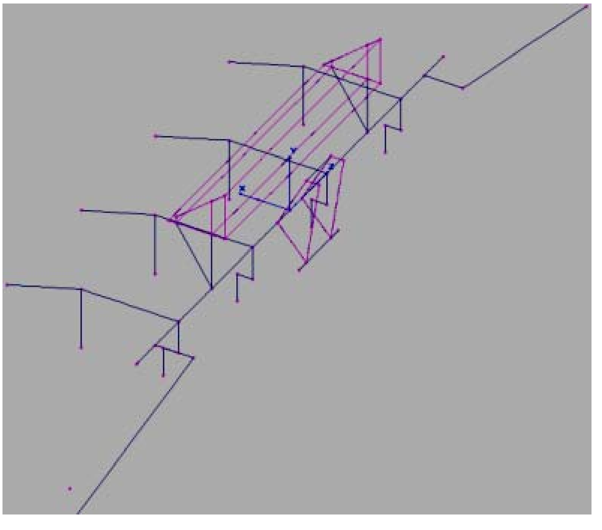

**Fig. 2** Geometrical model (3D) of the assembly of the Miscanthus planting machine, MPM-4

Structural model of the structure analyzed by structural analysis method has four main components: ***geometry*** (geometrical model), ***the boundary conditions*** (conditions on the domain boundary created by the geometrical model), ***loading*** (external forces applied to the structure which can be external forces, moments, forces or gravitational field generated by centrifugal and pressure fields, etc.) and the **rheological model**, or in other words the type of material used and constant values which characterize it (one or more types of materials if the structure is built from several types of materials that are joined together).

The usual structural analysis programs have different types of controls for both construction and geometry, for applying external links (support, blocking or boundary conditions, initial conditions), for the application loads and for defining the rheological body.

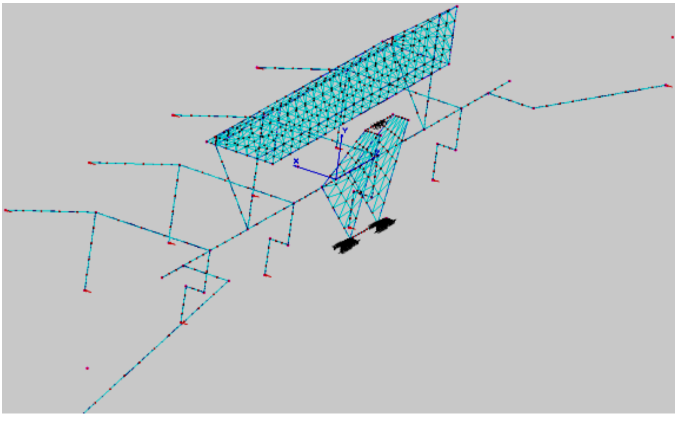

**Fig. 3** Discretization, the structural bearings and loading model: the geometry, elements and knots (elements of type BEAM3D for beams and elements of type SHELL3, two-dimensional type for surfaces)

*Boundary conditions*

The structure is supported on the mounting plates to the tractor and the lower bar at the base plate fixture. The plate's upper side propping up is done on the structural model of the clamping bolt. In the nodes located in these areas, the translations were considered to be zero. Support can be identified in Figures 3 and 4 with magenta arrows.

*Loading*

Loadings are of two types: gravitational, given by the own weight of the structure, respectively forces, which are generated by the action of the working organs into the soil: 735 N at each coulter, 400 N at each battery of disks burying the planting material and to nearly 50 N at each of the two markers. The loadings with forces are shown with yellow arrows on the structural model which is drawn in Figures 3 and 4. Resistance forces have the total value of 4640 N.

*Defining the material (rheological model)*

The rheological model is a homogeneous and isotropic linear elastic material whose characteristic constants are specific to a wide range of steel: the modulus of elasticity $E$= $2.1 \cdot 10^{11}$ N/m$^2$, Poisson's ratio $\nu$= 0.28 and the density $\rho$= 7800 kg/m$^3$.

The analysis is of static type, on a linear elastic material with inertial loadings that simulate the gravity loading and loads due to forces which are the result of the interaction between the machine working bodies and the soil.

## RESULTS AND DISCUSSIONS

*The structural analysis results*

The main results of the structural analysis are: the deformed shape of the structure, the relative displacement field (on components and resultant), the reaction forces, the tensorial field of the small strains – six components, as well as synthesis components, such as total deformation, tensorial field of the Cauchy stresses (six distinct components), and components of synthesis by means of which is estimated the safety factor of the structure, in this case the Von Mises stress.

In Figure 4 is given the map of the field distribution of relative displacement resultant (the deformation in engineering language) in the structural model. Its maximum value is 25.33 mm. In Figure 5 is given the distribution of resultant reaction force into the structural model nodes.

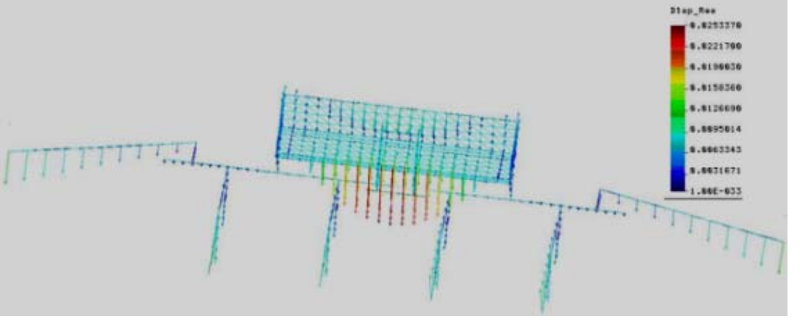


**Fig. 4** Field of relative displacement resultant into the structural model of the Miscanthus planting machine frame, in m

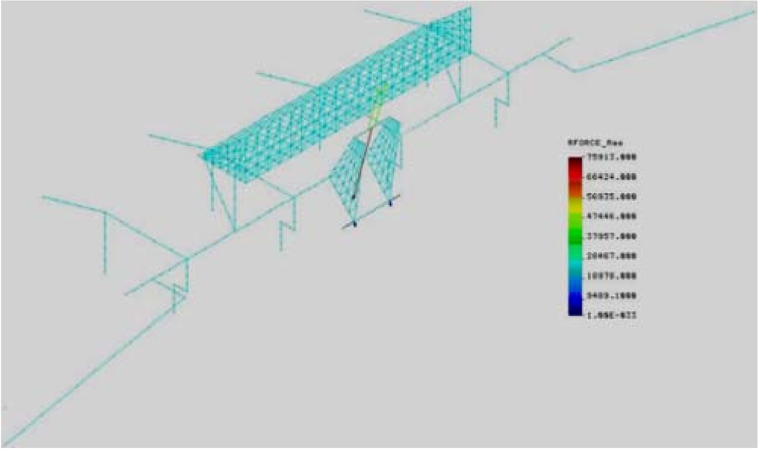

**Fig. 5** The map of the reaction forces field into the structure in stationary case, in N

In Figure 6 is given the map of equivalent stress field (Von Mises), [1], [5], into the structural model of the Miscanthus planting machine, MPM-4, on its non-deformed shape. The maximum stress into the structure reaches the value of 70.54 MPa. This value is localized in the attachment plates to the tractor and it is due to some stress of concentration introduced by the sharp peaks of some items of type SHELL3. An eventual re-discretization can fix these concentrations. The idealization itself introduced by the combination of a plate and a bar, therefore a punctual joint, may favor unrealistic stress concentrations. On the main resistance beam the stresses have values below 40 MPa and they are localized in the nearby the mounting area for the connection plates to the tractor and the area of fastening the working sections on the beam.

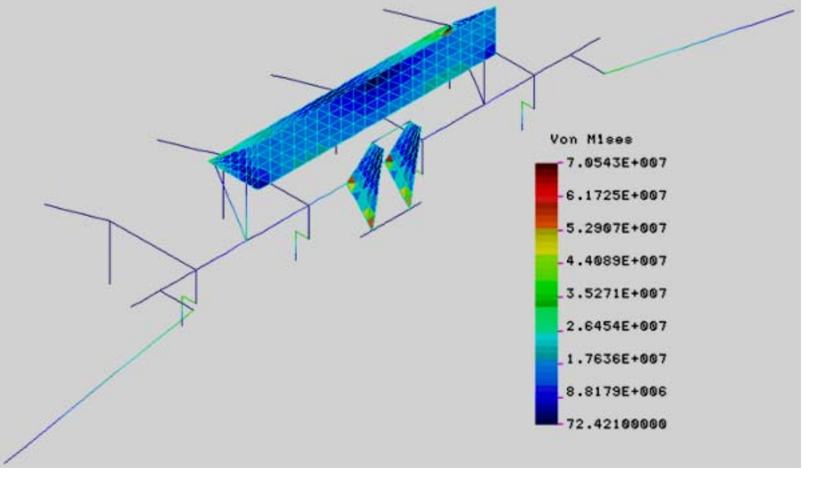


**Fig. 6** The field of equivalent stress (Von Mises) into the structure, in Pa

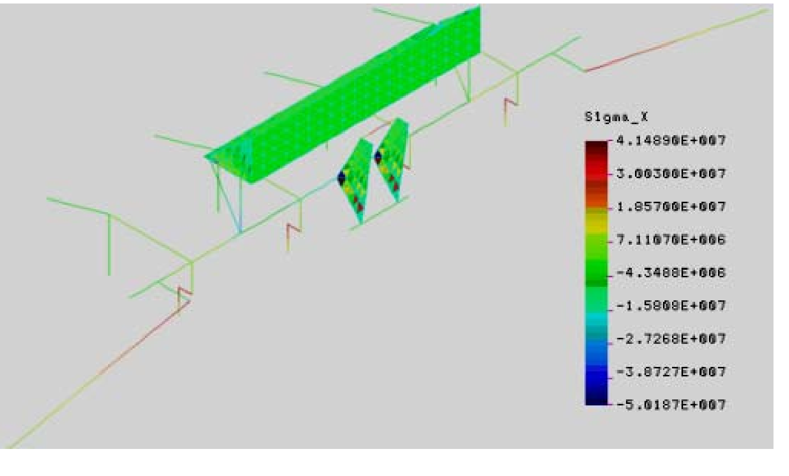


**Fig. 7** The field of axially stress into the structure, in Pa

In Figure 7 it is given the state of the axial stress (stretching - compression into the structure bars). On this map it can be seen the most loaded bar area, found on the fastening system of the working organs support on the supporting structure.

The Ox-axis reaction in the attachment points to the tractor indicates a value of -5840 N, and on the Oy direction, the value of 3610 N.

*Field Tests*

The testing of the machine version manufactured after the theoretical examination by structural analysis has the role of checking the quality of the work and behavior of the structure at normal and overload efforts. In addition to this, during the field tests, data are collected in order to make possible the simulation of loading on the test stand in laboratory conditions.

Such tests for Miscanthus planting machine were performed in the field, by measuring the mechanical response of the structure in the terms of traction force and of strains into the essential locations designated following the structural analysis results. For measuring the traction force it was used a device interposed between the tractor and the planting machine. The device consists of three 30 kN load cells mounted parallel with the ground, between the sideways and central tie rods of the tractor and the three points linkage assembly on the planting machine. Also, 14 strain gauges were used, being located on the main resistance beam (Figures 11 and 12). The strain gauges chosen had 350±0,35% Ω resistance with a gauge factor of 2,09±0,7% and a 3 mm grid length. The measuring amplifier used was of QuantumX MX1615 type, especially designed for taking measurements with strain gauges. Both the strain gauges and the measuring amplifier are manufactured by HBM Germany. We have chosen the quarter bridge configuration for our tests. The procedure for calibrating the strain gauges consisted of using a calibration unit which was inserted into the circuit in place of the strain gauge and then it was replaced after calibration by the strain gauge. We have used a strain indicator calibrator model 1550A from Vishay Micro-Measurements.

Aspects from the field testing activities are presented in Figures 8 and 9.

**Fig. 8** Aspects from experimentation activity (dynamic tests)

**Fig. 9** Aspects from experimentation activity (setting up data acquisition)

A typical sequence of variation of traction force recorded during working tests in the field with the Miscanthus planting machine is given in Figure 11. Tests were conducted at working depths between 6 and 12 cm (for all four working sections), at speeds between 4.4 and 5.18 km/h. The testing plot had a lenght span of 90 m over 50 m width. The working width of the planting machine was of 3 m. We did three repetitions for each type of test from which we calculated the mean values for strain and traction force. Statistical analysis and the interpolation of experimental data lead to a mean traction force between 7194 and 8425 N.

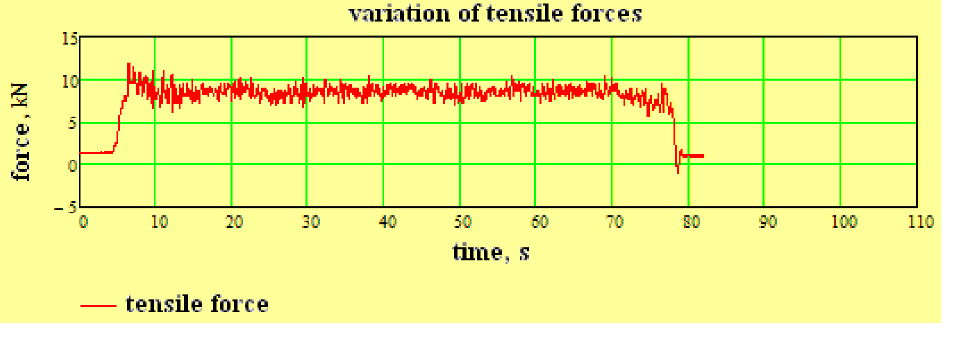


**Fig. 10** Typical sequence of variation of traction force in the working tests, in the field

It can be noticed that in the structural model, loading was made on the working and supporting organs that came in contact with the soil, while the experimental estimation was made by measuring the strains on the tractor tie rods and converting them into forces, then algebraically summating them to obtain the traction force. By performing this operation in a similar way for the structural model, there is obtained a value of traction of about 7645 N which fits perfectly in the experimental results.

For a thorough examination we should analyze the experimental data, of which the most important are the strains that can be converted into stresses. The strains were measured in

14 locations on the borders of some structural elements. The strain value (or stress) in each location must be compared with the value in the appropriate location of the structural model, given the fact that we found that the structural model loading lead to a value of traction force in line with the experimental values. The average experimental values measured and the theoretical ones obtained from FEM analysis are presented in Table 1.

**Table 1** Comparison in terms of the stress in the locations where strain gauges were applied to the structure

| Strain gauge no. / Tension, MPa | M1 | M2 | M3 | M4 | M5 | M6 | M7 | M8 | M9 | M10 | M11 | M12 | M13 | M14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Experimental value | **-18.9** | *-7.5* | *8.0* | **-9.9** | **22.1** | *8.0* | **1.23** | *2.2* | **-29.6** | *6.2* | *-8.0* | **2.7** | **23.8** | **-25.8** |
| Theoretical value | **-9.9** | *-9.9* | *-9.9* | **-9.9** | **-21.4** | *-21.4* | **-21.4** | *-21.4* | **-21.4** | *-21.4* | *7.05* | **7.05** | **-21** | **-21** |

In Table 1, the strain gauges M1, M4, M5, M7, M9, M12, M13 and M14 are oriented along the axis of the resistance beam, and the rest are oriented perpendicular to its longitudinal axis.

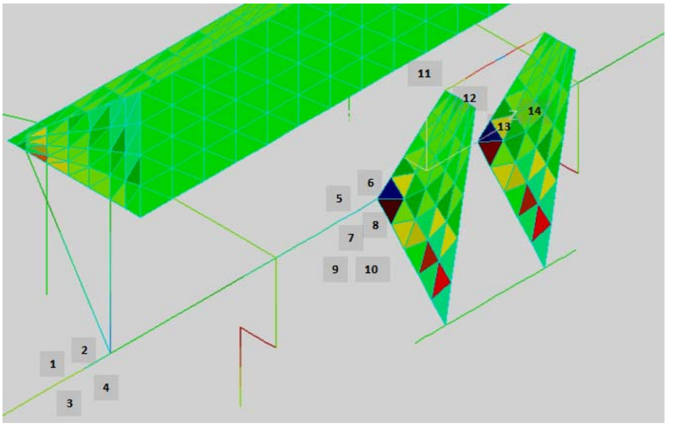


**Fig. 11** Locations of strain gauges

The validity of the structural model (at least partial) is confirmed by the fact that it identifies the largest stressed area in the supporting bars for the working organs which is located in the fastening area to the supporting structure of the Miscanthus planting machine. The stressed area can be seen in the Figures 6, 7 and 11. During the experiments at highest working speed, when high maximum stresses appeared in the beams on which there were mounted strain gauges, it appeared irreversible deformation of the upper part of two of the three working organs supports (Figure 13). The working regime has been forced expressly to highlight the weaknesses of the structure at the meet of some shocks or peaks of load.


**Fig. 12** Locations of strain gauges - details

**Fig. 13** Working organs supports irreversibly deformed during the forced working regime

## CONCLUSIONS

The main results of the structural analysis have been presented in the section devoted to the global structural model of the Miscanthus planting machine. We made a comparison between theoretical and experimental results regarding the traction force. We saw that theoretically forecast is well framed by experimental measurements. However, this comparison is insufficient at least for the reason that theoretical traction force is estimated by the reactions in the attachment points of the structure at the tractor’s tie rods, while the experimental traction force is estimated starting from the indications of the load cells mounted to the sideways and central tie rods of the tractor.

The comparison for the strain gauges orientated perpendicular to the longitudinal axis of the resistance beam have no meaning in this simple model, because the structural model is constructed with idealized beams by one-dimensional elements.

The structural model is validated by measurements in the terms of the traction force and stress (strain). This finding allows the use of the structural model in advanced study of modal analysis, stability and eventually the fatigue life.

The satisfactory concordance between the experimental results and the structural model shows that the experimental results can be used to develop some excitation signals for the structure in laboratory experiments, in accelerated regime, specific to the study of the fatigue behavior and vibration regime. The way in which critical signal selection is done and the checking of their correct application reported to the real and structural model constitutes the subject for another paper.

The concordance between the experimental results and the theoretical ones of the structural model indicate that the mode of construction is correct and the constant values involved in the model are estimated correctly. The assumptions of loading and boundaries choosing are validated.

For a more accurate comparison in terms of the traction force and a possible estimation of vertical pushing forces we suggest to extend the model with the tie rods of the tractor and to support the structure to the tractor's tie rods ends.

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42. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

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Stručni rad
Expert paper

# TESTIRANJE TEHNIČKIH SUSTAVA U ZAŠTITI BILJA U REPUBLICI HRVATSKOJ

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## SAŽETAK

*U cilju dobivanje GlobalGap certifikata, obavljena su testiranja tehničkih sustava u zaštiti bilja u voćnjaku Obreška (vlasništvo Belja d.d.), koju su proveli djelatnici Zavoda za mehanizaciju Poljoprivrednog fakulteta u Osijeku. Testiranjem je obuhvaćeno 16 raspršivača, na kojima se prema EN 13790 standardu, provjeravala ispravnost rada pojedinog sustava. Ulaskom Hrvatske u EU naslijeđena je direktiva 2009/128/EC i 2006/42/EC koja propisuje obavezni pregled tehničkih sustava u zaštiti bilja (raspršivači i ratarske prskalice). Navedena direktiva uvedena je u Pravilnik o održivoj uporabi pesticida (NN 142/12), prema kojem svi uređaji pri zaštiti bilja do studenog 2016. moraju nositi naljepnicu o redovitom tehničkom pregledu, a uređaji koji su proizvedeni prije 1995. godine moraju biti pregledani najkasnije do studenoga 2014. godine. Zbog navedene problematike i približavanja rokova navedene direktive postaju aktualne te im se treba pridavati dodatnog značaja.*

***Ključne riječi**: tehnički sustavi u zaštiti bilja, rukovatelji, testiranje, EN 13790 standard*

## UVOD

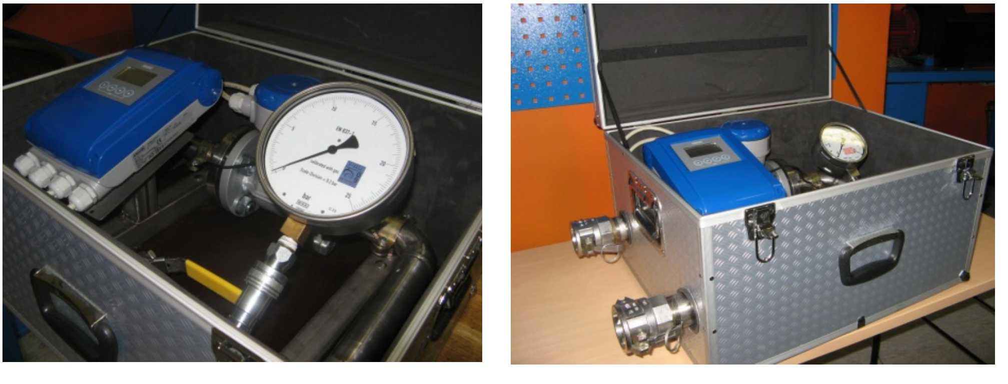
Testiranja tehničkih sustava u zaštiti bilja u Europskoj uniji počela su krajem devedesetih godina prošlog stoljeća te su testiranja pokazala koji su dijelovi prskalice najpodložniji kvarovima. U Njemačkoj testiranja su pokazala da je najveći broj neispravnih prskalica uzrokovan neispravnim mlaznicama. Od preko 70000 testiranih prskalica, kod 19% utvrđene su neispravne mlaznice (Reitz i Gamzlemeier, 1998). U Belgiji u razdoblju od 1995. do 1998. godine testirano je 17 466 prskalica od kojih 86% je bilo neispravno zbog neispravnih manometara i mlaznica (Langenakens i Pieters, 1999). Ozbiljnija testiranje tehničkih sustava u Republici Hrvatskoj krenula se krajem prošlog desetljeća i već onda su zabilježeni loši rezultati površinske raspodjele tekućine pri radu ratarskih prskalica (Banaj i sur., 2000). Najvažniji čimbenik cjelokupnog stroja za zaštitu bilja predstavlja mlaznice te ona obavlja najvažnije funkcije propuštanja zadane količine tekućine u jedinici vremena, raspršuje tekućinu tvoreći kapljice odgovarajućih veličina te formiraju mlaz odgovarajućeg oblika (Banaj i sur., 2010). Veliki problem stvaraju potrošene i začepljene mlaznice koje daju veće ili manje količine protoka, pa je potrebno da se neispravna mlaznica zamijeni (Bugarin i sur., 2000). Prema najnovijim istraživanjima i podatcima, stanje tehničkih sustava u zaštiti bilja u istočnoj Hrvatskoj je vrlo loše (Banaj, Đ. i sur., 2012), te je neophodno podizanje ispravnosti uređaja na višu razinu, kako ne bi došlo do provođenja restriktivnih mjera uređenih Pravilnikom o održivoj uporabi pesticida.

## MATERIJAL I METODE RADA

Tijekom lipnja 2013. godine Zavod za mehanizaciju Poljoprivrednog fakulteta u Osijeku obavlja testiranje tehničkih sustava u zaštiti bilja u voćnjaku Obreška, radi dobivanja izvještaja o ispravnom stanju testiranih uređaja koji se prilažu pri podnošenju zahtjeva za GlobalGap certifikat. Za provedbu testiranja korištena je oprema Zavoda za mehanizaciju, Poljoprivrednog fakulteta u Osijeku. Zavod posjeduje svu potrebnu opremu za provedbu testiranja tehničkih sustava u zaštiti bilja po normi EN 13790 koja je osnova za provedbu direktiva 2009/128/EC i 2006/42/EC Europske unije. Mjerenje kapaciteta crpke obavljeno je pomoću elektromagnetskog mjerača protoka tvrtke Krohne (Slika 1.), dok je ispravnost manometra utvrđivana pomoću komparatora tlaka Volos (Slika 2.). Mjerenje protoka mlaznica na raspršivaču provedeno je s uređajem Volos II (Slika 3.).

*Kontrola kapaciteta crpke*

Prema normi *EN 13790* dozvoljeni pad kapaciteta crpke može najviše iznositi do 10 % od nazivnog kapaciteta. Kontrola kapaciteta crpki mjeri se sa elektromagnetskim mjeračem prikazanim na slici 1. Skupni prikaz testiranih crpki prikazan je u tablici 1.



**Slika 1** Elektromagnetni mjerač kapaciteta crpke tvrtke *Krohne*

*Kontrola ispravnosti manometra*

Komparator tlaka *Volos* (Slika 2.) prema standardu *EN 837-1* posjeduje kontrolni manometar (valjani certifikat) sa klasom točnosti 0.6 te s mjernim područjem do 25 bar. Na uređaj *Volos* postavlja se kontrolni manomatar i manometar koji se treba provjeriti. Rezultati ispitivanih manometara prikazani su u tablici 1. Po normama u EU manometri koji se ugrađuju na tehničke sustave u zaštiti bilja moraju imati minimalni promjer od 63 mm te točnost manometra koji se ispituje mora biti ± 0,2 bar kada se radi o ispitnom području od 0 do 2 bar. Ako se radi o većem ispitnom području odstupanje može iznositi do ± 10 %.


**Slika 2** Komparator tlaka Volos

*Kontrola ispravnosti mlaznica*

Mlaznice predstavljaju najveći problem pravilnog rada tehničkog sustava u zaštiti bilja. Vrlo je često da se izlazni otvor mlaznice brzo potroši pa se poveća protok s obzirom na tablično označenu vrijednost. Vrlo često imamo pojavu da se mlaznice začepe uslijed lošeg pročišćavanja tekućine. Europski standard nalaže da treba zamijeniti svaku mlaznicu koja ima protok manji ili veći od 10% s obzirom na tablične vrijednosti pri odgovarajućem radnom tlaku. Mjerenje protoka mlaznica na raspršivačima obavljeno je s uređajem *Volos II* koji na sebi ima menzuru za svaku ispitivanu mlaznicu, slika 3. Skupni prikaz testiranih mlaznica prikazan je u tablici 1.

**Slika 3** Uređaj za mjerenje protoka mlaznica –*Volos II*

## REZULTATI ISTRAŽIVANJA

Testiranje je obavljeno na 16 raspršivača (12 raspršivača tvrtke *Agromehanika* i 4 raspršivača tvrtke *Tifone*), od kojih je 14 vučenih i 2 nošena uređaja. Nošeni raspršivači raspolažu sa spremnikom obujma 440 l, a na usmjerivače zraka je postavljeno 10 mlaznica. Vučeni raspršivači raspolažu sa spremnikom obujma 1500 l, a na usmjerivače zraka postavljeno je 12 mlaznica. Na sve raspršivače su postavljene klipno – membranske crpke. Na sve raspršivače postavljene su mlaznice koje stvaraju šuplji konusni mlaz i to:*TeeJetTXB 8002* i *8004*, *Albuz ATR 80* – žute, *Lechler TR 8002*. Skupni prikaz tehničkih karakteristika i ispitivanih sustava raspršivača prikazan je u tablici 1.

**Tablica 1** Neki od testiranih parametara važnih za rad tehničkih sustava u zaštiti bilja

| Proizvođač | Vučeni/nošeni | Obujam spremnika (l) | Ispravnost crpke (+/-) | Tip mlaznica | Ispravnost mlaznica (+/-) | Ispravnost manometra (+/-) |
|---|---|---|---|---|---|---|
| Agromehanika | Nošeni | 440 | + | Albuz ATR 80 – žute | - | + |
| Agromehanika | Nošeni | 440 | + | Albuz ATR 80 – žute | - | - |
| Agromehanika AGP 1500 EN | Vučeni | 1500 | + | Albuz ATR 80 – žute | + | + |
| Agromehanika AGP 1500 EN | Vučeni | 1500 | + | Albuz ATR 80 – žute | + | + |
| Agromehanika AGP 1500 EN | Vučeni | 1500 | + | Lechler TR 8002 | - | + |
| Agromehanika AGP 1500 EN | Vučeni | 1500 | - | TeeJet TXB 8004 | - | - |
| Agromehanika AGP 1500 EN | Vučeni | 1500 | + | TeeJet TXB 8004 | + | + |
| Tifone Vento | Vučeni | 1500 | - | Albuz ATR 80 – žute | - | - |
| Tifone Vento | Vučeni | 1500 | - | Albuz ATR 80 – žute | + | + |
| Tifone Storm | Vučeni | 1500 | + | TeeJet TXB 8002 | + | - |
| Agromehanika AGP 1500 EN | Vučeni | 1500 | + | TeeJet TXB 8002 | + | + |
| Agromehanika AGP 1500 EN | Vučeni | 1500 | - | TeeJet TXB 8004 | + | - |
| Agromehanika AGP 1500 EN | Vučeni | 1500 | + | TeeJet TXB 8002 | - | - |
| Agromehanika | Nošeni | 440 | + | Albuz ATR 80 – žute | - | + |
| Tifone Vento | Vučeni | 1500 | - | Albuz ATR 80 – žute | + | + |
| Agromehanika AGP 1500 EN | Vučeni | 1500 | + | TeeJet TXB 8004 | + | + |

Od ukupnog broja testiranih raspršivača na njih 5 utvrđen je neispravan rad crpki (31,25%), a na 7 raspršivača utvrđen je neispravan rad mlaznica (43,75%). Neispravan rada manometra utvrđen je na 6 raspršivača (37,50%), a kapanje tekućine je utvrđeno na 3 raspršivača (18,75%). S obzirom na vizualni pregled, 3 raspršivača ne zadovoljavaju *EN 13790* standard.

## ZAKLJUČAK

Prilikom testiranja raspršivača voćnjaka Obreška, utvrđuju se znatna odstupanja rada raspršivača od propisane norme *EN 13790*. Navedeno stanje rezultat je tehnoloških i eksploatacijski zastarjelih strojeva, te strojevi u zatečenom stanju, pri testiranju ne mogu zadovoljavajuće obavljati zaštitu bilja. Tek nakon zamjene neispravnih dijelova (obavljeno na mjestu testiranja), ispitivani raspršivači zadovoljavaju kriterije ispravnosti tehničkih sustava u zaštiti bilja te mogu poslužiti kao primjer provođenja dobre poljoprivredne prakse na površinama voćnjaka Obreška.

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# TESTING TEHNICAL SYSTEMS IN PLANT PROTECTION IN REPUBLIC OF CROATIA

V. TADIĆ, Đ. BANAJ, D. PETROVIĆ, D. KNEŽEVIĆ, N. SELETKOVIĆ

*In order to obtain the GlobalGap certificat, testing of technical systems in crop protection in Obreška orchard were carried out with employees of Agricultural faculty in Osijek. Sixteen mistblowers are tested, according EN 13790 standard. With Croatian entry in EU the directives 2009/128/EC i*

*2006/42/EC were inherited. This directive provides for mandatory review of technical systems in plant protection (mistblowers and boom sprayeres). The directive was introduced in Regulation on sustainable use of pesticides (*NN 142/12*), according to which all devices in crop protection until the November, 2016 must have a label on the regular technical overview. Devices manufactured before1995, must have a label until November, 2014. Due to the aforementioned problems and approaching deadlines, directive becomes current and they should be given additional significance.*

***Key words:*** *tehnical systems in plant protection, handler, testing, EN 13790 standard*

42. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

UDK 631. 347
Stručni rad
Expert paper

# VERTIKALNA RASPODJELA ZRAČNE STRUJE RASPRŠIVAČA AGP 200 ENU

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## SAŽETAK

*U radu su prikazani rezultati testiranja vertikalne raspodjele zraka po visini usmjerivača na lijevoj i desnoj strani raspršivača tvrtke Agromehanika AGP 200 ENU. Navedeni raspršivač posjeduje aksijalni ventilator promjera 585 mm s 8 lopatica. Lopatice se mogu postaviti u 5 različitih zakošenja. Navedeni raspršivač pri brzini vrtnje vratila ventilatora od 540 min$^{-1}$ i pri položaju lopatica na broju „1“ ostvario je prosječnu brzinu zraka po visini usmjerivača na lijevoj strani od svega 2,81 m/s pri standardnoj devijaciji od 1,016 i s koeficijentom varijacije od 36,16%. Ista prosječna vrijednost utvrđena je i na desnoj strani. Povećanjem broja okretaja ventilatora na 1620 min$^{-1}$ ostvarena je prosječna brzina zraka na lijevoj strani raspršivača od 7,99 m/s uz standardnu devijaciju od 1,902 i koeficijent varijacije od 23,81%. Prosječna brzina zraka na desnoj strani iznosila je 9,84 m/s s koeficijentom varijacije od 22,33%. Maksimalnim zakošenjem lopatica raspršivač pri brzini rotacije vratila ventilatora od 540 min$^{-1}$ ostvario je prosječnu brzinu zraka po visini usmjerivača na lijevoj strani od 5,52 m/s pri standardnoj devijaciji od 2,319 i s koeficijentom varijacije od 42,03%.. Na desnoj strani ostvarena je prosječna brzina zraka od 5,97 m/s sa standardnom devijacijom od 1,974 i koeficijentom varijacije od 33,09%. Povećanjem broja okretaja ventilatora na 1620 min$^{-1}$ ostvarena je prosječna brzina zraka na lijevoj strani raspršivača od 17,46 m/s. Na desnoj strani utvrđena je prosječna vrijednost od 17,96 m/s s koeficijentom varijacije od 35,05%. Pri najvećem broju okretaja vratila ventilatora uz najveće zakošenje utvrđena je najveća brzina zraka na obje strane od 25,67 m/s.*

***Ključne riječi:*** *brzina zraka, aksijalni ventilator, raspršivač AGP 200 EN, vertikalna raspodjela zraka*

## UVOD

Poljoprivredna tehnika je sastavnica svake poljoprivrede i jedan od najznačajnijih čimbenika kvantitativne i kvalitativne proizvodnje hrane. Intenzifikcija proizvodnje hrane, između ostaloga, zahtjeva i intenzivniju uporabu tehnike koja može neprikladnom primjenom narušiti krhku ekološku ravnotežu. Razvoj strojeva i uređaja u suvremenoj aplikaciji pesticida od iznimnog je značenja u suvremenoj poljoprivredi. Intenzivna uporaba pesticida, doprinosi povećanju prinosa, ali i narušava sklad ekosustava. Ovo je rezultat navedenog tehnološkog napretka, ali i sve veće potrebe za hranom rastućeg svjetskog stanovništa. Precizna aplikacija pesticida podjednako je važna iz ekoloških razloga, efikasnosti kemijske zaštite kao i potrebe smanjenja utroška inputa u proizvodnji. Postizanjem što veće preciznosti aplikacije, a time i potpune djelotvornosti postupaka zaštite, tehnički sustavi (prskalice, raspršivači) moraju ostvarivati konstrukcijsku i tehničku ispravnost da bi se ostvario odgovarajući radni potencijal. S obzirom na navedene činjenice, u zemljama EU uvode se pravilnici obaveznog pregleda tehničkih sustava u zaštiti bilja direktivom *2009/128/EC i 2006/42/EC*, kojima je temelj standard *EN 13790.* U Republici Hrvatskoj utvrđena je nezadovoljavajuća ispravnost tehničkih sustava u zaštiti bilja, te se svi strojevi moraju evidentirati i testirati do početka 2016. godine. Unatoč intenzivnim istraživanjima u alternativnim metodama zaštite bilja od bolesti, štetnika i korova, kemijska metoda je najdjelotvornija te ima važnu ulogu u postizanju visokih priroda i kakvoće poljoprivrednih proizvoda 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. Mogu se koristiti raspršivači sa aksijalnim i radijalnim ventilatorom, raspršivači sa tangecijalnim usmjerivačima, raspršivači sa fleksibilnim vodovima i drugo. Nabrojane izvedbe raspršivača koriste se za različite uzgojne oblike trajnih kultura te uvelike utječu na kvalitetu raspršivanja pesticida, tj. na pokrivenost tretirane površine, veličinu kapljica mlaza i depozit pesticida po trajnom nasadu. Uz tehničku ispravnost radnog stroja u zaštiti bilja posebice je važno pravilno podesiti parametre prskanja – brzinu rada stroja, radni tlak, količinu zraka, količinu tekućine po jedinici površine i tip mlaznice. Samo sinergija pravilno podešenih parametara prskanja i tehnička ispravnost stroja daju adekvatne rezultate. Nepravilno podešeni parametri prskanja utječu na smanjenu pokrivenost površine, pojavu zanošenja kapljica, povećanu potrošnju zaštitnog sredstva, povećanu potrošnju vode po jedinici površine, slabo prodiranje zaštitnog sredstva u krošnju te niz drugih negativnih utjecaja koje dovode do opetovane pojave štetočinja.

## ZADATAK I CILJ ISTRAŽIVANJA

Zadatak ispitivanja je primjenom standardnih metoda utvrditi vertikalnu raspodjelu zračne struje na obje strane raspršivača AGP 200 ENU. Na temelju znanstvenog saznanja dobivenih 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 tekućine u trajnom nasadu.

## STANJE PROBLEMA I DOSADAŠNJA ISTRAŽIVANJA

Protok i brzina zraka također su važni tehnički čimbenici zaštite trajnih nasada. Služe kao dodatno sredstvo razbijanja mlaza i stvaranja malih kapljica (hidropneumatska i pneumatska dezintegracija), te kao sredstvo koje će tekućinu mlaza dodatno usmjeriti i transportirati na cilj prskanja. Brzina zraka ima bitan utjecaj na pomicanje listova i grana (tzv. otvaranje krošnje) da bi zaštitno sredstvo bilo deponirano u sredini krošnje. Vrlo važno je da pri zaštiti trajnih nasada brzina zraka bude veća od 12,2 m/s (Randall, J.M., 1971). Zhu, H. i sur. (2006) u svome istraživanju navode podatak, gdje pri radu konvencionalnog aksijalnog raspršivača bez visinskih usmjerivača zraka, brzina zraka sa 40 m/s na izlazu iz usmjerivača zraka pada na 19,4 m/s kad struja zraka počne doticati rubove krošnje na udaljenosti 1,79 m od raspršivača. Svensson, S.A. (2001), navode da je povećana brzina zraka na izlazu usmjerivača zraka preduvjet za bolji depozit i pokrivenost površine unutar krošnje. Ovo nije slučaj kod mladih trajnih nasada gdje je mala lisna površina te povećavanje brzine zraka dovela do povećanog zanošenja kapljica Landers, A. i sur., (2004). Navedeni autor utvrđuje da se smanjivanjem brzine zraka (mladi trajni nasadi) za 25% povećava *VMD* za 31%, te se tako osigurava optimalna pokrivenost površine i smanjeno zanošenje. Za nasade koje imaju bujnu krošnju ili koji su u kasnijim razvojnim stadijima, treba koristiti strojeve koji mogu razviti veću brzinu i protok zraka. Banaj, Đ. i sur. (2010) preporučuju testiranje strojeva prema maksimalno ostvarenoj brzini i protoku zraka za pojedini trajni nasad. U njihovom istraživanju testirana su tri različita aksijalna raspršivača (*Tifone Vento, Myers N1500 i Hardi Zenit*) od kojih je *Hadi Zenit* ostvario najveći protok zraka od 44.590 $m^3$/h. Jedan od problema 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 % Fox, R.D. i sur., (1992). Stoga, pri određivanju brzine zraka za pojedini nasad treba voditi računa da optimalna brzina zraka stiže do cilja prskanja De Moor., i sur., (2000). Vrlo često se događa da kod uzgojnih oblika koji su veći od 3 – 4 m optimalna brzina zraka ne dolazi do vršnih grana. Pokrivenost površine tih djelova krošnje je realtivno mala i štetnici nalaze mjesta na kojima će preživjeti utjecaj pesticida. Razlog navedenom je nepravilno podešna brzina zraka na usmjerivačima ili korištenje neadekvatnog raspršivača. Ovi problemi mogu se riješiti pravilnim optimiranjem brzine zraka po cijeloj vertikalnoj osnovici kulture ili korištenjem radijalnih raspršivača s tangencijalnim usmjerivačima. Naravno, moguće je korištenje i specijalnih izvedbi aksijalnih raspršivača sa visinskim usmjerivačima zraka De Moor, A. i sur. (2000). Vođeni ovom problematikom Salyani, M., i Fox, R.D. (1999) su istraživali pokrivenost površine (VOP-i i analiza slike) pri istim parametrima prskanju i vremenskim uvjetima za devet različitih tipova raspršivača. Raspršivač koji je ostvario najbolji rezultat pokrivenosti površine preporučen je za eksploataciju u nasadu gdje su raspršivači bili ispitivani. Brzina zraka često se kombinira sa čimbenicima brzine kretanja raspršivača i norme raspršivanja. Tako je Marucco, P. i sur. (2008) istraživao utjecaj šest različitih brzina rada raspršivača (3,9 – 13 km/h), šest različitih brzina zraka (3,7 – 23 m/s) i četiri različite norme raspršivanja (200–1000 l/ha) u nasadu breskve. Istraživanje je pokazalo da je najbolji rezultat pokrivenost površine i depozita ostvaren pri brzini rada stroja od 7 km/h, brzini zraka od 14 m/s i normi raspršivanja od 400 l/ha. Povezano s ovim istraživanjem autori Panneton, B. i sur. (2004), utvrdili su da se smanjivanjem brzine kretanja stroja, (do 5 km/h) u trajnim nasadima (vinograd, jabuka), pokrivenost površine poveća za signifikantnu vrijednost. Berčič, S.

(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. Povezano s ovime, Derksen, R.C. i sur. (2007) navode da se pri zaštiti trajnih kultura sa zračno–injektorskim mlaznicama (formiraju velike kapljice) treba stvoriti povećana turbulentnost zraka, da se velike kapljice uspiju deponirati unutar krošnje. Jedan od nedostataka klasičnih aksijalnih raspršivača bez usmjerivača zraka je manja količina zraka s desne strane stroja za 8–11%. Ova greška je konstrukcijske prirode i smjera rotacije ventilatora pa bi se trebali koristiti aksijalni raspršivači s dva ventilatora, koji rotiraju u suprotnim smjerovima ili aksijalni raspršivači s usmjerivačima zraka (Godyn. A., i sur., 2008).

## MATERIJAL I METODE RADA

Ventilator rotacijom lopatica stvara određenu brzinu i protok zraka koji je važan tehnički čimbenik raspršivanja i ima funkciju dezintegracije mlaza, te nošenja tekućine na cilj prskanja. Protok i brzina stvaraju struju zraka s turbulentnim vrtloženjem čija je uloga pomicanje grana i listova koji omogućuju prolazak tekućine do sredine krošnje i pokrivanje obje strane lista (tzv. „otvaranje krošnje"). Ugrađeni aksijalni ventilator stvara veliki turbulentni protok s relativno malim tlakom i brzinom zraka. Za razliku od njih, radijalni ventilatori stvaraju veliki tlak i brzinu zraka, ali sa malim protokom. Isto tako vrlo je značajno da optimalna brzina zraka dolazi do cilja prskanja, tj. da cijeli predmet zaštite (trs/stablo) ima podjednaku brzinu zraka na vanjskim rubovima krošnje. Uslijed navedene ujednačenosti ostvaruje se zadovoljavajuća pokrivenost tretirane površine, jer će zrak omogućiti „otvaranje krošnje". S obzirom na navedenu problematiku te uslijed tehničke izvedbe raspršivača, radijalni ventilatori ostvaruju bolju vertikalnu raspodjelu brzine zraka u odnosu na aksijalne. Glavna tehnička obilježja ventilatora prikazuju se kroz protok zraka u $m^3/h$, brzinu zraka, m/s i vertikalnu distribucija zraka na izlazu ventilatora.

*Raspršivač AGP 200 ENU*

Raspršivač je projektiran za precizna prskanja voćnjaka i vinograda, izuzetno je kratak što je posebice važno za uporabu sa manjim traktorima. Sastoji od nosećeg okvira sa spremnikom tekućine koji je napravljen od polietilenskih vlakana i nalijevnim sitom, crpke, regulatora tlaka i protoka, usisnog pročistača, tlačnog pročistača, trodjelnog ventila, mlaznice za miješanje, ventilatora sa usmjerivačem zraka i membranskih nosača mlaznica. Ispitivani raspršivač opremljen je sa dodatnim spremnikom za pranje unutrašnjosti glavnog spremnika i spremnikom za čistu vodu koja služi za pranje ruku. Ventilator je smješten u zadnjem dijelu stroja koji usmjerava zrak ravnomjerno na lijevu i desnu stranu te je podesiv s obzirom na geometriju i bujnost nasada.

**Slika 1** Raspršivač tijekom ispitivanja

**Tablica 1** Važniji tehnički podaci ispitanog raspršivača AGP 200 ENU

| | |
|---|---|
| Volumen spremnika (l) | 200 |
| Traktorski priključak | I. kategorije |
| Dimenzije raspršivača (mm x mm x mm) | 960 x 1200 x 1320 |
| Masa stroja (kg) | 151 |
| Promjer ventilatora (mm) | 585 |
| Kapacitet zraka (m³/h) | 12000 do 32000 |
| Izlazna brzina zraka (m/s) | < 40 |
| Maksimalni broj okretaja ventilatora ($min^{-1}$) | 1620 |
| Tip nosača mlaznica | Dvostruki |
| Broj nosača mlaznica | 10 |
| Nazivni volumen (l) | 200 |
| Oznaka usmjerivača | 585/10 |
| Tip mlaznica | Lechler TR 80 ISO 015 i ISO 02 |

**Slika 2** Raspršivač AGP 200 ENU

**Slika 2** Raspršivač AGP 200 ENU

## REZULTATI ISTRAŽIVANJA

U tvrđivanje vertikalne raspodjele zračne struje raspršivača AGP 200 ENU obavljena je u praktikumu za mehanizaciju uporabom meteorološke postaje postavljene na vertikalni sustav za pomicanje po visini. Prosječna temperatura zraka u vrijeme istraživanja iznosila je 22,5 °C uz relativnu vlagu zraka od 64,5 %. Iz naredne tablice možemo vidjeti da je ispitivani raspršivač tvrtke *Agromehanika* ostvario pri brzini rotacije vratila ventilatora od 540 min$^{-1}$ i pri položaju lopatica na broju 1, prosječnu brzinu zraka po visini usmjerivača na lijevoj strani od svega 2,81 m/s pri standardnoj devijaciji od 1,016 i s koeficijentom varijacije od 36,16%. Povećanjem broja okretaja ventilatora na 1080 min$^{-1}$ pri zadržavanju istog ukošenja lopatica došlo je do povećanja prosječne brzine kretanja zraka na 5,66 m/s uz koeficijent varijacije od 32,35%. Ugrađeni ventilator pri broju okretaja od 1620 min$^{-1}$ ostvario je prosječnu vrijednost brzine zraka po cijelom izlazu usmjerivača na lijevoj strani raspršivača od 7,99 m/s uz standardnu devijaciju od 1,902 i koeficijent varijacije od 23,81%. Najveća brzina zraka pri brzini vrtnje ventilatora od 540 min$^{-1}$ na lijevoj strani iznosila je 4,80 m/s. Povećanjem broja okretaja na 1080 min$^{-1}$ utvrđena je najmanja brzina kretanja zraka od 0,27 a najveća 8,37 m/s. Najveća brzina zraka utvrđena je na lijevoj strani pri broju okretaja ventilatora od 1620 min$^{-1}$ s položajem lopatica na broju 1 od 11,57 m/s.

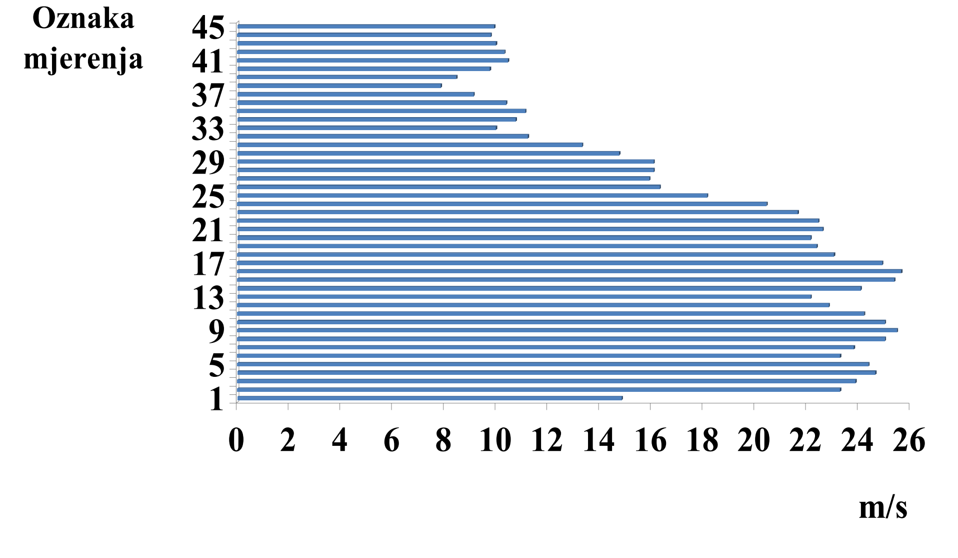
Na desnoj strani raspršivača pri brzini rotacije ventilatora 540 min$^{-1}$ s položajem lopatica na broju 1 ostvarena je ista prosječna vrijednost brzine zraka od 2,81 m/s sa standardnom devijacijom od 0,983 i koeficijentom varijacije od 34,96%. Povećanjem broja okretaja na 1080 min$^{-1}$ na istoj strani došlo je do povećanja prosječne brzine zraka na 6,25 m/s odnosno nešto više nego na lijevoj strani raspršivača. Dobivena vrijednost ostvarena je uz standardnu devijaciju 1,899 i koeficijent varijacije od 30,40%. Povećanjem broja okretaja ventilatora na 1620 min$^{-1}$ odnosno na broj okretaja vratila traktora od 540 min$^{-1}$ utvrđena je prosječna brzina zraka na desnoj strani od 9,84 m/s s koeficijentom varijacije od 22,33%. Pri istim uvjetima provjere utvrđena je minimalna brzina gibanja zračne struje od 6,87 m/s, a maksimalna vrijednost iznosila je 14,03 m/s. Vidljivo je da su prosječne vrijednosti kretanja brzine zraka nešto veće na desnoj strani u odnosu na lijevu stranu raspršivača. Maksimalnim zakošenjem lopatica na broj „5“ ostvarene su znatno veće prosječne vrijednosti brzine zraka. Pri broju okretaja vratila ventilatora od 540 min$^{-1}$ i pri najvećem ukošenju lopatica na broju „5“ ostvarena je prosječna brzina zraka po visini usmjerivača na lijevoj strani od 5,52 m/s pri standardnoj devijaciji od 2,319 i s koeficijentom varijacije od 42,03%. Povećanjem broja okretaja ventilatora na 1080 min$^{-1}$ pri zadržavanju istog ukošenja lopatica došlo je do povećanja prosječne brzine kretanja zraka na 11,06 m/s uz koeficijent varijacije od 43,99% sa standardnom devijacijom od 4,867. Aksijalni ventilator pri broju okretaja od 1620 min$^{-1}$ ostvario je prosječnu vrijednost brzine zraka po cijelom izlazu usmjerivača na lijevoj strani raspršivača od 17,46 m/s uz standardnu devijaciju od 6,503 i koeficijent varijacije od 37,25%. Najveća ostvarena brzina zraka na izlaznom usmjerivaču pri 540 okretaja ventilatora na lijevoj strani iznosila je 8,40 m/s. Povećanjem broja okretaja na 1080 min$^{-1}$ utvrđena je najveća brzina kretanja zraka od 16,83 m/s. Najveća, uopće utvrđena, brzina zraka ostvarena na lijevoj strani pri broju okretaja ventilatora 1620 min$^{-1}$ s položajem lopatica na broju „5“ iznosila je 25,67 m/s. Na desnoj strani raspršivača pri broju okretaja ventilatora od 540 min$^{-}$1 s položajem lopatica na broju „5“ ostvarena je prosječna vrijednost brzine zraka od 5,97 m/s sa standardnom devijacijom od 1,974 i koeficijentom varijacije od 33,09%. Povećanjem broja okretaja ventilatora na 1080 min$^{-1}$ na istoj strani došlo je do povećanja prosječne brzine zraka na 11,81 m/s odnosno nešto više nego na lijevoj strani raspršivača. Dobivena vrijednost ostvarena je uz standardnu devijaciju 4,092 i koeficijent varijacije od 34,65%. Povećanjem broja okretaja ventilatora na 1620 min$^{-}$1, odnosno brzinu vrtnje vratila traktora od 540 min$^{-}$1 utvrđena je prosječna brzina zraka na desnoj strani od 17,96 m/s s koeficijentom varijacije od 35,05%. Pri istim uvjetima provjere utvrđena je minimalna brzina kretanja od 7,87 m/s, a maksimalna vrijednost iznosila je 25,67 m/s kao i na lijevoj strani raspršivača.

**Tablica 2** Prosječna brzina zraka na izlaznom otvoru raspršivača

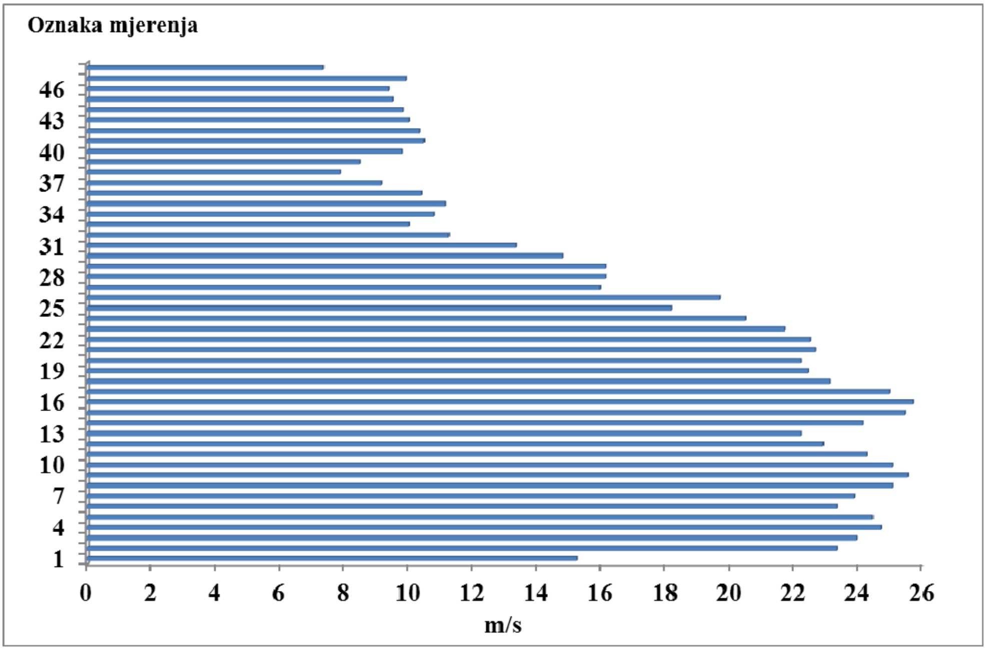
| Broj okretaja vratila traktora, min$^{-1}$ | Prosječna brzina zraka na izlaznom otvoru, m/s | | | | | |
|---|---|---|---|---|---|---|
| | Lijeva strana | | | Desna strana | | |
| | Položaj I | Položaj III | Položaj V | Položaj I | Položaj III | Položaj V |
| 180 | 2,81 | 3,14 | 5,52 | 2,81 | 2,90 | 5,97 |
| 360 | 5,66 | 6,15 | 11,06 | 6,25 | 6,81 | 11,81 |
| 540 | 7,99 | 9,59 | 17,46 | 9,84 | 10,05 | 17,96 |

**Tablica 3** Brzina zraka na izlaznom otvoru s određenim statističkim pokazateljima

| Broj okretaja vratila traktora, $min^{-1}$ | Izmjerena i izračunata vrijednost | | Lijeva strana | | | Desna strana | | |
|---|---|---|---|---|---|---|---|---|
| | | | Položaj | | | | | |
| | | | I | III | V | I | III | V |
| 180 | $v_{sr}$ | m/s | 2,81 | 3,14 | 5,52 | 2,81 | 2,90 | 5,97 |
| | $v_{min}$ | m/s | 0,53 | 0,60 | 0,37 | 0,50 | 1,73 | 2,37 |
| | $v_{max}$ | m/s | 4,80 | 4,83 | 8,40 | 4,53 | 4,37 | 8,43 |
| | *s. d.* | m/s | 1,016 | 1,108 | 2,319 | 0,983 | 0,827 | 1,974 |
| | *k. v.* | % | 36,16 | 35,28 | 42,03 | 34,96 | 28,52 | 33,09 |
| 360 | $v_{sr}$ | m/s | 5,66 | 6,15 | 11,06 | 6,25 | 6,81 | 11,81 |
| | $v_{min}$ | m/s | 0,27 | 0,47 | 0,40 | 2,27 | 0,53 | 3,37 |
| | $v_{max}$ | m/s | 8,37 | 9,97 | 16,83 | 9,53 | 9,87 | 16,83 |
| | *s. d.* | m/s | 1,833 | 2,471 | 4,867 | 1,899 | 1,992 | 4,092 |
| | *k. v.* | % | 32,36 | 40,20 | 43,99 | 30,40 | 29,26 | 34,65 |
| 540 | $v_{sr}$ | m/s | 7,99 | 9,59 | 17,46 | 9,84 | 10,05 | 17,96 |
| | $v_{min}$ | m/s | 4,90 | 2,53 | 7,33 | 6,87 | 0,23 | 7,87 |
| | $v_{max}$ | m/s | 11,57 | 14,03 | 25,67 | 14,03 | 14,67 | 25,67 |
| | *s. d.* | m/s | 1,902 | 2,939 | 6,503 | 2,196 | 3,196 | 6,294 |
| | *k. v.* | % | 23,81 | 30,64 | 37,25 | 22,33 | 31,81 | 35,05 |




**Slika 4** Raspodjela brzine zraka po visini izlaznog usmjerivača na lijevoj strani ispitivanog raspršivača ($n_{ventilator}$ = 1620 $min^{-1}$, zakošenje lopatica-položaj “5“)




**Slika 5** Raspodjela brzine zraka po visini izlaznog usmjerivača na desnoj strani ispitivanog raspršivača ($n_{ventilator}$ = 1620 min$^{-1}$, zakošenje lopatica-položaj "5")

## ZAKLJUČAK

Na temelju provedenih istraživanja i polučenih rezultata vertikalne raspodjele zračne struje raspršivača AGP 200 ENU mogu se donijeti sljedeći zaključci:

- ugrađeni aksijalni ventilator pri rotaciji vratila od 540 min$^{-1}$ i pri najmanjem ukošenju lopatica ostvario je prosječnu brzinu zraka po visini usmjerivača na lijevoj strani od svega 2,81 m/s,
- pri istom položaju lopatica uz broj okretaja ventilatora od 1080 min$^{-1}$ ostvarena je prosječna brzina zraka na lijevoj strani od 5,66 m/s uz koeficijent varijacije od 32,35%,
- pri maksimalnom broju okretaja od 1620 min$^{-1}$ ostvarena je prosječa vrijednost brzine zraka po cijelom izlazu usmjerivača na lijevoj strani raspršivača od 7,99 m/s,
- najveća brzina zraka pri brzini vrtnje ventilatora od 540 min$^{-1}$ na lijevoj strani iznosila je 4,80 m/s.
- pri brzini vrtnje ventilatora od 540 min$^{-1}$ s najmanjim nakošenjem lopatica ostvarena je ista prosječna vrijednost brzine zraka na desnoj strani od 2,81 m/s sa standardnom devijacijom od 0,983 i koeficijentom varijacije od 34,96%,

- povećanjem broja okretaja na 1080 min$^{-1}$ na istoj strani došlo je do povećanja prosječne brzine zraka na 6,25 m/s, uz standardnu devijaciju 1,899 i koeficijent varijacije od 30,40%,
- pri broju okretaja ventilatora od 1620 min$^{-1}$ utvrđena je prosječna brzina zraka na desnoj strani od 9,84 m/s s koeficijentom varijacije od 22,33%,
- pri maksimalnom zakošenju lopatica i pri rotaciji vratila ventilatora od 540 min$^{-1}$ ostvarena je prosječna brzina zraka po visini usmjerivača na lijevoj strani od 5,52 m/s,
- povećanjem broja okretaja ventilatora na 1080 min$^{-1}$ došlo je do povećanja prosječne brzine kretanja zraka na 11,06 m/s,
- pri 1620 okretaja vratila ostvarena je prosječnu vrijednost brzine zraka po cijelom izlazu usmjerivača na lijevoj strani raspršivača od 17,46 m/s,
- na desnoj strani raspršivača pri broju okretaja ventilatora od 540 min$^{-}$1 s položajem lopatica na broju „5“ ostvarena je prosječna vrijednost brzine zraka od 5,97 m/s,
- povećanjem broja okretaja ventilatora na 1080 min$^{-1}$ na istoj strani došlo je do povećanja prosječne brzine zraka na 11,81 m/s,
- povećanjem broja okretaja ventilatora na 1620 min$^{-}$1 utvrđena je prosječna brzina zraka na desnoj strani od 17,96 m/s s koeficijentom varijacije od 35,05%,
- pri istim uvjetima provjere utvrđena je minimalna brzina kretanja od 7,87 m/s, a maksimalna vrijednost iznosila je 25,67 m/s kao i na lijevoj strani raspršivača.

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# VERTICAL DISTRIBUTION OF AIR CURRENT WITH AGP 200 ENU MISTBLOWER

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*In this paper the results from vertical air distribution testing are shown through height of air deflector on the left and right side of Agromehanika AGP 200 EN mistblower. This mistblower has an axial fan, with 585 mm in diammeter and 8 blades. Blades can be setted in five different positions. At 540 min$^{-1}$ rotation speed of the fan shaft and at first position of blades, mistblower achieved 2.81 m/s average air speed on left side of air deflector with standard deviation of 1.016 and 36.16% coefficient of variation. Similar avereage value has determined on the right side of air deflector. With increasing the number of fan shaft rotation speed at 1620 min$^{-1}$, the left side of air deflector achieved average air speed of 7.99 m/s with standard deviation of 1.902 and 23,81% coefficient of variation. Average air speed on the right side of air deflector was 9.84 m/s with coefficent variation of 22,33%. With blades setted on maximal position and with fan shaft rotation speed of 540 min$^{-1}$, mistblower on the left side of fan deflector achieved average air speed of 5.52 m/s with standard deviation of 2.319 and 42.03% coefficient of variation. Average air speed on the right side of air deflector was 5.97 m/s with coefficent variation of 33.09%. With increasing the number of fan shaft rotation speed at 1620 min$^{-1}$, the left side of air deflector achieved average air speed of 17.46 m/s. Average air speed on the right side of air deflector was 17.96 m/s with coefficent variation of 35.05%. At maximum speed rotation of fan shaft with maximal position of setted blades, the largest air speed for both side was 25,67 m/s.*

***Key words:*** *Air speed, Axial fan, AGP 200 EN mistblower, Vertical air distribution*

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# CANOPY ADAPTED ORCHARD SPRAYING

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## SUMMARY

*For more efficient orchard spraying an air-blast sprayer with variable geometry of spraying arms was developed and realized by the Agricultural Institute of Slovenia in collaboration with the Faculty of Mechanical Engineering from Ljubljana, Slovenia. The sprayer was based on a conventional trailed design (by Agromehanika) upgraded with three hydraulically moveable spraying arms and a radial fan which provides individual air streams for each spraying arm. At the end of each spraying arm two spraying nozzles for pesticide application were mounted. Additionally the sprayer was equipped with a laser scanner (LIDAR), a computer and a National Instruments Compact Data Acquisition system (NI cDAQ) to read signals from positioning sensors and operate electromagnetic valves of hydraulic cylinders and spraying nozzles. Positioning of the spraying arms was done by activating electromagnetic valves for hydraulic cylinders mounted on the arms. They were in a control loop with a feedback from positioning sensors mounted on hydraulic cylinders (linear sensors) and arm joints (angular sensors). Positioning of the spraying arms was based on a real-time data of a canopy shape. It was continuously measured with LIDAR as the trailer was moving by along the row. From scanned points a canopy contour was determined. Contour was determined only for the side of the row closer to the sprayer. For communication with sensors and to control and operate the sprayer LabView programming language was used. During spraying the arms of the sprayer were moving so that positions of nozzles were adapting according to the canopy contour. The sprayer was tested under laboratory and real (orchard) conditions. Experimental results from orchard spraying showed increased coverage and reduced drift which were measured using water sensitive papers. Pesticide consumption was also reduced.*

***Key words:*** *laser scanner, LIDAR, variable geometry, canopy contour, LabView, pesticide reduction*

## INTRODUCTION

Spraying in orchards can be viewed in multiple ways which change according to changes in ranking of some values people have. Presently, economical and ecological aspects of spraying rank quite high which means that for spraying its efficiency, costs and environmental impact are important issues. From engineering point of view these issues contain proper coverage of tree canopy, reduction of pesticide consumption and reduction of drift and other pesticide losses into soil, air and water [2, 3]. Importance of these issues is also reflected by a commitment of the EU policy towards a reduced pesticide use and generally increasingly stringent legislation [1, 7, 8]. In accordance with goals mentioned above possible solutions can be found in variable spraying. Such spraying commonly adapts to a target shape, size and location with a variable spraying rate. In addition to that present paper describes a new approach which is fundamentally different. It is based on a premise that advanced spraying must be regarded as a local phenomenon where not only a tree canopy is important but also a sprayer. As trees are variable in their size and shape it is justified to assume that for efficient spraying also the sprayer must change its geometry. Our paper gives some insight in development and operation of a prototype sprayer with automatically changing geometry which is continuously adapting to a tree canopy.

## MATERIALS AND METHODS

*Sprayer hardware*

The sprayer (Figure 1) is an air-assisted sprayer with three hydraulically movable spraying arms for spraying one side of a row of trees. Its detailed description can be found in [5]. Each arm covers one height segment of a row. Ends of arms are equipped with spraying nozzles and air spouts. Moving of the spraying arms to the desired locations is based on an inverse kinematics algorithm which basically provides numerical solutions for actuation of hydraulic cylinders of all eight degrees of freedom.

For the measurements of a canopy shape LIDAR (model SICK LMS 111, SICK AG Waldkirch, Reute, Germany) was used. It was connected to a computer (with the Intel Core i5-3570 processor and a solid-state drive) in a computer box (Figure 2) via TCP/IP and was accessed with a NI LabView program (National Instruments Corporation, Austin, TX, USA). LIDAR was mounted on the sprayer 2.4 m ahead of the spraying arms and 2 m from the ground. It has a view of 270° but due to the one-sided experimental sprayer design only measurements from one side of the sprayer were used. The measuring plane of LIDAR was perpendicular to the row and the tractor-sprayer axis. It was operating at 50 Hz acquisition rate with angular resolution of 0.5°. A choice to use LIDAR as a primary sensor for canopy characterization was based on our previous experience with various sensors (ultrasonic, IR etc.) where LIDAR performed the best. LIDAR is also increasingly used in vineyards [4] so a trend of replacing ultrasonic sensors (due to their somehow inferior performance [9]) can be generally observed.

In the electronics box National Instruments Compact Data Acquisition (NI cDAQ) chassis NI cDAQ-9174 with two modules for analog inputs (NI 9205) and digital outputs

(NI 9476) were mounted. Digital outputs were connected to relays which operated electromagnetic valves.

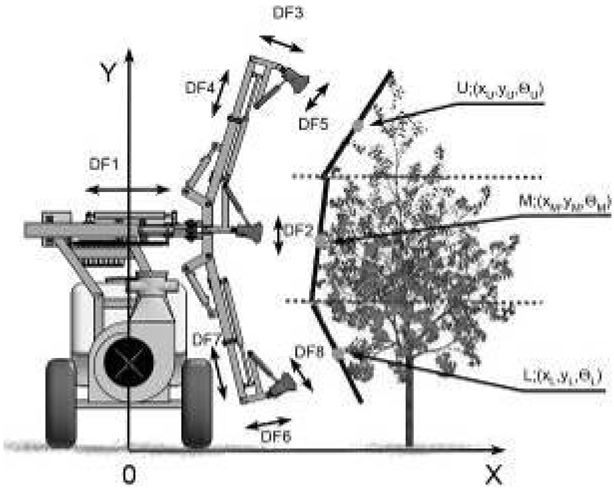


**Figure 1** Canopy adapted spraying with variable-geometry sprayer


**Figure 2** Sprayer with sensors and manipulators (1 - LIDAR with protective housing, 2 - computer box, 3 - electronics box, 4 - electromagnetic valves, 5 - sprayer arms and air ducts, 6 - basic sprayer, 7 - radial fan)

*Sprayer software*

The sprayer computer run Windows XP operating system. Programming of the sprayer was done in NI LabView. Inside the main program there were several subprograms for communication with LIDAR and spraying manipulator, for data processing etc. Programs were continuously running from the beginning of spraying until they were stopped with an external command. Nevertheless the main program was written so that the sprayer was not spraying if it standed still or if there was no tree to be sprayed in front of it. In this way unwanted deposits were reduced. Communication between independent subprograms was on the basis of global variables. Advantage of using independent subprograms was in parallelization of tasks, shorter execution times, their increased transparency and higher flexibility.

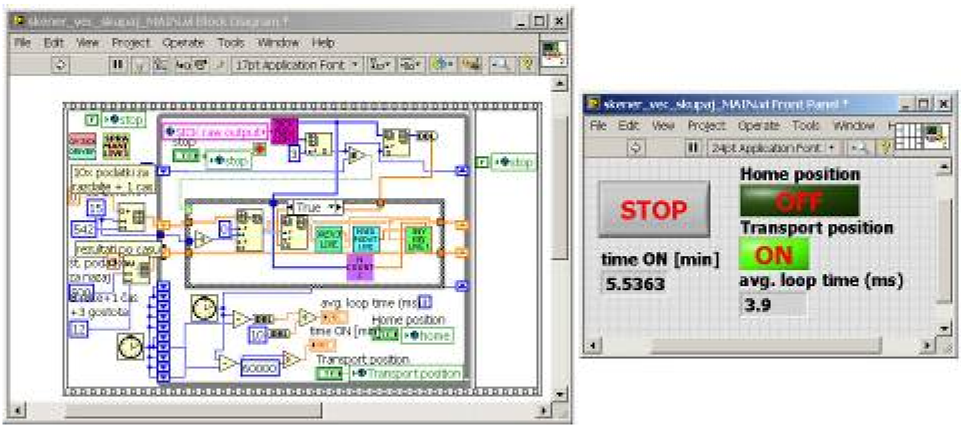


**Figure 3** Main program in LabView

During spraying measured points at a given position along a row were sent from LIDAR to the computer and were imported into the main spraying program (Figure 3). From them a contour of the canopy was determined. Afterwards the contour was approximated with three linear segments corresponding to three spraying arms and for each segment its normal was calculated [6]. Next, possible positions for each spraying arm were computed. Positions were based on a spray angle of nozzles so that optimum coverage of the canopy segment was obtained. Positions were chosen so that there was no possibility of contact between the spraying arm and the canopy. Finally consecutive positions were smoothed to facilitate real movements of the spraying arms performed by hydraulic cylinders. Obtained positions were saved into internal database with corresponding timestamps. According to measured sprayer velocity an delay when spraying arms reach scanned position was estimated. Based on this delay appropriate data were read from the database so that spraying arms always moved according to a canopy shape next to them.

A subprogram for interaction with the sprayer hardware worked on the basis of inputs and outputs of NI cDAQ. Analog inputs provided measurements from sensors (linear and angular positions of the spraying arms, travel velocity) while digital outputs were used to control electromagnetic valves (used for operation of hydraulic cylinders and spraying nozzles). Its execution time was below 1 ms. In this particular case such short time was very favorable because positioning of the spraying arms was realized iteratively. This means that a measured position was compared with a desired position so when spraying arms reached the desired position this was quickly detected. Because of this there was very little overshooting and correcting therefore the spraying arms stayed in favorable spraying position for a longer period of time.

*Laboratory experiments*

Laboratory experiments were performed with the sprayer which was stationary and a model of a tree which was also stationary but rotating around its vertical axis. Angular velocity of the model was set with a frequency converter. With faster rotation higher tractor velocity was simulated. The model was positioned relatively to the sprayer at a distance corresponding to the expected working distance between the sprayer and a row of trees during orchard spraying. The model was set in front of the sprayer so that LIDAR was scanning its shape just as it would scan a canopy (Figure 4). Rotation of the model was found necessary because it enabled smooth movements of the spraying arms without jitter. Positioning of the spraying arms was visually compared with the shape of the tree model and very good matching was achieved. During laboratory experiments also endurance of sprayer electronics and hydraulics was tested by running sprayer continuously for 10 hours. It operated without any problems so a conclusion was done that they were suitable for continuous orchard use.

**Figure 4** Laboratory testing based on LIDAR measurements of a solid model of a tree

Orchard experiments

The experiments were done in the research orchard of Brdo pri Lukovici (46°10'N, 14°40'E, the Agricultural Institute of Slovenia). The measurements were performed on spindle trained apple trees on cultivar 'Breaburn' grafted on M.9 rootstock at 1.5 m spacing and 3.5 m inter-row distance. The trees were fully foliated, their average height was 3 m (max. 3.5 m). Spraying was done with water. The sprayer was equipped with TeeJet hollow cone nozzles TXA80 01VK and 02VK (orange and yellow, 0.68 l/min and 1.40 l/min at 10 bar, respectively). All experiments were conducted at pressure 10 bar. Spray coverage was observed by water sensitive papers (WSP). Size of WSPs was 76x26 mm. They were placed on four random apple trees along the row used for the experiments. WSPs were attached to leaves in pairs so that one WSP faced the sprayer and the other was turned away from it to observe spray coverage on both sides of leaves. According to a typical geometry of a tree canopy they were placed with regard to a tree height (upper, middle and bottom position), depth (front, middle and back position) and side (left, right position). Apart from these positions some WSPs were also placed on the side of the row opposite to the sprayer where they were placed on laths between the rows: one laying on the ground and one vertical with WSPs at heights 1, 2 and 3 m from the ground. These were used for drift observations. At the end of each spraying experiment WSPs were collected and quantitatively evaluated. Analytical methods used for their evaluation were based on computer-aided visualization of their scanned images. WSPs were scanned with resolution of 1200 DPI.

Spraying of trees was done at five different regimes:

1) sprayer with adapting spraying arms, nozzles open all the time,

2) sprayer with adapting spraying arms, nozzles open according to row density (method 1),

3) sprayer with adapting spraying arms, nozzles open according to row density (method 2),

4) comparison with a classical sprayer,

5) sprayer with adapting spraying arms, nozzles open all the time (no. 1 repeated).

Differences between methods 1 and 2 were in density limits set for nozzle opening and in nozzle combinations. The first method used both orange and yellow nozzles while the second method preferably used orange nozzles with lower volumetric flow rate. The classical sprayer used for comparison was a trailed sprayer with a 800 mm axial fan (sprayer type Zupan 1100L , Slovenia, with pump Annovi/Reverberi AR904, Italy). Its working parameters were set according to the best orchard practice. It was set so that it sprayed only one side of the row. Sprayer velocity during all experiments in the second phase was 1 m/s. Weather conditions during spraying were dry and hot (30°C) with wind velocities under 1 km/h.

## RESULTS AND DISCUSSION

In Figure 5 live LIDAR measurements of the rotating model are presented in Cartesian coordinates. They are presented in the front panel of a relevant subprogram. This graphical representation was omitted in the final version to make it faster and lighter. However, even with this subprogram the front panel of the main program (on the left side of a display in Figure 5) shows an average loop time of 0.3 ms.

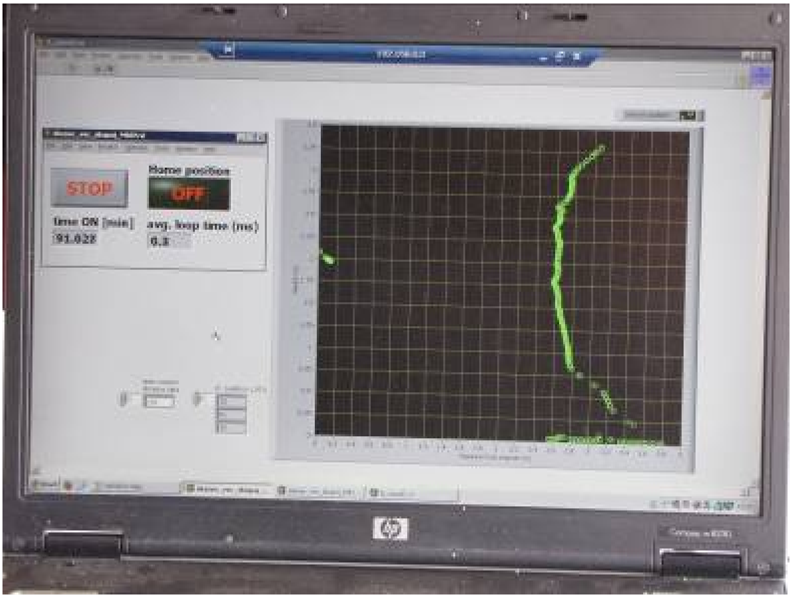


**Figure 5** Real-time scanning results of rotating tree model in LabView

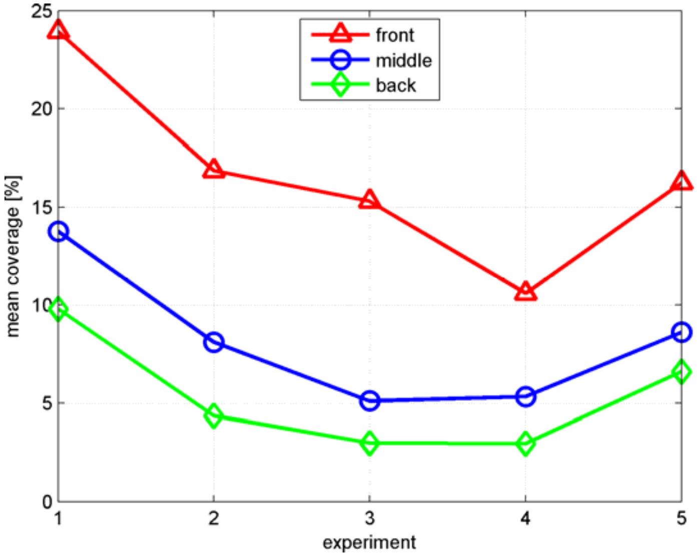


**Figure 6** Mean spray coverage

In Figure 6 mean coverage is presented according to a canopy depth in direction away from the sprayer. In all cases coverage on the front side is more than two times higher than coverage on the back. Such results are expected and in accordance with [ref.]. It is desired that during spraying no spray goes through the canopy to exit on the other side so small coverage on the back is favorable in this aspect. In reality this side is properly covered when spraying is done from the other side, too.

Figure 7 presents the same data but normalized with regard to the classical sprayer (experiment no. 4). Values above 1 indicate a performance better than a "best practice" with the classical sprayer. The best coverage was obtained when nozzles were opened all the time which is expected. Experiments 2 and 3 (with methods where nozzles were closing according to measured density) showed smaller increase in coverage. The second method was apparently much less suitable as performance was increased only in the front part of the canopy (red line). It is also interesting that for experiments 1 and 5 when nozzles were open all the time coverage of the back part of the canopy (green line) was relatively more increased. As described above this is not necessary desirable as it may cause higher drift because more spray escapes through the canopy. Difference in coverage between the experiments 1 and 5 which were of the same kind can be accounted to changing turbulence affecting spray deposits inside the canopy and locations where WSPs were mounted.

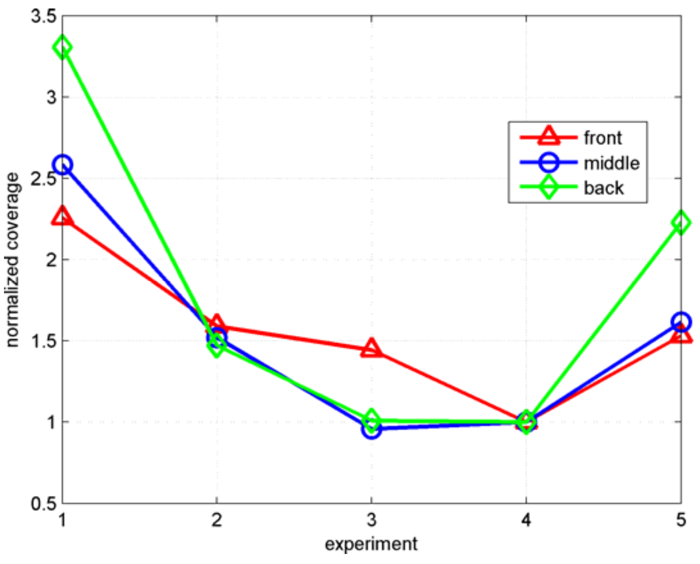


**Figure 7** Normalized mean spray coverage

There are several reasons for poor performance of the experiments with variable nozzle opening (2, 3). The first is that we expected that some drops would drift downwards from the middle third because of gravity and would therefore reduce a necessary amount of spray (generally obtained by direct spraying in that part). As the weather was hot and dry drops were quickly drying (while in the air) and drift towards the ground was smaller. The next reason was that in the lower third of trees trunks were often very exposed and so when

LIDAR measured a tree it detected a trunk instead of leaves. We did not want to spray trunks but only leaves so to compensate for this effect the limits for activating sprayer nozzles were raised in the lower part. Further reason for poor coverage is related to a way how nozzles were mounted on air spouts. They were mounted so that one nozzle was at the upper end and the other was at the lower end of the spout so basically they did not cover the same area. When nozzles were turned off it happened not only that a quantity of spray was diminished but also that spray was not directed into certain area any more. In cases where canopy was denser or thicker turbulent air flow inside the canopy aided to distribute the spray more evenly but in the case of the lower third of trees where there was only a little canopy (between trunks) the flow from the remaining nozzle was not distributed across the whole third.

## CONCLUSIONS

The paper presents experimental air-assisted orchard sprayer with a variable geometry of spraying arms. They were automatically positioned with regard to real-time LIDAR measurements of a tree canopy so that they continuously followed the shape of a sprayed canopy. Results from the spraying experiments in the orchard showed that the new sprayer with automatic positioning of the spraying arms achieved much higher spray coverage than a classical air-assisted sprayer with fixed geometry. Coverage varied according to different test settings but in the best case with the new sprayer it was more than three-times higher than with the classical sprayer. In this way amount of pesticides used for spraying can be reduced. Such favorable results were made possible by using an innovative sprayer design presently upgraded with LIDAR sensor for distance measurements. An important contribution towards autonomous operation was done by developing appropriate software algorithms which integrated real-time orchard data, spraying characteristics and hardware functionality into a single operative unit.

## ACKNOWLEDGEMENT

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Original scientific paper

# FRUIT THINNING WITH SELECTIVE SPRAYING

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## SUMMARY

*Experimental fruit thinning was performed in an orchard on apple trees of Elstar and Brina variety. Fruit thinning, which gives bigger fruit and reduces the effect of alternate bearing, was done by spraying during development of fruit (phenological growth stage 71 using the BBCH-scale). A precision GPS module was added to an air-blast sprayer previously upgraded with electromagnetic valves, relays, National Instruments Compact Data Acquisition (NI cDAQ) system and a computer. Selective spraying was based on a number of flowers on each individual apple tree. Flowers were manually counted during full flowering when trees were also recorded with a camera. For each picture a corresponding GPS position was logged. Precise GPS positioning was based on a u-blox LEA-6T module and Real-Time Kinematics for which a base station signal was obtained via GSM modem from Slovenian GPS network SIGNAL. GPS signals were processed by RTKLib program package. In this way real-time positioning in a cm-range was possible. Precise locations of apple trees were determined from recorded pictures. Location of a tree was determined so that a trunk was in the center of the picture. Locations and corresponding number of flowers were stored on the computer mounted on the sprayer. During thinning GPS positioning was done in the same way (as during the recording of trees). Based on a current sprayer location the number of flowers of the nearest tree was compared against a threshold value. When the number of flowers was higher than the threshold value the electromagnetic valves, which were mounted before the spraying nozzles, opened and the tree was sprayed. In this way only over-flowering trees were thinned. For manipulation of electromagnetic valves based on a number of flowers a LabView program was written. Selective spraying of alternating apple trees resulted in reduced spray consumption, more evenly loaded trees and higher quality of apples. It is also expected that with such spraying alternate bearing will be reduced in the future.*

**Key words:** *GPS, Real-Time Kinematics, alternate bearing, orchard, electromagnetic valves, LabView*

## INTRODUCTION

Alternate bearing is unwanted phenomenon of strong yield variations from year to year. It can be caused by different stress factors or as natural yield alternation typical for specific species [3]. Such behavior can be reduced by eliminating excessive flowers or fruitlets by thinning. Thinning can be mechanical, chemical or manual and it increases fruit size, firmness and sweetness [2]. As such it is necessary for high-quality yields. Commonly chemical thinning is used in orchards as manual thinning is very labor intensive while mechanical thinning is a very promising technology for the future (environmentally friendly) but is more expensive than chemical thinning and presently still showing strong variation in results due to multiple operating parameters and different mechanical designs [7]. The main issue with mechanical thinning is potential tree damage (trunk, limbs and leaves) [6] while chemical thinning is very dependent on weather conditions [2].

In our study several innovative approaches were combined into expert thinning system with aims to design a versatile and automatic thinning platform and to reduce consumption of chemical compounds used for chemical thinning. The study was divided into two parts. In the first part images of apple flowers was recorded. In the second part chemical thinning (spraying) was done. In the next section both parts are described in details.

## MATERIALS AND METHODS

The experiment was done in the research orchard of Brdo pri Lukovici (46°10’N, 14°40’E, the Agricultural Institute of Slovenia) on apple trees of cv. 'Brina' and 'Elstar'. The two phases of the experiment (visualization of flowers and spraying) were done when apple trees were on the BBCH scale [4] at the phenological stage 65 (full flowering) and 72 (fruit size up to 20 mm), respectively.

*First phase*

In this phase images of blooming apple trees were recorded with a RGB CCD camera (Figure 1). The camera was mounted on a vehicle which was driving along a row of trees. The camera was mounted so that one tree covered a whole image. As close as possible to the camera a GPS antenna was mounted. For precise GPS positioning U-blox EVK-6T kit with LEA-6T precision timing chip was used. Positioning was based on Real-Time Kinematics technique for which a second GPS signal from a referential base station was needed. In our case it was obtained through GSM network from SIGNAL (Slovenian national network of referential GPS stations). Both signals were processed in real-time using RTKLib programming package [8]. The whole set-up enabled positioning with precision up to 2 cm [5]. Images of trees were recorded on a computer which simultaneously recorded a precise corresponding position for each recorded image.

**Figure 1** Blooming apple tree, day and night image

Further on images were post-processed to determine a trunk position and a number of flowers. Trunk positions were later used for determining a center of each tree while the number of flowers was a decisive parameter for spraying the tree or not. As post-processing of images is by itself quite demanding and extensive topic [1] in the present paper it will not be described into further details. For each tree flowers were also manually counted to obtain referential (true) values and these numbers were used for the final spraying.

*Second phase*

In the second phase apple trees were sprayed if they had 50 or more flowers. For this a modified air-blast sprayer AGP 200 ENU (from Agromehanika d.d., Slovenia) was used. The sprayer was mounted and driven by a compact tractor AGT 835 (also from Agromehanika). Figure 2 shows a rear view of the tractor with the sprayer together with 1) electronics box, 2) electromagnetic valves, 3) GPS antenna, 4) speed indicator, 5) fan, 6) 5 spraying nozzles, 7) tank, 8) pump. During the experiment only nozzles on the right side of the sprayer were active while electromagnetic valves for the left-side nozzles were closed. On the other side of the sprayer (not visible on Figure 2) a computer with a GSM modem and a GPS module was mounted.

In the electronics box National Instruments Compact Data Acquisition chassis NI cDAQ-9174 with two modules for analog inputs (NI 9205) and digital outputs (NI 9476) were mounted. Digital outputs were connected to relays which were used to operate electromagnetic valves for spraying. Spraying pressure was 10.5 bar, driving velocity was 4.2 km/h, nozzles were hollow cone ALBUZ ATR 80 (red) equipped with anti-drip valves. Measured continuous output through all 5 nozzles was 11.1 L/min. Volumetric flow rate was measured by a flow meter Elster S100/A, class A. Data acquisition and regulation of electromagnetic valves was programmed in LabView.

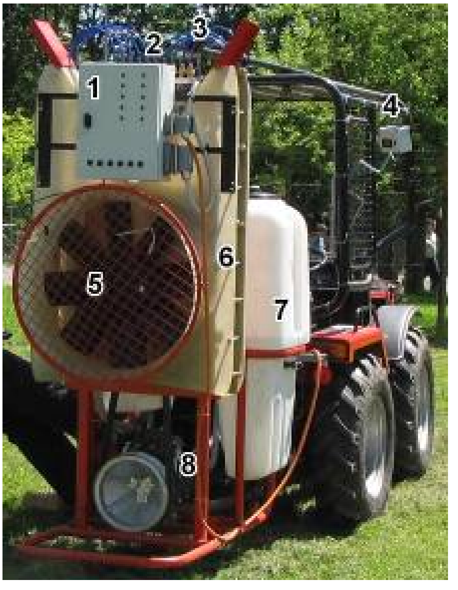


Figure 1 Tractor with mounted sprayer

## RESULTS AND DISCUSSION

In Figure 3 results from GPS measurements are presented. On the left side apple trees of cultivar Brina are shown and on the right side of cultivar Elstar. There were 18 Brina trees in a 47 m long row (2.6 m spacing between trees) and 70 Elstar trees in a 126 m long row (1.8 m spacing between trees). Circles marking tree positions are not proportional to crown or tree size. However as indicated in Figure 3 Brina trees were trained as separate trees (spacing between them) while Elstar trees were trained continuously (no spacing between the trees).

According to the spraying algorithm a number of flowers for each tree was superposed over GPS data. Figure 4 demonstrates this coupling for Brina trees. For tree positions the same data as in Figure 3 are used but they are shown in length units relatively to the beginning of the row. Number of flowers for each tree is indicated with a different color according to the color scale shown on the right where black equals no flowers and white equals maximal number of flowers. With regard to the threshold value of 50 flowers trees marked with triangles were not sprayed.

The spraying algorithm developed for our experiment can be outlined in the following way. Current GPS position of the sprayer was continuously compared with a database of previously recorded tree positions and the closest tree was selected. If distance between the current position and the tree was small enough and if the number of flowers for that tree was above the threshold spraying was activated (electromagnetic valves opened). If any condition was not fulfilled electromagnetic valves closed. In Figure 5 front panel of the spraying program written in LabView is presented.

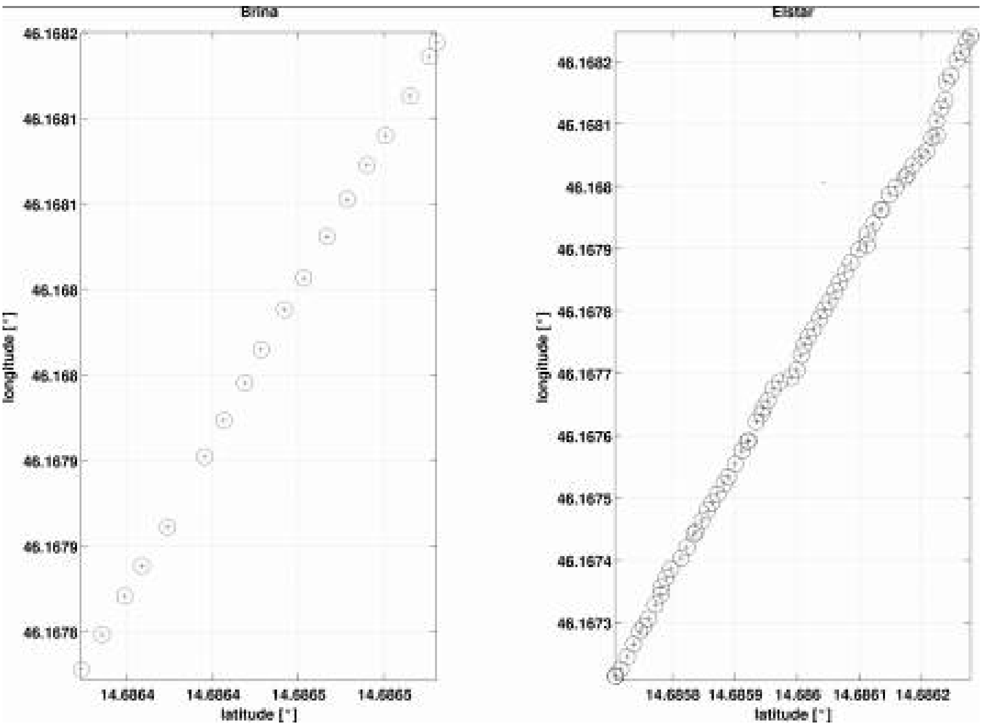


Figure 2 GPS locations of trees

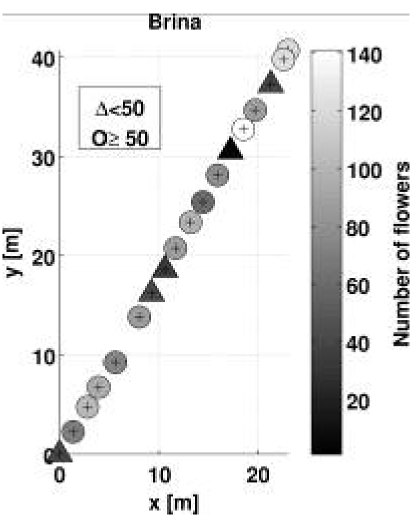


**Figure 4** Brina trees with corresponding numbers of flowers

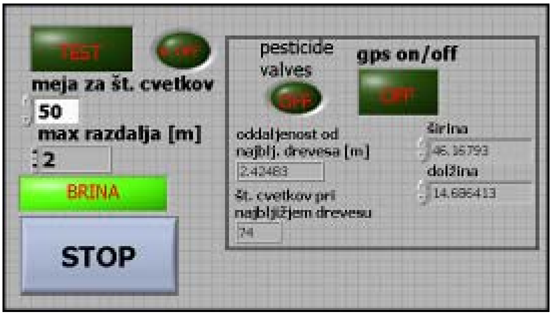


**Figure 5** Front panel of the spraying program in LabView

Spraying results are presented in Table 1. Spray savings were calculated with regard to theoretical amounts of spray used if measured lengths of the rows were continuously sprayed. As can be seen from the results volume savings are consistent with relative number of trees below the spraying threshold (trees not meant to be sprayed).

**Table 1** Spray savings

| | **Brina** | **Elstar** |
|---|---|---|
| Ratio of sprayed trees [%] | 72.2 | 24.3 |
| Volume of spray [L] | 10.8 | 10.8 |
| Spray volume savings [L] | 4.67 | 30.7 |
| Relative spray vol. savings (1) [%] | 30.2 | 73.9 |
| Ratio of unsprayed trees (2) [%] | 27.8 | 75.7 |
| Difference (1)-(2) [%] | 2.4 | -1.8 |

The main difference in the spraying results can be seen at the end where for Brina the difference between the ratio of unsprayed trees and the relative spray volume savings is positive while for Elstar it is negative. For Brina this means that spray consumption was even a bit below a value that could be expected on a basis of a number of sprayed trees. The difference is a practical result of a spraying process which was calibrated so that for a given tree (that needed to be sprayed) it started a little after the edge of a crown (delayed start) and stopped a bit before the end of the crown (early stop). A purpose of such calibration was that in dense tree rows (such as Elstar) an effect of overlapping trees was reduced.

## CONCLUSIONS

Chemical thinning of apples was successfully performed on alternately bearing trees. The experiment in which orchard trees were selectively sprayed on a basis of a number of flowers showed that current technologies including precision GPS positioning, computer-aided visualization and sensing are suitable for their integration into autonomous spraying system. For their integration LabView graphical programming language was successfully used. The results showed that spray savings are proportional to a number of non-sprayed trees. The presented approach showed possible future economic benefits resulting from decreased spray consumption.

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42. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

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# OCJENA KVALITETA VRŠIDBE NOVIH SORATA TRITIKALEA

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## SAŽETAK

*U radu su prikazani rezultati ispitivanja u vršidbi tritikalea mobilnom vršalicom tip V-08 proizvođača „Ernet“ iz Kikinde na pokusnim poljima Instituta za krmno bilje u Kruševcu. Na malim pokusnim parcelama poslije košenje usjeva, vršidba je sastavni dio ubiranja sjemenskog tritkalea. Cilj ispitivanja je bio praktična primjena i ocjena kvalitete rada uređaja u vršidbi sortnog sjemena tritikalea u mikro pokusima.*

*Tijekom istraživanja ustanovljeni su gubici sjemena na slamotresima i sitima vršalice koji se pojavljuju u neovršenim klasovima i slobodnom sjemenu u ovršenoj masi. Visina gubitaka i kvaliteta ovršenog sjemena ovise o sorti, vlažnosti sjemena u momentu žetve, od broja okrertaja bubnja, zazora između bubnja i podbubnja, veličine otvora na sitima i njihove čistoće. U radu vršalice ukupni gubici sjemena kretali su se od 2,45% do 7,10% od čega je manji dio gubitka sjemena na sitima od 0,08% do 0,15%, a ostalo su gubici na slamotresima.*

*Kvaliteta vršidbe određivana je na temelju prosječnog uzorka uzetog iz vrećice u koju je sjeme prikupljeno iz vršalice. Kasnije je u laboratoriji na separatoru tipa Dakota iz prosječnog uzorka izdvojeno cijelo, šturo i polomljeno sjeme i ostale primjese. Kvaliteta vršidbe je bila zadovoljavajuća jer se udio čistog sjemena kretao od 93,94% do 98,62%, šturog sjemena od 0,66% do 5,40% i primjesa od 0,12% do 1,98%.*

***Ključne riječi**: vršalica, tritikale, sjeme, pokusne parcele, gubici sjemena, kvaliteta vršidbe.*

## UVOD

Tritikale kao nova vrsta strnih žitarica nastala je križanjem pšenice i raži. U ovoj novoj vrsti, selekcioneri su kombinirali visok potencijal za prinos i dobru kvalitetu pšenice i tolerantnost na biotičke i abiotičke stresove raži. Ciljevi programa oplemenjivanja tritikalea su uglavnom usmjereni na najvažnije agronomske karakteristike kao što su prinos zrna, prinos biomase, nutritivna vrijedost, ranozrelost i bolja ispunjenost zrna.

Tritikale se najčešće koristi kao dodatak u ishrani stoke ili kao dodatak pšeničnom brašnu u pekarskoj industriji, dok se danas sve češće upotrebljava kao zamjena dijela slada u industriji proizvodnje piva (Grujić i sur. 2009).

Poboljšanjem karakteristika, tritikalea postaje sve više značajniji i zastupljeniji u proizvodnji, tako da su površine pod ovom vrstom u stalnom porastu. U svijetu se tritikale uzgaja na površini iznad 3 miliona ha, a u Srbiji zauzima oko 10000 ha (Đekić i sur. 2009). Prinos zrna po jedinici površine jedan je od najvažnijih faktora koji utječu na rentabilnost i ekonomičnost proizvodnje. Prosječan prinos tritikalea u Srbiji zadnjih godina kreće se od 4,0-10,0 t/ha ovisno o tipu zemljišta. Što pokazuju rezultati za agroekološke uvjete Kraljeva (centralna Srbija) da na jako kiselim zemljištima tipa pseudoglej prosječni prinosi su od 3,42-4,08 t/ha (Jelić i sur. 2013).

Zadnjih pedesetak godina selekcioneri su mnogo uradili na stvaranju novih sorata strnih žitarica. Jedan od problema koji se javio u početku stvaranja novih sorata jeste žetva mikro pokusa. Potrebno je bilo da se veliki broj malih parcela požanje ručno za što se angažiralo mnogo ljudskoga rada. U Srbiji neki instituti posjeduju specijalizirane kombajne za žetvu pokusnih parcela. Međutim, zbog njihove visoke nabavne cijene, mnogi instituti, savjetodavne stručne službe i druge organizacije koje su ovlaštene da postavljaju oglede u cilju priznavanja novih sorata nisu u mogućnosti da nabave iste. U cilju rješavanja ovoga problema tvrtka „Ernet" iz Kikinde je proizvela univerzalnu laboratorijsku vršalicu za žetvu raznih kultura u mikropokusima, a koju su nabavili u Institutu za krmno bilje u Kruševcu.

Cilj istraživanja je da se u praktičnoj primjeni uređaja u vršidbe tritikalea, utvrdi kvaliteta rada u pogledu dobivanja što većih količina čistog sortnog sjemena. Tijekom istraživanja ustanovit će se i ukazati na određene nedostatke u konstrukciji i radu vršalice, kako bi se oni kasnije otklonili, a sve u cilju daljnjeg usavršavanja uređaja.

## MATERIJAL I METODE

Ispitivanja mobilne vršalice tip V-08 vršena su na pokusnim površinama za selekciju, radi priznavanje novih sorata tritikalea. Instituta za krmno bilje u Globoderu. Na pokusnim mikro parcelama površine 5m$^2$ (4 x 1,25m) posijane su različite sorte tritikalea. Tijekom istraživanja, a neposredno prije žetve, utvrđeno je stanje usjeva, izmjerena je visina biljaka i vlažnost sjemena. Proces ubiranja žetvene mase tritikalea odvijao se u dvije faze. U prvoj fazi, usjev sa mikro parcele, na kojoj je zasijana po jedna sorta tritikalea, prvo je ručno pokošen. U drugoj fazi sva pokošena masa je također ručno pokupljena i postupno ubacivana u vršalicu. Vršidba usjeva sa jedne parcele trajala je sve dok izvršaj ne bude potpun, to jest iz vršalice ne izađe cjelokupno sjeme i slama jedne sorte. To znači da sjeme jedne sorte nije smjelo miješati sa sjemenom sa naredne parcele odnosno druge sorte.

Poslije završetka žetve jedne sorte tritikalea izmjerena je masa ovršenog sjemena i određena njegova vlažnost.

Gubici na slamotresima određivani su tako što je za vrijeme vršidbe ispod njih postavljeno platno u kojem je uhvaćena sva slama i pljeva. Iz ovršene mase ručno su odvojeni neovršeni klasovi, a sjeme je iz pljeve izdvojeno pomoću posebnih sita i stavljeno u vrećice na koje je obilježena šifra sorte i broj uzorka. Gubici na donjem situ hvatani su na posebnom platnu koje je postavljeno ispod njega. Također su s njega i uzimani svi neovršeni klasovi koji su propali kroz otvore podbubnja. Poslije izvršaja jedne parcele (sorte) izmjerena je masa slame, pljeve i sjemena, na temelju čega je utvrđena ukupna žitna masa koja je prošla kroz vršalicu. Kasnije je u laboratoriju izvršeno odvajanje sjemena od pljeve kao i zrna iz klasa. Zatim su na analitičkoj vagi izvršena mjerenja sjemena. Rezultati dobiveni mjerenjem sjemena su prikazani kao gubici vršalice, koji se javljaju u vidu čistog sjemena i neovršenih klasova, nastali u vršidbi tritikalea.

Kvaliteta žetve određivan je tako što je iz vrećice ovršenog sjemena uziman prosječan uzorak. U laboratoriji je na separatoru tipa Dakota iz prosečnog uzorka izdvojeno i izmjereno cijelo, šturo i polomljeno sjeme i ostale inertne materije prisutne u izvršenoj masi.

## REZULTATI I DISKUSIJA

U borbi za dobivanje što većih prinosa, pored rada na selekciji, agrotehnici i tehnici ubiranja, posebnu pozornost treba obratiti na gubitke koji se javljaju u žetvi tritikale.

Žetva sjemena tritikalea je jedna od najvažnijih i najosjetljivijih operacija u procesu tehnologije proizvodnje i umnožavanja sortnog sjemena koje je u procesu priznavanja. Od načina žetve i tehničko tehnoloških rješenja primijenjene mehanizacije u velikoj mjeri ovisi količina ubranog sjemena i njegova kvaliteta.

**Tablica 1** Tehničke karakteristike mobilne vršalice "ERNET" tip V-08
**Tab. 1** Technical features of a mobile thresher "ERNET" Type V-08

| Parametri – Parameters | V-08 |
|---|---|
| Nominalna snaga motora traktora – Engine power (kW) | 29,5 |
| Širina bubnja – Drum width (mm) | 500 |
| Promjer bubnja – Drum diameter (mm) | 350 |
| Broj letava bubnja – Number of drum rails | 6 |
| Broj okretaja bubnja – Drum revolution ($min^{-1}$) | 450-1000 |
| Površina sita – Sieve surface ($m^2$) | 0,49 |
| Zazor bubanj-podbubanj – Clearance drum-concave (mm) | 20-8 |
| Masa – Mass (kg) | 470 |
| Visina x širina x dužina – Height x width x length (mm) | 2020 x 1350x 3300 |

Vršalica „Ernet V-08“ je u osnovi namijenjena za vršidbu malih uzoraka ratarskih kultura sa mikro pokusnih parcela. Sa određenim adaptacijama i podešavanjima vršalica se može koristi i za vršidbu soje, uljane repice, suncokreta, krmnog i ljekovitog bilja.

Na vršalici je predviđeno reguliranje: broja okretaja bubnja, zazora između bubnja i podbubnja, jačina zračne struje, reguliranje otvora srednjeg sita, reguliranje nagiba donjeg sita, kao i mogućnost njegove zamjene u ovisnosti od kulture koja se vrši. Reguliranje broja okretaja radnih tijela se vrši izmjenom remenice, a ovisno od stanja usjeva i kulture koja se vrše.

U našim istraživanjima ispitano je pet sorti tritikalea koje su u postupku priznavanja i u istraživanjima su označene brojevima, a čije su karakteristike prikazane u tablici 2.

Ispitivanja vršalice su obavljena u povoljnim vremenskim uvjetima. Meteorološki podaci tijekom istraživanja očitani su na meteorološkoj stanici ADAS smještenoj na imanju Instituta za krmno bilje. Tijekom ispitivanja nije bilo oborina, a dnevne temperature kretale su se u granicama od 21,0$^0$C do 33,9$^0$C. Relativna vlažnost zraka se kretala od 53% u jutarnjim do 25% u popodnevnim satima.

**Tablica 2** Osnovne karakteristike ispitivanih sorata tritikalea
**Tab. 2** Basic characteristics of triticale in the examination

| Sorta - Cultivar | 161 | 162 | 164 | 165 | 166 |
|---|---|---|---|---|---|
| Broj zasijanog sjemena na 1m$^2$ Number of sown seeds per 1m$^2$ | 550 | 560 | 560 | 570 | 570 |
| Prinos sjemena u momentu žetve u kg na 5m$^2$ Yield at the time of harvesting in kg per 5m$^2$ | 2,85 | 3,03 | 2,30 | 2,58 | 2,33 |
| Vlaga sjemena pri žetvi % Seeds moisture at harvesting in % | 10,2 | 10,8 | 10,2 | 11,6 | 9,8 |
| Visina biljke od osnove do vrha klasa Plant height from the base to the top of the ear in cm | 110 | 100 | 105 | 104 | 113 |
| Datum nicanja Date of germination | 23. 02. 2012. | 25. 02. 2012. | 27. 02. 2012. | 28. 02. 2012. | 28. 02. 2012. |
| Datum klasanja Date of heading | 13. 05. 2012. | 16. 05. 2012. | 10. 05. 2012. | 13. 05. 2012. | 13. 05. 2012. |
| Datum žetve Date of harvest | 10. 07. 2012. | 10. 07. 2012. | 10. 07. 2012. | 10. 07. 2012. | 10. 07. 2012. |

Na ispitivanim parcelama usjev tritikale je bio čist, bez korova, ujednačene visine, uspravan i bez poleglih biljaka. Prosječna visina biljaka kretala se u granicama od 100 do

113cm, što ovisi o sorti. Na površini od 5m$^2$ ostvareni prinos zrna iznosio je od 2,30 do 3,03kg ili 460 do 606g/m$^2$. Eksperimentalna istraživanja su obavljena pri punoj zrelosti svih sorata tritikalea, pri vlažnosti sjemena od 9,8-10,8%.

**Tablica 3** Gubici sjemena tritikale na vršalici
**Tab. 3** Seed losses in triticale threshing machine

| Broj uzorkaS ample number | Masa uzorka Sample weight (g/m$^2$) | Gubici slamotresa Strow walker losses | | | | Gubici sita Sieve losses | | Ukupni gubici Total losses | |
|---|---|---|---|---|---|---|---|---|---|
| | | U klasu In ear | | U sjemenu In seed | | U sjemenu In seed | | | |
| | | g/m$^2$ | % | g/m$^2$ | % | g/m$^2$ | % | g/m$^2$ | % |
| 161 | 570 | 6,05 | 1,06 | 7,23 | 1,27 | 0,69 | 0,12 | 13,97 | 2,45 |
| 162 | 606 | 3,24 | 0,53 | 18,08 | 2,98 | 0,36 | 0,06 | 21,68 | 3,57 |
| 164 | 460 | 2,26 | 0,49 | 27,09 | 5,89 | 0,67 | 0,15 | 30,02 | 6,53 |
| 165 | 516 | 4,66 | 0,90 | 31,56 | 6,12 | 0,41 | 0,08 | 36,63 | 7,10 |
| 166 | 466 | 8,86 | 1,90 | 11,33 | 2,43 | 0,47 | 0,10 | 20,66 | 4,43 |

Usjev svih pet sorata tritikalea je prije vršidbe ručno pokošen na jednaku visinu strnike od 15cm. Prilikom ručnog prikupljanja pokošene mase i ubacivanja u vršalicu, vodilo se računa da ne dođe do osipanja sjemena. Vršalica je bila agregatirana na traktoru IMT 539 koji je radio sa 1100 - 1200 o/min radilice.

Temeljni pokazatelj kvalitete rada vršalice je količina sjemena koje se gubi tijekom vršidbe, ne uzimajući u obzir osipanje sjemena prilikom sakupljanja pokošene mase. Veličina gubitaka u vršidbi tritikalea ovisi od tehničkih osobina vršalice, pravilnog reguliranja njenih radnih dijelova, tehničkog stanja i režima rada traktora, umješnosti radnika prilikom ubacivanja mase u vršidbeni uređaj. Pored toga gubici sjemena ovise i od stanja usjeva, sklopa biljaka, sortnih osobina, faze zrelosti, odnosa zrna i slame, vlage, zakorovljenosti, poleglosti usjeva i vremenskih uvjeta.

Kolika će biti visina gubitaka i kvaliteta rada vršalice kombajna ovisi prije svega od mehaničko-fizičkih osobina sjemena pojedinih sorata, vlažnosti sjemena i reguliranja broja okretaja bubnja i zazora između bubnja i podbubnja (Brkić i sur. 1990, Zimmer i sur. 1990, Koprivica i Komarčević 1996, Barać i sur. 2006, Malinović i sur. 2005).

Kontrola kvalitete rada uređaja za vršidbu se izvodi radi utvrđivanja količine ne izdvojenog zrna tj. zrna koje je zaostalo u klasu nakon prolaza kroz uređaj za vršidbu ili čistoga zrna ispalog van vršalice. Gubici vršalice u vršidbe tritikalea prikazani su u tablici 3. Gubici su određivani na slamotresima i na sitima, a prikazani su kao gubici u klasu i gubici u sjemenu.

Analizirajući gubitke vršalice (tablica 3) uočava se da ukupni gubici pri vršidbi pet sorti tritikale iznose od minimalnih 2,45% kod sorte 161 do maksimalnih 7,10% od prinosa kod sorte 165. Jedan od razloga ovakve velike razlike u gubicima može biti i način doziranja mase u vršalicu pri čemu neravnomjernost i razlika u količini ubačene mase može utjecati na sam proces izvršaja. Također i razlika sorata tritikalea u slamnosti može limitirati kapacitet vršalice. Gubici na slamotresu su znatno veći od evidentiranih gubitaka na situ. Za žitne kombajne dozvoljeni maksimalni gubici na slamotresima su 0,50%, na sitima 0,30% i 0,05% na bubnju (Brkić i sur. 1990). U procesu odvajanja zrna od slame i pljeve najopterećeniji dio je prva polovica sita kako su dokazali i zabilježili Simu i Filip (2012), Stoica i sur. (2009) i Voicu i sur. (2009). Mehandžić (2003) navodi da ovisno od sorte pšenice i režima rada vršidbene komore kod laboratorijske vršalice, količina neovršenih klasova se kreće od 1,3-3,6 % kod sorte "Novosadska rana 5", a kod sorte "Pesma" od 4,5-8,6%. Također i istraživanja Tadića i suradnika (1998) ukazuju da o sorti u velikoj mjeri ovisi visina gubitaka i kvaliteta ovršenog zrna. Ukupni gubici kod pšenice sorte Europe 90 iznosili su 1,47% a kod sorte Pobjeda 4,53% uglavnom gubici u neovršenim klasovima. Prema istraživanjima Stacey i sur. (2006) gubici zrna u žetvi tritikalea su se kretali u granicama od 0,08 do 0,5% od prinosa.

Meleg (1991) navodi da režim rada vršalice kombajna mora osigurati kvalitetno izvršenje i čišćenje i da gubici neovršenih klasova budu do 0,5%. Isti autor navodi da lom i oštećenje zrna je maksimalno do 3 %, od čega lom zrna ne smije biti veći od 1%. Iz tablice 4 može se zamjetiti da mehaničkih primjesa i nečistoća u ovršenoj masi ima vrlo malo (do 0,32 %), a pljeve do 1,85 % ovisno o sorti tritikalea. Primjese su činili žetveni ostaci kao što su dijelovi stabljike, lista i klasa. Prema tim podacima može se konstatirati da je vršilica obavila kvalitetno čišćenje zrna bez loma i oštecenja. Prema istraživanjima Shahbazi i sur. (2012) kod tritikale su oštećenja sjemena u odnosu na pšenicu bila veća.

**Tablica 4** Kvaliteta ovršenog sjemena tritikale u %
**Tab. 4** The quality of harvested triticale seed in %

| Sorta<br>Cultivar | 161 | 162 | 164 | 165 | 166 |
|---|---|---|---|---|---|
| Čisto sjeme<br>Pure seed | 96,19 | 93,95 | 93,94 | 97,36 | 98,62 |
| Šturo sjeme<br>Scarce seed | 3,69 | 5,40 | 3,74 | 0,66 | 1,12 |
| Krupne primjese<br>Impurities | 0,00 | 0,18 | 0,32 | 0,13 | 0,11 |
| Pljeva<br>Glumes | 0,12 | 0,47 | 0,00 | 1,85 | 0,15 |
| Ukupno<br>Total | 100 | 100 | 100 | 100 | 100 |

U vršidbi tritikalea sa vršalicom V-08 nije bilo oštećenja sjemena jer je obodna brzina bubnja podešena tako da bude što manja, ali su se gubici kod neovršenih klasova kretali u vrijednostima od 0,49-1,90 % od prinosa što je u granicama koje navodi Mehandžić (2003), Koprivica i sur. (2006), Đokić i sur. (2012, 2013).

Na temelju svega navedenog može se zaključiti da izborom režima rada vršidbene komore i poznavanjem fizičko-mehaničkih osobina sjemena tritikalea, može se osigurati maksimalni izvršaj zrna, minimalna količina neovršenih klasova, a gubici zrna svesti u tolerantne granice.

Primjese, polomljeno i šturo sjeme su nepoželjni u sjemenskoj robi, kao i u sjemenu za preradu, jer otežavaju njegovo čuvanje i čišćenje, a i utječu na kvalitetu dobivenog proizvoda.

Tijekom vršidbe tritikalea uočeni su i određeni nedostaci u funkcioniranju nekih dijelova na vršalici, koji se mogu eliminirati manjim izmjenama u konstrukciji vršalice kako bi se njen rad još više usavršio i bio kvalitetniji. Pravilnim podešavanjem i načinom rada vršalice V-8 može se ostvariti zadovoljavajuća kvaliteta ovršenog sjemena tritikalea s minimalnim gubicima sjemena na slamotresima i sitima.

## ZAHVALA

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# ESTIMATE OF THRESHING QUALITY FOR NEW TRITICALE CULTIVARS

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## SUMMARY

*This paper presents the examined qualitative characteristics of mobile thresher manufacturer„Ernet" from Kikinda, type V-08 for threshing seeds of field and vegetable crops at the experimental fields Institute for forage crops-Kruševac. On small experimental plots threshing is an integral part of the crop after harvesting. The aim of the investigations was practical application and evaluation of the device in certified seed threshing triticale in micro experiments.*

*Ongoing investigations have revealed the losses in seeds threshing straw walkers and sieves that appear in the tailings and spikes in threshed free grain mass. Height loss and quality of harvested seeds depends on the variety, seed moisture at harvest time, the number of revolutions the drum, the clearance between the concave hole size on screens and their purity. Overall losses in working threshing machines ranged from 1.4% to 2.62% % which is less than the loss of seeds on sieves from 0.16% to 0.83% of the yield, and the rest of the losses on the walkers.*

*Threshing quality was determined based on the average sample taken from the purse-bags in which they collected from seed threshers. Later, in the laboratory, broken and scarce seed and other ingredients are dissenting on the average sample separator (Dakota type).*

*Threshing quality was satisfactory because the share of pure seed ranged from 87.9% to 93.5%, a sicly seeds from 5.67% to 10.63% and other impurities from 0.25% to 1.64%.*

***Key words:*** *threshers, triticale, seeds, experimental plots, seed losses, threshing quality.*

42. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

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Pregledni rad
Review paper

# TRENDOVI RAZVOJA MEHANIZACIJE ZA SUŠENJE I SKUPLJANJE KRME U ZBOJEVE

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## SAŽETAK

*Primjena mehanizacije za sušenje i skupljanje krme na polju, kao i gubici hranjivih tvari ovise o metodi konzerviranja stočne hrane. Tretiranje otkosa može predstavljati "usko grlo" u spremanju krme zbog trenda povećanja radnog učinka kosilica, samoutovarnih prikolica, preša i krmnih kombajna. Povećanje radnog zahvata kosilica i sakupljačkih pick-up uređaja je utjecalo i na povećanje radnog zahvata strojeva za rastresanje, okretanje i prigrtanje krme na polju. Rotacijski rastresači-okretači su dosegli radni zahvat od 20,00 m s učinkom i do 20 ha h$^{-1}$. Za spremanje visoko vlažne krme može se izostaviti radna operacija rastresanja i okretanja. Bez obzira na porast broja kosilica s kondicionerom i siliranje krme s visokim sadržajem vode rotacijski rastresači-okretači će i dalje zadržati značaj radi spremanja sjenaže i sijena, kao i zbog vremenskih uvjeta koji ne omogućuju korištenje kondicionera. Rotacijske grablje sa 6 rotora imaju radni zahvat do 19,00 m i učinak do 20 ha h$^{-1}$. Zvjezdaste grablje su i dalje prisutne na tržištu zbog jednostavne konstrukcije i jer im nije potreban pogon od traktora. Razvija se koncepcija strojeva za oblikovanje zboja sa sakupljačkim pick-up uređajem i beskonačnim trakama radnog zahvata iznad 10,00 m. Upitno je u kojoj će mjeri trend u razvoju rotacijskih rastresača-okretača i grablji ići će smjerom daljnjeg povećanja radnog zahvata ili njihovog razvoja kao samokretnih strojeva. Specijalizirani samokretni strojevi bi se koristili u kraćim periodima u godini i pitanje je da li bi se potencijalni kupci odlučivali na takvu investiciju bez obzira na veličinu proizvodnih površina. Trend u razvoju mehanizacije za spremanje krme je: povećanje radnog zahvata i učinka uz što manje gubitke hranjivih tvari uzrokovanih rastresanjem, okretanjem, sakupljanjem i transportom krme.*

***Ključne riječi:*** *tretiranje otkosa, rotacijski rastresač i okretač, rotacijske grablje, zvjezdaste grablje, sušenje krme na polju*

## UVOD

Različite metode konzerviranja krme s obzirom na sadržaj suhe tvari različito utječu na gubitke hranjivih tvari. Sijeno sadrži oko 85% suhe tvari i potrebno je nekoliko dana sušenja u polju do sadržaja vode < 20%. Prije skladištenja sijeno se mora osušiti na 15% do 23% sadržaja vode (Srivastava et al, 2006). Sjenaža ili travna silaža (engl. grass silage) je silirana provenuta trava, travno-djetelinska smjesa i lucerna. U Hrvatskoj se za različite tipove travne silaže uvriježio naziv sjenaža (engl. haylage) (Katalinić et al., 2000). Sadržaj suhe tvari kod kvalitetne travne silaže je od 30% do 40% pri optimalnoj visina košnje između 5 i 7 cm, dok niža visina košnje od 5 cm uzrokuje veće onečišćenje krme s tlom (Niemöller, 2007). Kod višeg reza pokošena krma je položena na višu strn, a ne na tlo i bolje se suši, te strojevi za rastresanje, okretanje i prigrtanje djeluju manje agresivno na krmu koja se i manje onečišćuje tlom (Ligocki, 2003).

U postupku spremanja krme nastaju gubici hranjivih tvari uzrokovani procesima disanja biljnih stanica, prokišnjavanjem, fermentacijom i mehaničkim tretiranjem. Mehanički gubici hranjivih tvari nastaju prilikom košnje i kondicioniranja, sušenja krme na polju rastresanjem i okretanjem, sakupljanjem u zbojeve, zatim sakupljanjem sa samoutovarnom prikolicom, prešom ili krmnim kombajnom. Provenuta biljna masa se mrvi i lišće otpada kao posljedica rada strojeva koji zupcima pri rastresanju, okretanju i prigrtanju otkidaju lišće, pogotovo kada je krma prosušena na manje od 40% sadržaja vode. Drobljenje i otpadanje lišća osobito je izraženo kod djetelina, lucerne i travno-djetelinskih smjesa, jer se lišće u kojem je glavni dio hranjivih tvari suši znatno brže od stabljike.

Direktnim siliranjem neprovenute travne mase može se izostaviti primjena rotacijskih rastresača-okretača. Ušteda je u smanjenoj potrošnji goriva i manje je zbijanje tla, no može se izgubiti više od 10% suhe tvari zbog ocjeđivanja silažnog soka iz silosa. Pri lošim vremenskim uvjetima bolje je direktno siliranje jer odgađanjem košnje gubici hranjivih tvari mogu biti veći. Za siliranje trava visokog sadržaja vode koriste se aditivi - poboljšivači stabilnosti silaže. Vrste bilja s nižim sadržajem šećera, a više proteina manje su pogodne za siliranje, te ih je također potrebno tretirati aditivima u postupku siliranja. Nasuprot direktnog siliranja neprovenute mase, spremanje sijena ima niže troškove, no pri tom postupku mogu nastati veliki mehanički gubici hranjivih tvari.

Kod sušenja krme na polju gubici suhe tvari za 24 h ili manje, uobičajeno iznose od 10 do 30 g $kg^{-1}$ travne mase, odnosno od 1 do 3%, dok kod duljeg sušenja mogu iznositi i do 130 g $kg^{-1}$ svježe travne mase, odnosno i do 13%. Gubici hranjivih tvari pri rastresanju i okretanju provenute krme su od 0,5 do 3,0% suhe tvari za trave, dok kod lucerne mogu biti višestruko veći, i do 6 puta (Vranić, 2012).

U povoljnim uvjetima gubitak hranjivih tvari pri spremanju sijena lucerne može biti do 19%, a u nepovoljnim do 63%, no najčešći raspon gubitaka od 5 do 40% nastaje mrvljenjem i otpadanjem lišća (Zimmer et al., 2009). U postupku sušenja krme smanjuje se probavljivost krme, sadržaj vitamina C, a predugim sušenjem i sadržaj beta-karoten.

Gubici hranjivih tvari u polju ovise o metodi konzerviranja, vremenskim prilikama, biljnoj vrsti i njenoj fenološkoj zrelosti u trenutku košnje, te o strojevima za tretiranje mase. Za postizanje željenog sadržaja suhe tvari u krmi u što kraće vrijeme, a uz što manje gubitke hranjivih tvari i onečišćenja tlom, potrebno je koristiti strojeve velikog radnog učinka koji se u radu dobro prilagođuju konfiguraciji terena.

*Rastresanje i okretanje krme na polju*

Rastresanjem i okretanjem ubrzava se sušenja biljne mase na polju. Okretanjem se preokreće donji sloj krme, bliži tlu, te ga se izlaže djelovanju sunčeve topline i cirkulaciji zraka. Rotacijski rastresač-okretač ima dva ili više rotora sa zupcima koji se u parovima okreću nasuprotno, i pri tom tretiraju biljnu masu. Zavisno kutu nagiba rotora, stroj rastresa ili okreće biljnu masu. Rotor podupire kotač s pneumatikom, a prilagođavanje neravninama terena omogućuje zglobni okvir. Prednosti rotacijskog rastresača-okretača su velika radna brzina, veliki radni zahvat, dobra prilagodba konfiguraciji terena, te dobar radni učinak. Nedostaci su mogući gubici krme zbog otkidanja sitnih dijelova lišća (mehanički gubici hranjivih tvari), te što kod već prosušene mase treba smanjiti broj okreta rotora i mogućnost otkidanja zubaca pri nailasku na kamen ili slično.

Povećava se udio rastresača-okretača većih radnih zahvata, iznad 8,00 m. Rotacijski ratresači-okretači radnog zahvata iznad 15,00 m nisu pogodni za priključivanje na trozglobnu poteznicu, te su vučeni. Tvrtka Kuhn proizvodi rastresač-okretač radnog zahvata od 17,20 m; model GF 17002 GII (tablica 1) čiji radni učinak može biti i do 15 ha $h^{-1}$. Desna i lijeva sekcija su na krajevima spojene remenom s vučnim rudom radi ublažavanja naprezanja glavnog okvira s rotorima i osiguravanja stabilnosti u radu.

**Sl. 1** Rotacijski rastresač-okretač Krone KWT 2000, radni zahvat je 19,60 m
**Fig. 1** Rotary tedder Krone KWT 2000, working width is 19, 60 m

Proizvođač Krone je razvio vučene rastresače-okretače koji za pogon trebaju snagu od 18 kW za radni zahvata od 5,50 m, a 37 kW za radni zahvat od 8,80 m. Modeli Krone-a do 11,00 m radnog zahvata i 10 rotora se mogu priključivati na stražnju trozglobnu poteznicu. Za postizanje visokog učinka bitno je usklađivanje radnog zahvata kosilice i rotacijskog rastresača-okretača. Razmak između otkosa mora se podudarati s razmakom između parova rotora, tako dva rotora ravnomjerno rastresaju otkos bez gaženja kotačima traktora. Veliki radni zahvat od 19,60 m ima model Krone KWT 2000 i može ostvariti učinak od 18 do 20 ha $h^{-1}$ (sl. 1). Tvrtka Lely je najavila i predstavila rotacijski rastresač-okretač Lotus 2010 radnog zahvata većeg od 20,00 m.

Tvrtka Claas proizvodi modele Volto 1100 i 1100 T radnog zahvata od 10,70 m, s Max spread koncepcijom (zupci su postavljeni tangencijalno na rotor), što omogućuje šire i kvalitetnije rastresanje, viši učinak i nježnije tretiranje krme (sl. 2). Ruke rotora na kojem su pričvršćeni zupci su na krajevima zakrivljene pod kutom od 29.3°. Proizvođač Pöttinger za rastresače-okretače modele Hit koristi rotore sa zakrivljenim rukama, također radi boljeg rastresanja krme. Tvrtka Lely je za model Lotus razvila specijalno zakrivljene zupce prema unatrag poput kuke (sl. 3a) što im omogućuje veću savitljivost, veći nagib rotora pri okretanju krme i kvalitetno tretiranje krme bez obzira na promjer rotora (Wiedermann, 2010). Neki proizvođači ugrađuju rotore malog promjera koji osiguravaju vrlo dobru kvalitetu rastresanja i okretanja, te do 33% brže sušenje (Rath-Kampe, 2005), nakon trećeg prohoda proces sušenja je učinkovitiji, a što je bitno kod spremanja sijena (Berning, 2008).

U transportu rotacijskih rastresača-okretača okvir s rotorima se preklapa i podiže ili sklapa prema nazad da bi se postigla dozvoljena transportna širina na cestama. Priključci većeg radnog zahvata imaju dodatne transportne kotače koji su u funkciji samo tijekom transporta po cestama.

**Sl. 2** Rotacijski rastresač-okretač Claas Volto 1100/1100T s Max spread koncepcijom tangencijalno postavljenih zubaca
**Fig. 2** Rotary tedder Volto 1100/1100 T, Max spread concept with the tangential linkage of the tines

Bez obzira na sve veći udio kosilica s kondicionerom (uređajem za mehaničko tretiranje krme) na tržištu, rotacijski rastresači-okretači će i dalje zadržati značaj u spremanju sjenaže i sijena, kao i zbog vremenskih uvjeta koji ne omogućuju korištenje kondicionera (Rath-Kampe, 2005).

**Tablica 1** Rotacijski rastresači-okretači, rotacijske i zvjezdaste grablje velikog radnog zahvata
**Table 1** Rotary tedders and rakes, finger wheel rakes with large working widths

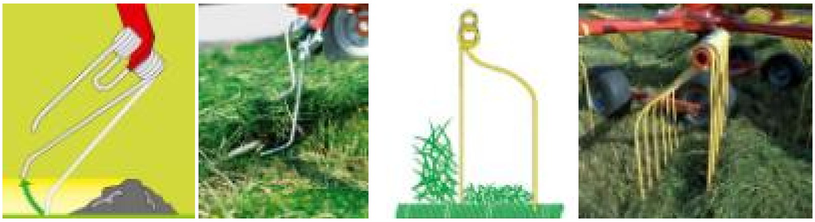
| Proizvođač/model Manufacturer /model | | Radni zahvat Working width (m) | Broj rotora No. of rotors | Širina zboja Swath width (m) | Potrebna snaga Power required (kW/KS) | Masa Weight (kg) |
|---|---|---|---|---|---|---|
| *Rotacijski rastresač-okretač:* | | | | | | |
| Claas | Volto 1320T | 13,00 | 10 | - | * | 2400 |
| Kuhn | GF 17002 GII | 17,20 | 16 | - | 73/100 | 3140 |
| Lely | Lotus 1500 Profi | 15,00 | 12 | - | 73/100 | 4300 |
| Pöttinger | Hit 12.4T | 12,70 | 12 | - | * | 2300 |
| *Rotacijske grablje:* | | | | | | |
| Class | Liner 4000 | 12,20-15,00 | 4 | 1,50-2,60 | * | 5850 |
| Krone | Swadro 2000 | 10,00-19,00 | 6 | 1,60-2,80 | 96/130 | 9400 |
| Pöttinger | Top 1252 C | 8,00-12,50 | 4 | 1,20-2,00 | 66/90 | 5950 |
| *Zvjezdaste grablje:* | | | | | | |
| John Deere | WR1218C<br>WR3419 | 11,00<br>10,50 | 18<br>19 | 1,00-1,50<br>do 2,40 | *<br>30/40 | 2268<br>2177 |
| Kuhn | SR 616 GII | 9,50 | 16 | 0,91-1,83 | 29/40 | 2165 |
| Tonutti | Dominator-Millenium V-20 Pro | 11,70 | 20 | 0,90-1,80 | 44/60 | 3035 |

*podatak nije naveden u prospektnim materijalima i na web stranicama proizvođača
no data in brochures or web pages

*Skupljane krme na polju - prigrtanje*

Spremamo li krmu bilo s visokim ili niskim sadržajem suhe tvari skupljanje u zbojeve ili prigrtanja moramo obaviti. Krma se prigrće u zbojeve zbog skupljanja sa samoutovarnim prikolicama, prešama i silažnim kombajnima.

Optimalan rad strojeva za skupljanje krme s polja zavisi o karakteristikama zbojeva, te stoga zboj ne smije biti zbijen, neujednačen ili/i s nedovoljno mase po dužnom metru. Pravilan zboj je pravokutnog poprečnog presjeka i za krmne kombajne je širok do 3,00 m, a za samoutovarne prikolice i preše je prilagođen unutarnjem razmaku kotača traktora (oko 120 cm). Radni zahvat sakupljačkog pick-up uređaja većine krmnih kombajna je 3,00 m; proizvođači Claas, Krone i New Holland nude i radni zahvat od 3,80 m, a John Deere i od 4,50 m. Zbojevi optimalne visine i širine, te ravnomjerne gustoće omogućuju povećani učinak samoutovarnih prikolica i silažnih prikolica i do 20% prema navodima tvrtke Pöttinger.



a b

**Sl. 3** Rotacijski rastresači-okretači tvrtke Lely sa zakrivljenim opružnim zupcima (lijevo - a) i rotacijske grablje tvrtke Ziegler sa zupcima u dva reda (desno - b)
**Fig. 3** Lely rotary tedders with hook tines which point backwards (left – a) and Ziegler rotary rake with two rows of tines (right – b)

**Sl. 4** Krone Swadro 2000 rotacijske grablje sa šest rotora, radnog zahvata podesivog od 10,00 do 19,00 m
**Fig. 4** Rotary rake Krone Swadro 2000, with six rotors and adjustable working width from 10,00 to 19,00 m

Usporedno ispitivanje 9 modela grablji različitih proizvođača pokazuje da grablje s manjom brzinom vrtnje rotora oblikuju uredniji zboj. Ustanovljeno je povoljno područje obodne brzine rotora od 5 do 8 m $s^{-1}$ uz gubitke od 1,8 do 3,8 % (Niemöller, 2008). Rotacijske grablje su u izvedbama od jednog do šest rotora. U intenzivnijoj poljoprivrednoj proizvodnji prevladavaju grablje s dva rotora, no neki profesionalni davatelji usluga rade isključivo s grabljama s četiri ili šest rotora. Radni zahvat grablji s četiri rotora od 15,00 m je dovoljan za visok učinak krmnih kombajna novije generacije, čime se izbjegavaju „uska grla" u proizvodnji. Proizvođač Krone je razvio koncepciju grablji sa šest rotora, a odustali su od planirane koncepcije samokretnog rastresača-okretača zbog ne isplativosti. Krone Swadro 2000 su vučene rotacijske grablje sa šest rotora promjenljivog radnog zahvata od 10,00 do 19,00 m i radnog učinka do 20 ha $h^{-1}$ (sl. 4). Zbog širokog zboja s velikom količinom biljne mase prikladne su kao "prethodnica" krmnom kombajnu sa sakupljačkim pick-up uređajem od barem 3,00 m radnog zahvata. Rotore i transportni okvir podupiru široki pneumatici radi zaštite travnjaka.

Rotacijske grablje Pöttinger TOP 1252 su s dvojnim pogonom, prednja dva rotora imaju hidrostatički prijenos snage, a stražnja dva mehanički. Ovo omogućuje zakretanje prednjih rotora prema unutra i dobivanje transportne visine od 3,99 m bez demontiranja ruku sa zupcima. Korištenjem globalnog sustava pozicioniranja (GPS-a) u radu sa rotacijskim grabljama izbjegava se preklapanja prohoda, nepotrebna prelaženja preko polja i preciznije okretanja na uvratinama.

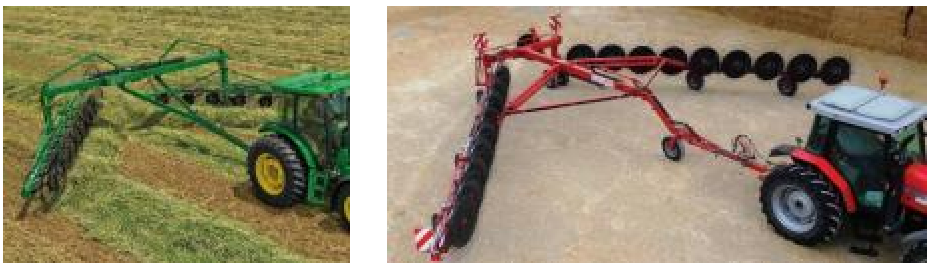
Tvrtka Ziegler je razvila grablje s opružnim zupcima u dva reda (dlz – Dauertest, 2007). Prednji red kraćih zubaca zahvaća veći dio krme ne zahvaćajući tlo, a stražnji red fleksibilnijih zubaca zahvaća preostali dio krme (sl. 3b). Opružni zupci u dva reda omogućuju preciznije prigrtanje krme uz smanjeno onečišćenje, te povećanje radne brzine za 30 do 50% (Niemöller, 2008).

**Sl. 5** Kuhn MergeMaxx 900, trakaste grablje, radni zahvat su 9,10 i 10,50 m (lijevo) i Roc RT 1220, radni zahvat je 12,20 m (desno)
**Fig. 5** Belt merger Kuhn MergeMaxx 900, working widths are 9,10 and 10,50 m (lrft) and Roc RT 1220, working width is 12,20 m (right)

Tvrtka Kuhn proizvodi trakaste grablje MergeMaxx 900 (sl. 5), gdje se krma podiže s pick-up uređajem i polaže na beskonačne trake, a zboj se oblikuje sa lijeve ili/i desne strane ili/i u sredini. Moguće je oblikovati samo jedan zboj (lijevi ili desni ili središnji) ili dva zboja u kombinacijama (sl. 6). Radni zahvat stroja i pick-up uređaja je 9,10 m pri oblikovanju središnjeg zboja, a 10,50 m pri oblikovanju zboja sa strane, jer je uračunata i širina zboja. Za pogon pick-up uređaja i beskonačne trake koristi se hidostatički prijenos snage i širina zboja može biti od 1,80 do 2,30 m. Razlog za primjenu ove koncepcije je dobivanje čišće krma s manjim mehaničkim gubicima lišća, što je izuzetno značajno pri spremanju lucerne čije je lišće nutricionistički vrijedno. Također, smanjeno onečišćenje krme umanjuje štetne aktivnosti bakterija i omogućuje povoljniji proces siliranja. Prema navodu proizvođača značajno je umanjeno prisustvo kamenja u krmi. Za pogon je potrebna minimalna snaga traktora od 103 kW, budući je masa stroja 7.058 kg. Tvrtka Roc je također razvila trakaste grablje, model RT 1220 radnog zahvata od 12,20 m računajući i širinu zboja, odnosno 10,80 m je radni zahvat samog pick-up uređaja (sl. 5). Stroj može oblikovati zboj sa desne ili/i lijeve strane i za pogon je potrebna traktor snage od najmanje 82 kW.

Zvjezdaste (sunce) grablje su i dalje prisutne na tržištu, prednost im je što su jednostavne konstrukcije i ne treba im pogon od traktora preko priključnog vratila. Cjenovno su konkurentne i njihov „preporod“ će ovisiti o smanjivanju nedostataka. Nedostaci zvjezdastih grablji su ”sklonost” onečišćenja krme zemljom, prosušena biljna masa oblikuje grude i klupka, te lošija prilagodba neravninama terena u odnosu na druge tipove strojeve za prigrtanje krme u zbojeve. Prednosti zvjezdastih grablji su velika radna brzina, nježno tretiranje krme, jednostavna konstrukcija kojoj nije potreban mehanički pogon i može se koristiti s traktorom manje snage.

**Sl. 6** Kuhn MergeMaxx 900 trakaste grablje, tri kombinacije u oblikovanju dva zboja
**Fig. 6** Belt merger Kuhn MergeMaxx 900, three different delivery modes with two swaths



**Sl. 7** Zvjezdaste grablje John Deere WR3419, radni zahvat je 10,50 m (lijevo) i Tonutti Dominator Millenium V-20 Pro, radni zahvat je 11,70 m (desno)
**Fig. 7** Finger wheel rakes John Deere WR3419. working width is 10,50 m (left) and Tonutti Dominator Millenium V-20 Pro, working width is 11,70 m (right)

Tvrtka Tonutti proizvodi zvjezdaste grablje Dominator Millenium V-20 Pro radnog zahvata od 11,70 m s 20 zvjezdastih kotača (sl. 7). Ovakav tip zvjezdastih grablji može konkurirati rotacijskim grabljama, no kod tretiranja velike količine duge krme može doći do oblikovanja klupka i gruda (Wiedermann, 2010). Tvrtka Elho proizvodi grablje V-TWIN VT750 (sl. 8), radnog zahvata od 4,50 do 7,50 m i širine zboja od 1,00 do 1,50 m. Stroj se sastoji od dviju vodoravnih grablji s 336 zubaca i pogoni se hidrostatičkim prijenosom snage, a mase mu je 2.150 kg. Krma je nježno tretirana podizanjem s brojnim zupcima, čišća je i nema oblikovanja klupka i gruda, a zboj je prozračan. Model Elho V-Twin VT600 Flex (sl. 8) ima radni zahvat od 6,00 m s 240 zubaca, širine zboja je od 1,20 do 1,30 m i može se priključivati s prednje strane traktora s prešom i ovijačem bala. Takav agregat omogućuje istovremeno prigrtanje, prešanje i ovijanje bala u jednom prohodu. Grablje se mogu priključivati i standardno sa stražnje strane, širina zboja je od 1,20 do 1,30 m i masa stroja je 860 kg.

**Sl. 8** Elho grablje V-TWIN VT750 radnog zahvata od 4,50 do 7,50 m (lijevo) i V-Twin VT600 Flex radnog zahvata od 6,00 m (desno)
**Fig. 8** Elho swathers V-TWIN VT750, adjustable working width from 4,50 to 7,50 m (left) and V-Twin VT600 Flex, working width is 6,00 m (right)

## ZAKLJUČAK

Sušenjem krme u polju povećava se sadržaj suhe tvari ali i gubici hranjivih tvari, dok se siliranjem krme s visokim sadržajem vode smanjuju gubici hranjivih tvari u polju, ali se povećavaju u silosu ocjeđivanjem silažnog soka. Siliranje visoko vlažne krme omogućuje izostavljanje rastresanja i okretanja, te je manji broj prohoda sa strojevima, manji utrošak goriva, manje onečišćenje krme i manje zbijanje tla. Bez obzira na sve veći udio kosilica s kondicionerom na tržištu, rotacijski rastresači-okretači će i dalje zadržati značaj, pogotovo zbog vremenskih uvjeta koji ne omogućuju uvijek korištenje kondicionera i radi spremanja sjenaže i sijena.

Povećanje radnog učinka kosilica, samoutovarnih prikolica, preša i krmnih kombajna je utjecalo i na povećanje radnog zahvata strojeva za sušenje i skupljanje krme u zbojeve. Radni zahvat rotacijskog rastresača-okretača je dosegnuo 20,00 m, a rotacijskih grablji sa šest rotora i do 19,00 m, učinak im može biti i do 20 ha $h^{-1}$.

Radi postizanja boljeg rastresanja i bržeg sušenja biljne mase izrađuju se rotacijski rastresači-okretači s manjim promjerom rotora. Kod spremanja travne silaže (sjenaže) dovoljno je nakon košnje krmu tretirati u dva prohoda da bi se postigao željeni sadržaj suhe tvari. Nakon trećeg prohoda s rotorima manjeg promjera proces sušenja je učinkovitiji, a što je bitno kod spremanja sijena.

Proizvođači rotacijskih rastresača-okretača zupce postavljaju tangencijalno na rotor ili izrađuju specijalno zakrivljene zupce radi kvalitetnijeg tretiranja krme. Za bolje prigrtanje krme razvijena je koncepcija rotacijskih grablji s opružnim zupcima u dva reda, što omogućuje manje onečišćenje krme tlom i povećanje radne brzine za 30 do 50%.

Radi smanjivanja gubitaka biljne mase na polju posvećuje se dodatna pažnja prilagođavanju rotora grablji i zglobnog vratila (kardana) neravninama terena. Bitno je dobro podešavanje strojeva za prigrtanje da bi se dobio što pravilniji oblik zboja i time bolje uskladio rad sa samoutovarnim prikolicama, prešama i krmnim kombajnom.

Razvijaju su i drugačije koncepcije strojeva za skupljanja krme u zbojeve, sa sakupljačkim pick-up uređajem i beskonačnim trakama. Krma je čišća i s manjim udjelom kamenja, te su mehanički gubici u otkidanju lišća manji što je pogotovo značajno za lucernu.

Zvjezdaste grablje i dalje imaju značaj na tržištu jer su cjenovno konkurentne zbog jednostavne konstrukcije i nije im potreban pogon od traktora, izrađuju se modeli s radnim zahvatom iznad 10,00 m.

Upitno je u kojoj će mjeri trend u razvoju rotacijskih rastresača – okretača i grablji ići u smjeru daljnjeg povećanja radnog zahvata ili njihovog razvoja kao samokretnih strojeva. Takvi specijalizirani samokretni strojevi bi se koristili u kraćim periodima u godini i pitanje je da li bi se potencijalni kupci odlučivali na takvu investiciju bez obzira i na povećanje proizvodnih površina. Neki proizvođači smatraju da povećanje radnog zahvata rotacijskih grablji sa četiri na šest rotora nije isplativo jer se malo povećava radni zahvat, a za skupljanje tako velikog zboja sa pick-up uređajem je potreban krmni kombajn velike snage motora.

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# THE TRENDS IN THE DEVELOPMENT OF SWATH TREATMENT MACHINERY

GORAN FABIJANIĆ, IGOR KOVAČEV, KREŠIMIR ČOPEC

*Methods of preserving forage crops determine the use of swath treatment machinery for field wilting or direct-cut along with dry matter losses of forage. Forage treatment may represent a bottleneck in the mowing and collection chain due to the trend of increasing working efficiencies of mowers, loader wagons, balers and forage harvesters. For this reason manufacturers offer swath treatment machinery which have a larger working width. The rotary tedders reach a working width of 20,00 m and area capacity of up to 20 ha $h^{-1}$. Ensilage forages with high moisture content levels can omit the working operation with rotary tedder. Regardless of the larger number of mowers with conditioners the rotary tedders will keep its firm place on the market for haylage or field-cured hay and because the weather conditions do not always allow conditioners to be used for mowing. The six-rotor center delivery rakes working at widths of up to 19,00 m and area capacity of up to 20 ha $h^{-1}$. The star-wheel swather is still present in the market, its advantages are in its simple design and the fact that no drive units are needed. There are new swather concepts in the form of a belt swather with pickups and working width greater than 10,00 m. Whether future trends are going to favour ever larger working widths or even self-propelled machines is yet undetermined. Specialized self-propelled machines would be used for short periods of the year and the question is whether the potential buyers would decide on such an investment, regardless of the size of the production area. The trends in the development of machinery for forage harvesting are: larger working widths, higher working efficiency, soil protection with less losses of nutrients caused by forage treatment (tedding, spreading, side raking and transporting).*

**Key words:** *swath treatment, rotary tedder, rotary rake, finger wheel rake, field drying forage*

42. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

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# EVALUATION OF VACUUM REGULATION IN A MECHANICAL MILKING MACHINE BY THE MEANS OF A VFD CONTROLLED VACUUM PUMP

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**SUMMARY**

*In order to maintain the stable vacuum needed for mechanical milking, air must be removed from the system at the same rate at which it enters the system through the pulsators, claws, leaks, unit fall-off and other equipments (such as milk meters, when present). Conventional vacuum control is accomplished by using a vacuum pump, sized for the maximum air flow into the milking system, running at full speed. The difference between the pump capacity and the actual flow of air entering the system is compensated by allowing air to enter the system through a vacuum regulator.*

*In this paper a variable frequency driver (VFD) is used in order to drive the vacuum pump at a controlled speed, so that the air removed equals the air entering the milking system; in this case no conventional controller or regulator is needed during milking. The VFD is controlled by the computer using a virtual instrument in order to emulate a PID regulator. The VFD technology is able to adjust the rate of air removal from the milking system, by changing the speed of the vacuum pump motor. This technology for controlling vacuum in a milking system allows a dramatic reduction in energy use, while still producing equivalent vacuum stability.*

*The tests aimed to evaluate the vacuum regulator characteristics and vacuum stability. A statistical analysis of the experimental results was performed and it showed that there was a significant difference between the experimental results obtained for the two methods of vacuum regulation (with vacuum regulator and VFD controller respectively). The experimental results proved that the used of the VFD controller led to a higher vacuum stability in terms of the difference between the set vacuum value and the achieved values.*

***Key words:*** *Variable frequency drive, milking equipment, vacuum stability.*

## INTRODUCTION

Mechanical milking is achieved due to the vacuum applied to the teat, by the means of a teatcup. In order to limit the development of congestion and edema and provide relief to the teat from the milking vacuum, the pulsation principle is used [3]. As shown in Figure 1, vacuum is applied to the teat through the vacuum chamber (7) created inside the liner (2). The collapse of the teatcup liner (2) beneath the teat is achieved when air at atmospheric pressure is admitted into the pulsation chamber (5) of the teatcup (fig. 1a); the liner opens, allowing the extraction of milk, when vacuum is applied to the pulsation chamber (fig. 1b).

Figure 2 presents a typical pulsation cycle and its phases, defined according to ISO 5707: 2007 standard; a is the increasing vacuum phase, b is the maximum vacuum phase, c is the decreasing vacuum phase and d is the minimum vacuum phase. The pulsation ratio is defined as the ratio between the duration of the a + b phases and the duration of the entire cycle (a + b + c + d).

Figure 3 presents the layout of a typical mechanical milking system [10], which contains a vacuum pump (2), driven by an electric motor (1); the vacuum pump creates vacuum into the vacuum pipeline (7), which is used for both the milk extraction and the pulsation of the liner. The vacuum level is regulated by the means of the vacuum regulator (4), placed downstream of the receiver. The vacuum pump is permanently operated at full capacity, providing a flow of air greater than the one entering the system through pulsators, claws, leaks. The difference between the air extracted by the pump and the necessary flow of air during milk extraction is compensated by the vacuum regulator, which opens to allow supplementary air to enter into the system when working vacuum increases above the desired level and closes when vacuum decreases below the necessary value; according to the ISO 5707:2007 standard the working vacuum should be maintained within ±2 kPa of the nominal vacuum.

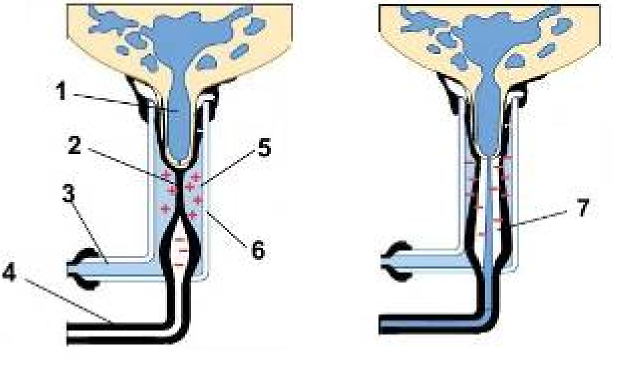


**Figure 1** The principle of milk extraction [9]; a-massage; b-milk extraction; 1-teat: 2-liner; 3-short pulse tube; 4-short milk tube; 5-pulsation chamber; 6-shell; 7-vacuum chamber

The importance of vacuum level and stability is due to the fact that cows have a biological limit for a positive reaction to vacuum and exceeding it may lead to damage of the teat tissue or slipping of milking clusters off the teat, resulting in an extended milking time and in improper milking; vacuum fluctuations generated within the milking cluster may lead to direct bacterial penetration, thus causing mastitis [5].

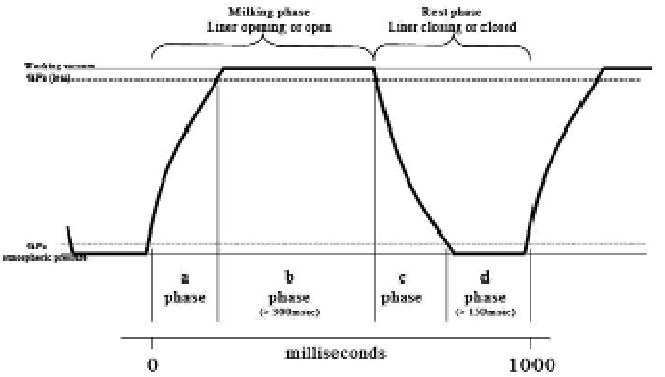


**Figure 2** The pulsation cycle

In order to make the vacuum pump draw only the amount of air needed to maintain the desired vacuum level the speed of the pump should be variable (as air flow depends on the pump speed); in this case no conventional regulator is needed to maintain the imposed vacuum during milking. The electric motor of vacuum pump is controlled by the means of a variable frequency driver (VFD).

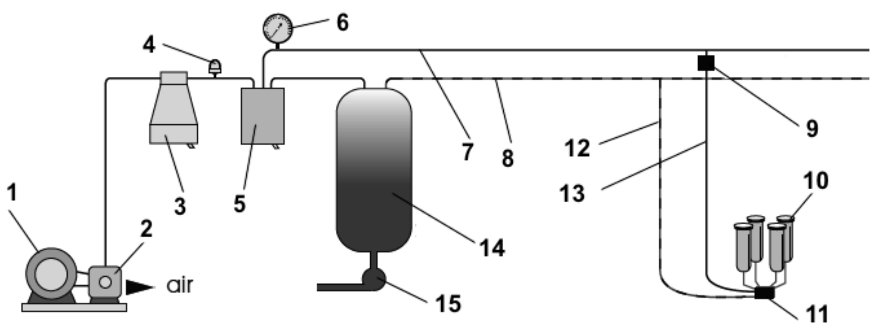


**Figure 3** Layout of a mechanical milking system; 1-electric motor; 2-vacuum pump; 3-interceptor; 4-vacuum regulator; 5-sanitary trap; 6-vacuum gauge; 7-permanent vacuum pipeline; 8-milk pipeline; 9-pulsator; 10-teatcup assembly; 11-claw; 12-long milk tube; 13-long pulse tube; 14-receiver; 15-milk pump

Figure 4 presents the basic diagram of milking system in which the variation of the pump speed allows the adjustment of the vacuum level; the VFD (8) senses the vacuum level in the permanent vacuum pipeline (1) and adjusts the speed of the electric motor (7) in order to keep the vacuum level constant. This solution has the potential to significantly reduce the energy consumption of the milking system; in a study conducted by Pazzona *et al.* [6] energy savings between 24 and 87% were reported. In the same paper the results of the falloff tests showed no significant differences between the systems controlled by conventional regulators and the ones controlled through the variation of the vacuum pump speed. It was conclude that, if the VFD controller is adjusted properly, it can meet or even exceed the vacuum stability recorded by the systems equipped with conventional regulators [6, 7], the target being a receiver vacuum within ±2 kPa of the vacuum set point during normal milking [11].

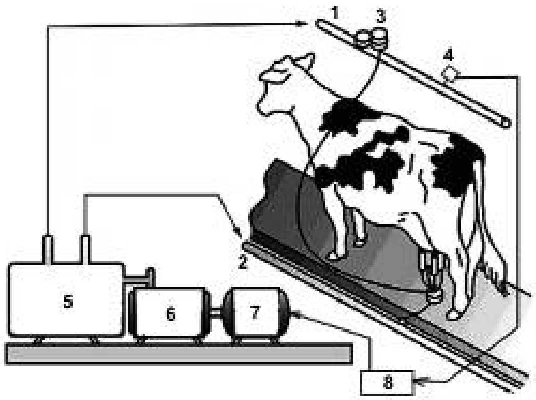


**Figure 4** Basic layout of a milking system with a VFD controlled vacuum pump;
1-permanent vacuum pipeline; 2-milk pipeline; 3-pulsator; 4-pressure sensor; 5-receiver; 6-vacuum pump; 7-electric motor; 8-VFD

The purpose of this study was to perform a comparative analysis between the two methods for vacuum regulation (the vacuum regulator method and the VFD controlled vacuum pump method), in a mechanical bucket milking system, in order to decide whether the use of a variable speed vacuum pump has the potential to improve vacuum stability, without adversely affecting the specific characteristics of the pulsation cycle (pulsation rate and ratio, duration of the pulsation phases). A closed loop PID (Proportional-Integral-Derivative) regulation system was developed in order to control the speed of the vacuum pump. The regulation system was emulated by the means of a NI USB 6009 data aquision board and the LabVIEW 7.1 control toolkit.

## MATERIALS AND METHODS

In this study a bucket milking machine was used; figure 5 presents a diagram of the milking system. The original system was equipped with a valve and spring type of vacuum regulator, placed on the pipeline connecting the interceptor (I) to the bucket (B); the electric motor (M) driving the vacuum pump (VP) was connected to the three phase power grid. A BRK pneumatic pulsator (P) was used to achieve the liner pulsation; the machine was equipped with four Boumatic R-1CX type teatcups. Artificial teats, manufactured according to the ISO 6690:2007 standard, were inserted into the teatcups. The vacuum pump provided an airflow of $4.38 \cdot 10^{-3}$ $m^3s^{-1}$ at a speed of 1350 $min^{-1}$.

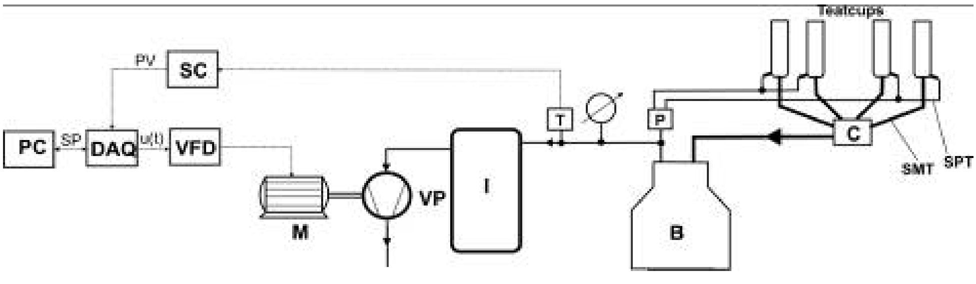


**Figure 5** Schematics of the tested milking system; DAQ-data aquision board; SC-signal conditioning unit; I-interceptor; VP-vacuum pump; M-electric motor; B-bucket; P-pulsator; SMT-short milk tube; SPT-short pulse tube; T-absolute pressure transducer; C-claw

During the tests a Smartec SPD015AAsil absolute pressure sensor (T, fig. 5) was used to monitor the vacuum in the permanent vacuum line, in order to provide the signal for the VFD controller. The electric signal from the pressure sensor was fed to the data acquisition (DAQ) board by the means of a signal conditioning unit (SC). The data aquision board was USB 6009 (National Instruments), with a sample rate of 48 kHz/s, four differential analog input channels and two analog output channels.

Based on the software running on the computer the entire system (DAQ board, VFD controller and computer) acts as a PID regulator for the vacuum level, for which the set point (SP) is the desired vacuum level and the process variable (PV) is the actual vacuum level in the vacuum pipeline. The controller calculates the output signal u(t), which is then used to command the VFD and adjust the running speed of the electric motor and vacuum pump. The PID controller output is given by the relation [1]:

$$u(t) = K_p \cdot \left[ e(t) + \frac{1}{T_i} \cdot \int e(t) \cdot dt + T_d \cdot \frac{de(t)}{dt} \right],$$

where the error signal is $e(t) = SP-PV$; $K_P$ is the proportional gain, $T_I$ is the integral time and $T_d$ is the derivative time.

The PID controller was built with the help of the PID control toolbox from LabVIEW 7.1 and a virtual instrument was created in order to provide the control signal to the VFD; figure 6 presents the control panel of the virtual instrument and figure 7 presents its block diagram.

The control panel (fig. 6) allowed the adjustment of the desired vacuum level (vacuum set point) and of the PID gains: proportional gain, integral time [min] and derivative time [min].

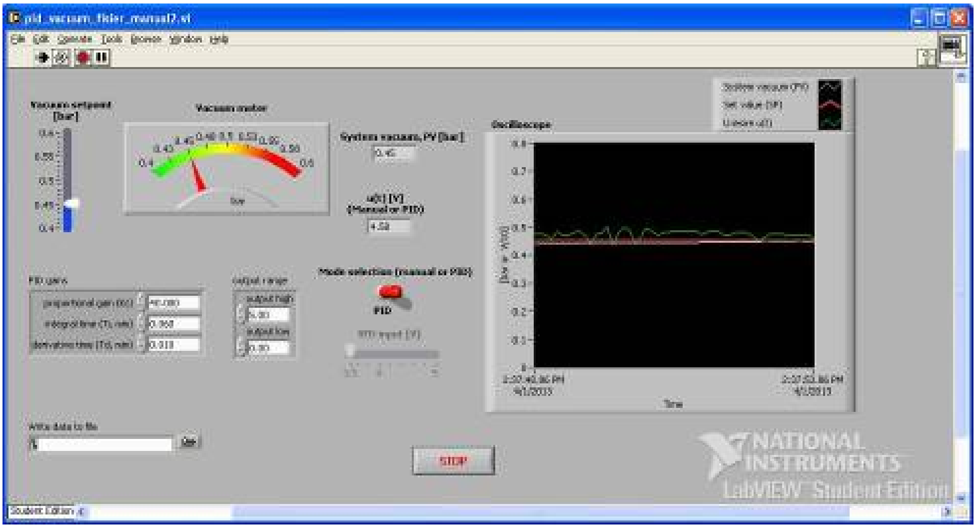


**Figure 6** The control panel of the virtual instrument

The output range of the PID controller was 0…5V, due to the characteristics of the data aquision board; an additional signal conditioning unit (not shown in fig. 5) was built to obtain the 0…10V range imposed by the variable frequency drive.

An oscilloscope display allowed the visualization of the vacuum set point, system vacuum and output signal of the PID controller.

The variable frequency drive unit was VFD 007M43B (0.7 kW maximum power of the electric motor); the output frequency range was set to 0...60 Hz for a range of the analog comand signal comprised between 0 and 10V [15].

In order to establish the working parameters of the milking process (pulsation rate and ratio, duration of the phases), two additional Smartec SPD015Aasil absolute pressure sensors (not shown on the diagram in fig. 5) were attached to the short pulse tube (SPT, fig. 5) and short milk tube (SMT). The pulsation ratio was defined according to the specifications of the ISO 5707:2007 standard.

The milking system was tested in two phases: the first phase aimed to tune the values of the PID gains ($K_P$, $T_I$ and $T_D$); the purpose of the second phase was to compare the two methods of vacuum regulation (classic regulator and adjustment of the pump speed).

For the first phase the Ziegler-Nichols tuning rules for the frequency response method were used; the disturbance was induced by changing the set point. For the second phase the permanent vacuum values were recorded, in a series of dry tests, performed for three vacuum levels: 0.35 bar, 0.40 bar and 0.45 bar (35, 40 and 45 kPa). In order to asses vacuum stability the results were compared, using the average value of the vacuum, the standard deviation and the standard error of the mean. Three tests were performed for each vacuum level and vacuum regulation method and the mean, standard error and standard error of the mean were calculated.

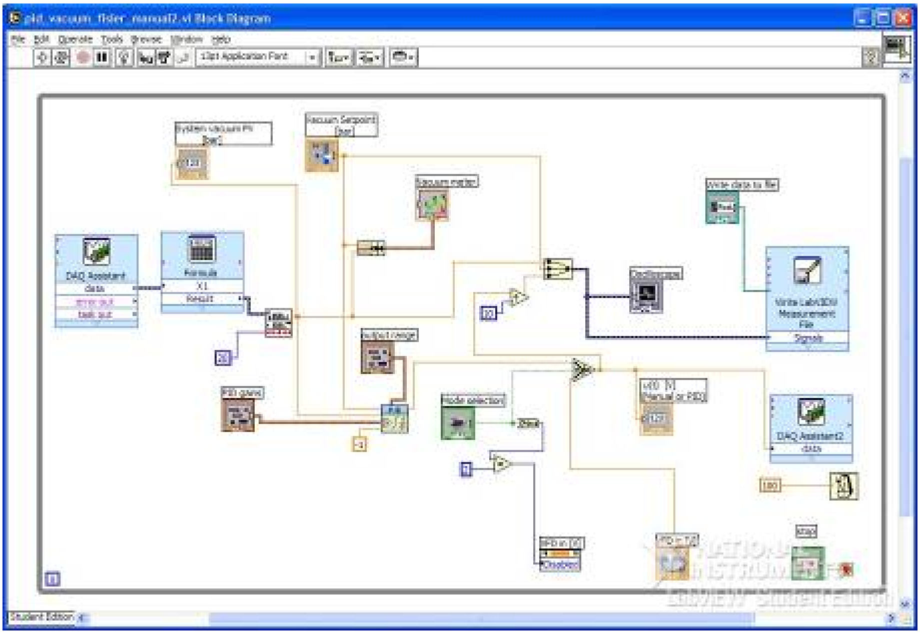

**Figure 7** The block diagram of the virtual instrument

In order to evaluate whether there was a significant difference between the two pairs of data (the permanent vacuum levels recorded for two regulation methods) a statistical analysis was performed. The Kolmogorov Smirnov test proved that data distribution was not normal; as a result, the Man Whitney rank sum test was performed; this test is a substitute for the two-sample t test when the samples are not normally-distributed populations [4]. The analysis was performed with a demo version of the SigmaPlot 12.5 software.

## RESULTS AND DISCUSSION

### *Tuning of the PID Controller*

In order to tune the PID controller using the Ziegler-Nichols tuning rules for the frequency response method, the integral time was set at 10000 and the derivative time was set to 0; the proportional gain was adjusted until the oscillations were sustained and had a constant amplitude. Finally, the critical gain was $K_c = 68$. The critical period $T_c$ was measured using the recorded vacuum signal (fig. 8); finally, it was established that the critical period was $T_c = 7.53\pm0.46$ s. The PID gains were then calculated using the formula presented in Table 1 [1].

For the case of the PID controller, the following gains were obtained: $K_P = 40$, $T_i = 4.76$ s (0.062 min), $T_d = 0.941$ s (0.015 min).

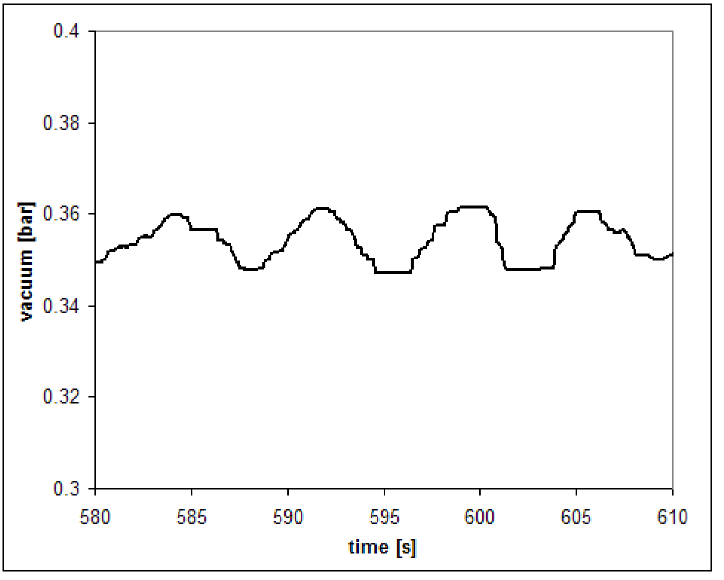


Figure 8 Vacuum signal during tuning

**Table 1** Controller parameters for the Ziegler-Nichols frequency response method

| Controller type | $K_P$ | $T_i$ | $T_d$ |
|---|---|---|---|
| P | $0.5 \cdot K_c$ | - | - |
| PI | $0.4 \cdot K_c$ | $0.8 \cdot T_c$ | - |
| PID | $0.6 \cdot K_c$ | $0.5 \cdot T_c$ | $0.125 \cdot T_c$ |

*Evaluation of the Working Parameters and Vacuum Stability*

The results referring to the working parameters of the system and vacuum stability are shown in Tables 2 and 3.

The results presented in Table 2 show that the working parameters of the system (pulsation rate and ratio, duration of the cycle phases) did not change significantly when passing from the classical method for vacuum regulation (based on the use of a valve type regulator) to the new one, based on the adjustment of the vacuum pump speed. A slight increase of the pulsation rate was however noticed when the second method was used, but the differences did not exceed 1%; the slightly higher pulsation rate resulted in a shorter b phase when the PID controller was used for vacuum regulation, but the requirements of the ISO 5707 standard were fulfilled.

An analysis of the individual values of the permanent vacuum showed that for the both methods the working vacuum was maintained within ±2 kPa of the nominal vacuum, in accordance with the requirements of the ISO 5707 standard.

The results presented in Table 3 show that the use of the PID controller method for vacuum regulation led to lower standard deviations and standard errors of the mean than the ones recorded when the classical vacuum regulator was used.

The statistical analysis of the results, performed by the means of the Man Whitney rank sum test [14], confirmed that, for each imposed value of the vacuum level (35, 40 and 45 kPa, respectively) there were significant differences between the data sets.

Table 2 Working parameters of the milking system

| Regulation method | Item | Vacuum level [kPa] | | |
|---|---|---|---|---|
| | | 35 | 40 | 45 |
| Vacuum regulator | Pulsation rate [cycles/min] | 48.4±0.231 | 51.9±0.266 | 55.9±0.200 |
| | Pulsation ratio [%] | 55.1/44.9 | 53.7/46.3 | 53.3/46.7 |
| | Duration of b phase* [%] | 44.9±0.137 | 41.98±0.362 | 39.74±0.270 |
| | Duration of d phase** [s] | 0.42±0.005 | 0.387±0.003 | 0.343±0.003 |
| PID controller | Pulsation rate [cycles/min] | 48.9±0.352 | 52.2±0.500 | 56.4±0.167 |
| | Pulsation ratio [%] | 54.6/45.4 | 53.8/46.2 | 53.2/46.8 |
| | Duration of b phase [%] | 44.02±0.352 | 41.21±0.405 | 39.40±0.113 |
| | Duration of d phase [s] | 0.42±0.006 | 0.387±0.012 | 0.337±0.003 |

Notes: *at least 30% of the cycle duration [11]; **at least 0.15 s [11].

Table 3 Results regarding vacuum stability

| Regulation method | Item | Vacuum level (SP) [kPa] | | |
|---|---|---|---|---|
| | | 35 | 40 | 45 |
| Vacuum regulator | mean vacuum level, $\overline{x}$ * [kPa] | 34.417 | 39.462 | 44.398 |
| | standard deviation, S [kPa] | 0.202 | 0.230 | 0.226 |
| | standard error of the mean, $S_{\overline{x}}$ ** [kPa] | 0.0142 | 0.0162 | 0.0159 |
| PID controller | mean vacuum level, $\overline{x}$ [kPa] | 34.514 | 39.381 | 44.580 |
| | standard deviation, S* [kPa] | 0.172 | 0.194 | 0.186 |
| | standard error of the mean, $S_{\overline{x}}$ ** [kPa] | 0.0121 | 0.0137 | 0.0131 |

Notes: *for 200 recorded values; ** $S_{\overline{x}} = S/\sqrt{n}$ .

## CONCLUSIONS

The permanent vacuum level in a bucket milking machine was adjusted by the means of a PID regulator, using a variable frequency driver in order to power the electrical motor driving the vacuum pump. The PID regulator, implemented using the NI LabView capabilities, was aimed to maintain a constant vacuum level.

The PID regulator was tuned in order to establish the PID gains using the Ziegler-Nichols frequency response method.

A series of dry tests were performed, at different vacuum levels, in order to compare the two methods of vacuum regulation (using a mechanical vacuum regulator and a PID regulator, respectively); the tests aimed to evaluate the working parameters of the milking system (pulsation rate and ratio, duration of the pulsation phases) and vacuum stability. The tests proved that vacuum regulation by the means of the PID controller has the potential to replace the classical method of regulation as it did not adversely affect the working parameters of the system, while achieving better results regarding the stability of the permanent vacuum.

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42. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

UDC 637.344
Pethodno priopćenje
Preliminary communication

# RESEARCHES FOR CAPITALIZATION AT A HIGHER QUALITY OF THE WHEY

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## SUMMARY

*In the processing of the milk, the whey is considered in many cases as a product without important value. In recent years it can see the increasingly of the possibilities of superior utilization of the whey. It is recognized for the health benefits of the whey with the both ways for people like prophylactic and also as treatment in the various diseases, including cancer. For greater of the whey value, it can be processed by different technologies in relation with the destination.*

*The paper contains a synthetic overview of the possibilities of recovery of the whey, detailing the use of membrane distillation method for the separation and concentration of whey. For investigation it was applied the method using Russian film composite membranes of the type MFFK-3. For that it has been a study about some influences of natural convention on the specific productivity of the used membranes. The scope of the experiments is the preparation of the membrane distillation (MD) technology for to apply on industry scale for a increasing of the performances of the whey utilizations.*

**Key words:** *whey, capitalization, membrane distillation, performances*

## INTRODUCTION

*Whey* or *milk serum* is the liquid remaining after milk has been curdled and strained. It is a by-product of the manufacture of cheese or casein and has several commercial uses. *Sweet* *whey* is manufactured during the making of rennet types of hard cheese like cheddar or Swiss cheese. *Acid whey* (also known as "sour whey") is obtained during the making of acid types of cheese such as cottage cheese.

For aged people, consumption of whey protein helps prevent bone loss. A diet, rich in whey protein, would help keep bones and muscles healthy and strong. Another effective benefit of whey protein is that it helps in supporting both healthy weight-loss, as an appetite suppressant and muscle enhancing nutritional programs. The market interest manifested is increasingly higher than for using whey proteins as nutritional supplements, in the sports, especially for bodybuilding practitioners. Whey protein is a rich source of essential amino acids for muscle growth healthy nails, skin and other connective tissues, thereby improving body composition and athletic performance enhancement for both adults and children, even infants. In its pure form, whey protein no contain little to no fat, lactose and cholesterol.

For to reap from the greatest whey value, it is necessary that to be studied in different processing possibilities by various technologies related to the destination. For the increasing of the percent from industrial recovery whey, more research is needed, using modern methods of treating whey. One of the most interesting methods of processing whey is using *membrane distillation (MD)*. This method performs basically a liquid evaporation process through the pores of the hydrophobic membrane. The driving force of MD is the difference in vapor pressure of the solvent on both sides of the membrane which is created by the temperature differences between the initial solution (giving side of the membrane) and the permeate (or refrigerant) on its receiving side. If to compare MD with baro-membrane methods (reverse osmosis, nano-, ultra- and microfiltration) MD has the advantage of being able to concentrate solutions of many non-volatile organic and inorganic substances to the concentrations almost close to the limit of their solubility (Bryk and Nigmatullin, 1994). At the same time permeate productivity remains satisfactory and the level of permeate purification is high. Therefore the usage of this process for juice concentration (Jiao *et al* 2004, Deshmukh *et al.* 2011), sugar-cane concentration (Nene *et al.* 2002), desalination of see-water (Al-Obaidani *et al.* 2008) and wastewater treatment (Gryta *et al.* 2006) is well known.

Great amount of whey is produced in dairy industry while making casein, soft and hard cheeses. It is used in obtaining a valuable lactose product (milk sugar). In order to do this, whey is clarified (remnants of milk fat and casein are separated), purified from ballast substances (whey proteins, mineral salts) and then lactose is concentrated and the solution with 50÷60 % of dry matters is directed for crystallization and drying.

However before being able to create effective equipment it is necessary to study the influence of the reciprocal direction of the mass transfer and natural convection, as well as influence of the amount of dry matters to the specific performance of the membranes at the temperatures close to industrial conditions.

For good capitalization at a higher quality of the whey, this paper want to establish some directions for the optimization of the conditions for the using MD whey, from the perspective of industrial extension. But, one of the preliminary priorities of industrial equipment design is to study the MD whey process, aiming at determining the equipment based on specific membrane performance in function of the dependence of the amount of dry matter and influence the direction of mass transfer mutual and natural convection.

## MATERIALS AND METHODS

*Membrane*

For the researches it was taken the hydrophobic porous membranes MFFK-3 (Russia), with a nominal mean pore size of 0.45 µm and a porosity of 80÷85 %. They are characterized by the highest specific productivity in comparison with other membranes of the MFFK series. The selectivity of the MFFK-3 in sodium chloride (NaCl) during MD process is over 99,7% (Zmievskiy et al 2010, 2011).

*Preparation of Solutions Model Solutions of Lactose and Whey*

The model of the solutions of lactose were prepared by the dilution of the crystalline food lactose (TOV "Himlaborreaktiv", Ukraine) in distilled water that was heated up to 323±5 K. At first, whey obtained during the production of the fermented milk curds at the industrial plant was purified from the residue of milk fat and casein by microfiltration. To do this, a circulation installation with the filter element (BCCF, Aquafilter, USA) cartridge and pores with the diameter of 5 microns was used.

The whey circulation in closed circuit made it possible to form the dynamic membrane on the surface of the filter element and keep mentioned components. Whey was selected after 20÷25 cycles. Further on the filtrate was pasteurized by heating to 345±2 K and by holding during 15÷20 s with a further rapid cooling to the temperature of 288÷293 K. Whey proteins were separated by ultra-filtration circulation setup with flat membranes UPM-50 (Russia) of round form and area of $2{,}35\cdot10^{-2}$ m$^2$. Due to the fact that these ultra-filtration membranes transmit about 5 % of whey proteins, whey proteins are denatured by heat and can contaminate the membrane in the MD process. To avoid this, the ultra-filtration permeate was kept at the temperature of 333 K and 20÷30 minutes later it was filtered through filter paper.

*Experimental Setups*

The laboratory setup (Fig.1) was consisted of two circulation loops – a “hot” one (for whey) and a “cold” one (distilled water). The principle of operation and the composition of the setup is clearly shown on Figure 1.

Depending on the purpose of the experiment whey was given to the upper or lower chamber of cell 1, which was installed vertically or horizontally. Volume rate of the solutions in both circuits was 0.025 dm$^3$/s. Two types of cells 1 were used: with circular or rectangular shape. The working area of the membrane was $6.64\cdot10^{-3}$ m$^2$ and $4.8\cdot10^{-3}$ m$^2$ respectively. These cells were used for separation of model solutions of lactose and for whey separation respectively.

For to make the study it was used the known theory (Aleksandrov and Rivkin 1975) that the partial pressure of water vapor over concentrated solutions is less than over water without additives. This can be characterized by a parameter called as water activity $a_w$ ($a_w \leq 1$). This indicator is defined by a well-known formula:

$$a_w = \frac{p}{p_w} \tag{1}$$

where: *p, $p_w$* – are partial pressure of water vapor over concentrated solution and fresh water accordingly, Pa.

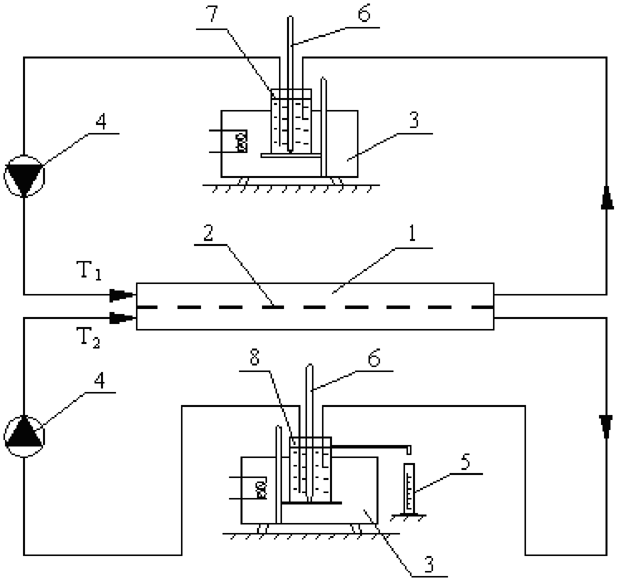


**Fig. 1** Schematic of the experimental setup; (1) Membrane cell, (2) membrane, (3) thermostats, (4) peristaltic pumps, (5) volumetric flask, (6) thermometers, (7) container for whey, (8) container for distilled water.

For the explanation of the experimentally established fact the values of Gr·Pr by Eq. (2) were calculated for the camera with buttermilk. The values are presented in the table. It is known (Yurnev and Lebedev 1976) that the critical value of $Gr \cdot Pr_k$ is equal to $7 \cdot 10^5$. If $Gr \cdot Pr_k \geq 7 \cdot 10^5$ the effect of natural convection must be take into account and the type of fluid flow will be laminar even with $Re < Re_k$.

$$Gr \cdot Pr = \frac{g\beta_1 \Delta T d_e^3 \rho_1 C_1}{\nu_1 \lambda_1} \tag{2}$$

where $\Delta T = | T_m - T_1 |$, $Tm = 0{,}5\ (T_1 + T_2)$, $d_e = 2 \cdot b \cdot h/(b+h)$ – equivalent diameter, b, h – channel width and height, respectively . Physical properties of solutions were selected at $T = 0{,}5\ (T_m + T_1)$. Kinematic viscosity $\nu_1$ and density $\rho_1$ were calculated by Eqs. (3) and (4)

(Polyanskiy and Shestov 1975, Polyanskiy and Shestov 1978), which were obtained while studying the properties of lactose model solutions. The choice of these formulas is caused by insufficient knowledge of ultrafiltration of whey permeate properties. According to the results (Byvaltsev *et al.* 1974, Byvaltsev *et al.* 1974) the thermal conductivity ($\lambda_1$) and heat capacity ($C_1$) were considered in calculations equal to $\lambda_1$=0,664 W/(m·K), $C_1$=3740 J/(kg·K). In the absence of data about the value of thermal expansion coefficient for our solution (β1) its value was considered the same as for water and was equal to $\beta_1=4{,}49\cdot10^{-4}$ 1/K.

$$\nu = \frac{1}{(\upsilon_{H_2O})^{-1} - A\cdot c} \tag{3}$$

where $\upsilon_{H2O}$ – viscosity of water at a temperature t of the solution, °C;
$A=2{,}29\cdot10^4+0{,}0465\cdot10^4\cdot(t-20)$.

$$\rho = \frac{10^5}{a\cdot(100 - c + \frac{e}{a}\cdot c)} \tag{4}$$

where

$$a = 1.0017 - \frac{0{,}15}{\frac{2000}{c} - 19} + 2{,}2\cdot10^{-4}\cdot t$$

$$e = 0{,}6058 + \frac{0{,}2}{\frac{2000}{c} - 19} + 5\cdot10^{-4}\cdot t$$

where c - is concentration of lactose, %; t - temperature of the solution, °C

**Table 1** Dependence of Gr·Pr on the concentration of lactose ($T_1$=333 K, $T_2$=298 K)

| c, % | $\upsilon\cdot10^7$, $m^2s^{-1}$ | ρ, kg $m^{-3}$ | Pr | $Gr\cdot10^{-4}$ | $Gr\cdot Pr\cdot10^{-4}$ |
|---|---|---|---|---|---|
| 5 | 6,19 | 1007 | 3,50 | 1,881 | 6,578 |
| 10 | 6,97 | 1027 | 4,03 | 1,472 | 5,936 |
| 15 | 8,02 | 1048 | 4,73 | 1,113 | 5,267 |
| 20 | 9,44 | 1070 | 5,69 | 0,804 | 4,571 |
| 25 | 11,46 | 1093 | 7,06 | 0,545 | 3,845 |
| 30 | 14,59 | 1117 | 9,18 | 0,336 | 3,087 |
| 35 | 20,07 | 1143 | 12,92 | 0,178 | 2,295 |

The table above shows Gr·Pr<7·10$^5$. However, knowing that the values of Gr·Pr with the level of dry matters at 5 % is 2.25 times higher than at 35 %, the natural convection has its influence on the MD process. The increase of solution viscosity in 3.24 times in this range of solids explains the reason why the difference between lines 1 and 2 (Fig. 4) disappeared.

## RESULTS AND DISCUSSION

It has been stated that the optimal temperature while condensation of lactose is 298÷333 K. The solution is heated to 348÷353 K at the final stages when the amount of solids comes up to 50-55 %. This allows dissolving completely the chaotically crystallized lactose and increasing super saturation. Basing on the foregoing, temperature rates for solutions containing lactose have been selected. The temperature of 298 K was mainly kept for "cold" solution (distilled water) because it was easy to implement it at the industrial conditions.

For the first model, solutions of lactose were concentrated. This allowed determining the nature of the changes in the specific performance of the membranes MFFK-3 from the amount of dry matters.

Therefore, in according with formula (1), at the same temperature difference but with the gradual increase of the number of dry matter the driving force and the specific performance of the membranes are decreasing. The MD process is also negatively affected by temperature and concentration polarization (Termpiyakul *et al.* 2005). All this leads to the more rapid decrease of the specific membrane performance in comparison with the water activity. This is clearly shown in Fig. 2.

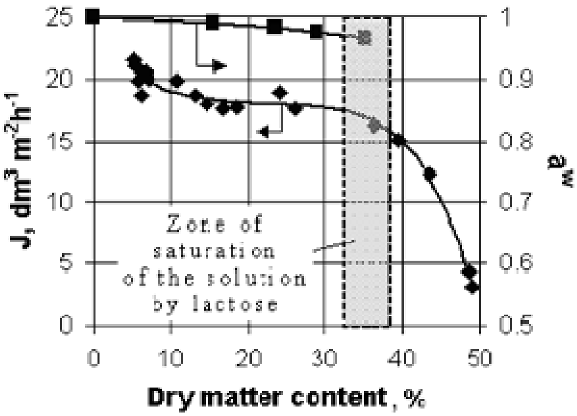


**Fig. 2** Dependence of membrane MFFK-3, the specific productivity (J) and water activity $a^w$ (Polyanskiy and Shestov 1975) on the dry matter content in the MD lactose model solutions. $T_1$= 330± 2 K, $T_2$= 298 K.

Upon reaching the solubility limit of lactose there is a sharp decrease in permeate flow through the membrane. This can be explained by the increase of solution viscosity as well as by possible deposition of lactose crystals on the surface of the membrane. The presence of mineral and organic matter in real solutions increases the solubility of lactose. That is why whey treated by the mentioned above method is necessary to be thickening to the number of solids 50÷60 % (depending on the proportion of lactose/non sugars).

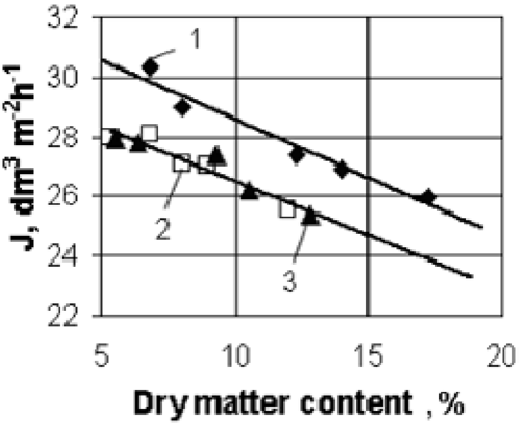


**Fig. 3** Dependence of membranes MFFK -3 specific productivity (J) on the dry matter content of whey in MD; (1), (2) horizontal location of the membrane, the "hot" chamber is above and below the diaphragm accordingly (3) vertical position of the membrane. $T_1$= 333K, $T_2$= 298K.

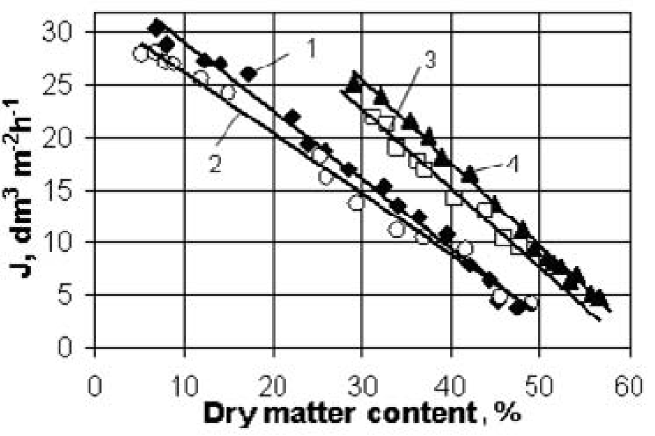


**Fig. 4** Dependence of the specific productivity (J) of membranes MFFK-3 on the amount of dry matter of whey with the MD of membrane horizontal arrangement: (1), (2) "hot" chamber is above and below the diaphragm accordingly, $T_1$ = 333 K, $T_2$ = 298 K, (3) "hot" chamber is under the membrane, $T_1$ = 348 K, $T_2$ = 313 K, 4 - "hot" chamber is under membrane, $T_1$ = 348 K, $T_2$ = 298 K.

In further studies the cell membrane (Fig.1) was installed both horizontally and vertically. When the cell was in horizontal position in some cases whey was given into the upper chamber while in other cases it was given into the bottom ones.

Fig. 3 shows that the highest specific capacity of membranes MFFK-3 is reached while concurrence of mass transfer and natural convection directions. It is interesting that the flow of permeate through the membrane is almost the same if the "hot" chamber is located above the diaphragm or vertically. This is obviously the effect of concentration polarization. The direction of natural convection in these cases is not assisting the "dilution" of the diffusion layers of less concentrated solution. We can conclude from the obtained results that the membrane-distillation plants for the separation of whey with horizontal membranes MFFK-3 will have bigger capacity than in the case of vertical arrangement. That is why the further studies were conducted with the horizontal arrangement of the membrane.

As it is shown on Fig.4 the specific productivity of the membranes MFFK-3 is lower on average of 12 % if the direction of mass transfer and natural convection is not the same (line 1 and 2). These values are typical for the beginning of the MD process of whey when the amount of dry matters does not exceed 5-10 %. With increasing of mass fraction of solids discrepancy is reduced and this difference virtually disappears by reaching 35-40 %. This phenomenon is primarily because the viscosity of the solution increases that leads to the deceleration of mass transfer by natural convection in the working chamber volume.

Due to the fact that high temperatures adversely affect the lactose and can be recommended at the final stages of concentration, the separation of whey at temperature 348 K were carried out with the quantity of dry matter above 25 %. The increase of specific membrane performance was observed even at the same temperature difference of the original solutions (line 1 and 3, Fig. 4). This is due to the nonlinear dependence of the partial pressure of water vapor on the temperature. Therefore, at the same temperature difference the driving force of the MD process will be higher at higher average temperatures. For example, when $\Delta T = 35$ K, $\Delta p = 16\,390$ Pa, if $T_1 = 333$ K and $T_2 = 298$ K (without taking into account the temperature polarization); $\Delta T = 35$ K, $\Delta p = 30\,500$ Pa, if $T_1 = 348$ K and $T_2 = 313$ K.

Fig. 4 shows that raising the temperature of whey and the driving force accordingly provides more concentrated solution. The linear dependence of specific performance and number of dry matter indicates the absence of crystallization of lactose in the experimental conditions. Increasing of $\Delta T$ enlarges the effect of temperature polarization on the process of MD. For example, $\Delta p$ (excluding thermal polarization) increases to 12.3 % and specific productivity to 8.5 % (lines 3 and 4).

## CONCLUSIONS

From these researches it has been stated that the dependence of the specific performance of the membranes MFFK-3 on the concentration of solids of whey is linear in the range of 5÷58 % solids. When the membrane MFFK-3 was placed In the horizontal position, their specific productivity increases on average to 12 % if the direction of mass transfer and natural convection are the same. However, with the increase of viscosity when the amount of dry matter is 35÷40 %, the effect of mutual direction of mass transfer and natural convection disappears. In other words it is not important the position of the "hot" chamber: under the membrane or over it. Also, the membrane distillation (MD) in setup with membranes MFFK-3, for the separation of whey will have better performance if the membrane is placed horizontally.

Given these optimizations of the equipment of whey processing it will give a high quality of the components from whey, thus increasing the possibilities of capitalization of whey in the industry.

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42. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

UDC 628.8:631.223.66
Prethodno priopćenje
Preliminary communication

# THE EFFECT OF DIFFERENT FAN FLOW RATE ON THE GAS COMPOSITION IN PIGLET PRE-FATTENING FACILITY

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## SUMMARY

*The influence of one vacuum fan Unitherm 6.3E on the quality of the air was examined in a pre-fattening facility for piglets in Vučja vas (Slovenia). The experiment involved measurements of $O_2$, $CO_2$, $NH_3$, and $H_2S$ concentration at varying airflows (0.18, 0.27, 0.34, 0.47 $ms^{-1}$) and flow rates (89.77, 135.14, 168.91 and 233.49 $m^3h^{-1}$) inside a space with the area of 35.96 $m^2$ and volume of 86 $m^3$ to evaluate compliance with legal exposure limits. Measurement locations were 5 cm and 66 cm above the ground in the seven pens and the service corridor. The poorest gas composition was found closer to the ground and in the corners. The highest $NH_3$ (4.12 ± 1.5 ppm) and $CO_2$ (851.03 ± 121.2 ppm) concentrations were detected at the lowest flow rate (89.77 $m^3h^{-1}$). The highest airflow (0.47 $ms^{-1}$) enabled statistically significant better ventilation, which decreased $NH_3$ (3.14 ± 1.2 ppm) and $CO_2$ (694.48 ± 89.5 ppm) concentration on the legislation levels. The results on the experimental farm showed that installation of two fans instead of one would be ideal, since they could work at lower airflow with less energy consumption. This would also allow consistent ventilation and better air quality in all parts of the facility, what is important for reducing animal stress and simultaneously increasing the efficiency of feeding.*

***Key words**: pig farm, fan, piglets, gas composition, ammonia, carbon dioxide, hydrogen sulfide*

## INTRODUCTION

Ammonia research at swine facilities started in 1963 in an exploratory phase of study by Day et al. (1965) to investigate gases and odors in two swine finishing buildings. In addition to $CO_2$, $H_2S$, and $CH_4$, $NH_3$ was detected also in the solid-floor of building that was cleaned daily. Agricultural air quality studies have experienced revolutionary changes in the past three decades, especially after the introduction of advanced analytical instruments and personal computers (Ni et al., 2009). In the mid-1980s modern techniques was introduced, which was characterized by gas analyzers allowing highly sensitive and continuous $NH_3$ concentration determination, and ventilation control monitoring in Canada (Clark and McQuitty, 1988). In the 1990s, more intensive field investigations were conducted in some European countries (Aarnink et al., 1996). A lot of experiments in Europe included a 6-month continuous field monitoring study in Belgium (Berckmans al., 1998), and a large survey of aerial pollutants within and emissions from 329 livestock buildings in Northern Europe (Wathes et al., 1998).

According to the United States Environmental Protection Agency (USEPA, 2004), $NH_3$ and $H_2S$ are the most recognized hazardous gases that are emitted from animal waste. Agricultural $NH_3$ emission is believed to relate to soil acidification, degradation of ecosystems and potential health hazards to humans and animals (Donham et al., 1995). Factors influencing ammonia concentrations and emissions in different swine facilities are mainly affected by barn design, manure storage method, farm management, feed ration and type, animal age and activity, live mass density, outdoor temperature, ventilation design and control, time of day, and season.

Ammonia concentrations vary considerably inside swine barns as well as in the barn ventilation exhausts in the range from 0 to 40 ppm. Compared with in-house $NH_3$ concentrations among sow, nursery, and finisher houses, the highest values are generally detected in finishing barns (Koerkamp et al., 1998). The typical range of instantaneous $NH_3$ concentrations outside swine barns and in the vicinity of open manure storage facilities is less than 0.5 ppm, considerably lower than that of in-house $NH_3$ concentrations. On the other side, diurnal and seasonal variations usually show higher concentrations at night and in winter, respectively, in barns and at lagoons. Ni et al. (2000) presented data of temporal and spatial $NH_3$ concentration variations inside a finishing barn and its deep pit headspace. Their diurnal patterns were correlated with those of barn ventilation rates, which were relatively low at night due to lower outdoor temperatures. Burton and Beauchamp (1986) also showed inverse relationships of inside $NH_3$ concentrations with outdoor temperatures. Over a 1-year period, February had the highest monthly average concentration of about 21 ppm and August had the lowest of about 6 ppm.

The main purpose of the research was to investigation the gases composition on the piglets fettering facility in Slovenia and compares the results with the latest EU legislative values.

## METHODS

The experimental site was a family swine farm located in Vučja vas (NE Slovenia), where the majority of pig farming operations is located. The experiment was conducted in a pre-fattening facility for piglets, which consisted from seven pens in the total area of 35.96 $m^2$ and volume of 86 $m^3$. The on-site waste storage treatment is located just beneath the pens at the normal liquid level. The barn is equipped with one vacuum fan Unitherm 6.3E, which is vertically oriented with the exhaust fans face upwards and four laterally oriented fresh air openings. The piglets were housed in at approximately 4th week and rested for the following 7 weeks, weighing 7–8 kg upon arrival and gaining an average 0.35 kg per day.

| | | | |
|---|---|---|---|
| Barn 1 slotted floor | Barn 2 slotted floor | Barn 3 slotted floor | Barn 4 slotted floor |
| Barn 1 solid floor | Barn 2 solid floor | Barn 3 solid floor | Barn 4 solid floor |
| Corridor left | Corridor centre | | Corridor right |
| | Barn 7 solid floor | Barn 6 solid floor | Barn 5 solidfloor |
| | Barn 7 slotted floor | Barn 6 slotted floor | Barn 5 slotted floor |

**Figure 1** Experiment layout in the pre-fattening barn

For measuring the effectiveness of the vacuum fan 17 points were selected in different parts of the barn as seen on the Figure 1; two points in each pen, where point 1 was 5 cm above the bare concrete floor, and point 2 was 5 cm above the slatted floor. Additional three points were selected 5 cm above the concrete corridor in the middle of the pen; left, right and just beneath the fan. The second part of the experiment involved the same measuring points in the 66 cm layer. The measurements were performed during the June and July 2013. A full description of the pig numbers, weights, and number of weeks in rotation for each pen is provided later in Table 2.

For measuring the gaseous concentration and environmental data an ECHO analyzer was applied. It contains pulsed fluorescence $H_2S/SO_2$ analyzer, $NH_3$ analyzer, which measures ambient ammonia by using the chemiluminescence principle, moisture sensor, thermal sensor, air velocity sensor and pressure sensor. These analyzer draws in sample air at 1.0–1.2 $lmin^{-1}$ through an internal vacuum pump. During the field study, zero and span checks for $H_2S$ and $NH_3$ concentration were conducted daily.

## RESULTS AND DISCUSSION

Ammonia and carbon dioxide concentrations

In the following chapter we are going to discuss only the ammonia and carbon dioxide concentrations, since there was no significant influence of increasing air flow rates on $O_2$ concentration, temperature, pressure and moisture content. On the other hand, we did not detect any $H_2S$ concentration as might be expected from the literature reports.

Figure 2 shows the average concentration of ammonia ($NH_3$) in the pre-fattening barn at 17 different points within a measuring period of two months 5 cm above the floor. As seen the legislative upper limit of 10 ppm $NH_3$ was not exceeded in any part of the barn, which means the air quality was very good. However, still there is a significant higher concentration of $NH_3$ concentration in the corner of pen 1 (5.67 ppm) and pen 7 (4.67 ppm), because these are the most allocated points in the barn from the fan. The main reason for lower vacuuming effect lies in the vertical walls between the neighboring barns, which prevent the higher airflow. The main reason for installing the walls is i) to prevent the fighting between different groups of piglets from neighboring pens and ii) to prevent the air draft, which is most important threat for respiratory illnesses.

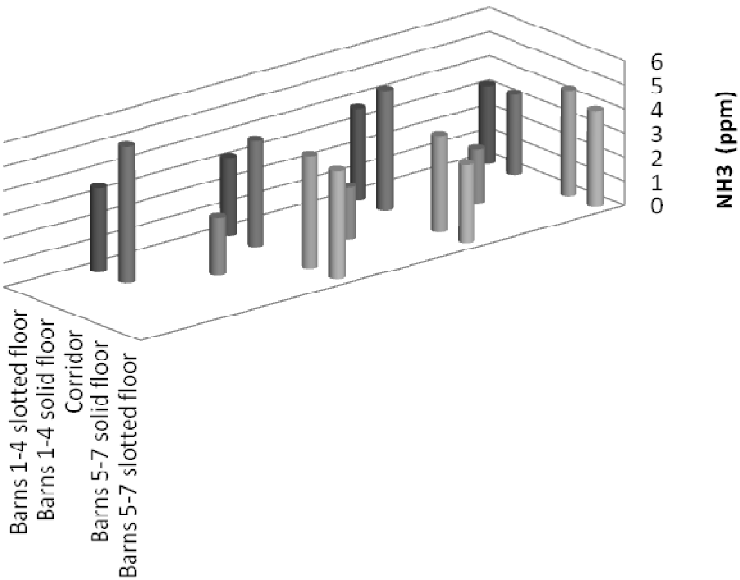


**Figure 2** Distribution of ammonia concentration ($NH_3$) in the pre-fattening barn on the 5cm height

**Table 1** Average $NH_3$ and $CO_2$ concentration on the 5 and 66 cm height.

| Measuring point | Average piglet weight [kg] | $NH_3$ [ppm] | | $CO_2$ [ppm] | |
|---|---|---|---|---|---|
| | | 5 cm | 60 cm | 5 cm | 60 cm |
| Pen 1 slotted floor | 14.75 | 3.50 | 3.42 | 756 | 685 |
| Pen 1 solid floor | 14.75 | 5.67 | 3.50 | 951 | 784 |
| Pen 2 slotted floor | 15.87 | 3.25 | 2.99 | 707 | 655 |
| Pen 2 solid floor | 15.87 | 4.40 | 3.33 | 878 | 691 |
| Pen 3 slotted floor | 13.84 | 3.80 | 3.60 | 744 | 699 |
| Pen 3 solid floor | 13.84 | 5.00 | 4.20 | 880 | 720 |
| Pen 4 slotted floor | 16.75 | 3.25 | 3.20 | 797 | 701 |
| Pen 4 solid floor | 16.75 | 3.33 | 3.20 | 820 | 802 |
| Corridor left | | 2.25 | 2.16 | 580 | 551 |
| Corridor center | | 2.17 | 2.10 | 410 | 403 |
| Corridor right | | 2.40 | 2.25 | 564 | 480 |
| Pen 5 slotted floor | 21.34 | 4.00 | 3.80 | 976 | 774 |
| Pen 5 solid floor | 21.34 | 4.40 | 3.90 | 1090 | 915 |
| Pen 6 slotted floor | 16.16 | 3.25 | 2.78 | 752 | 691 |
| Pen 6 solid floor | 16.16 | 4.00 | 3.50 | 822 | 758 |
| Pen 7 slotted floor | 14.66 | 4.50 | 3.27 | 810 | 725 |
| Pen 7 solid floor | 14.66 | 4.67 | 3.33 | 895 | 863 |

Generally the $NH_3$ concentration was significantly higher above the solid floor than above the slotted floor, because in the second case the slurry had been released through the channels and the plug every week, which was sufficient to decrease the ammonia concentrations in this particular part of the pens. This problem was already reported by Aarnink et al., 1996, who detected the higher concentration due to increased urination and defamation on the solid floor. Namely, ammonia is released through the bacterial and enzymatic decomposition of nitrogen compounds contained in the excreta, especially in the urine, which is more accumulated on the solid floor. The higher $NH_3$ concentration in particular pens is also correlated with the average piglets' weight. As seen from Table 2 the finest air was measured at the average piglet weight of 13.84 kg and the poorest at the average piglet weight of 21.34 kg.

The most effect of the vacuum fan was detected in the corridor where the lowest $NH_3$ concentration (2.17 ppm) was measured in the center point, (2.25 ppm on the left point and 2.40 ppm on the right point. Slightly higher concentration was detected on the right point due to the uneven distribution of pens (four on one side and three on the other side of the corridor).

As represented in Table 1, the average $NH_3$ concentration was lower in all measuring points 66 cm above the floor in comparison to 5 cm height, which confirmed the dilution effect of air mixing caused by the fan. On the other side, this data confirmed the $NH_3$ as a heavy gas once ageing.

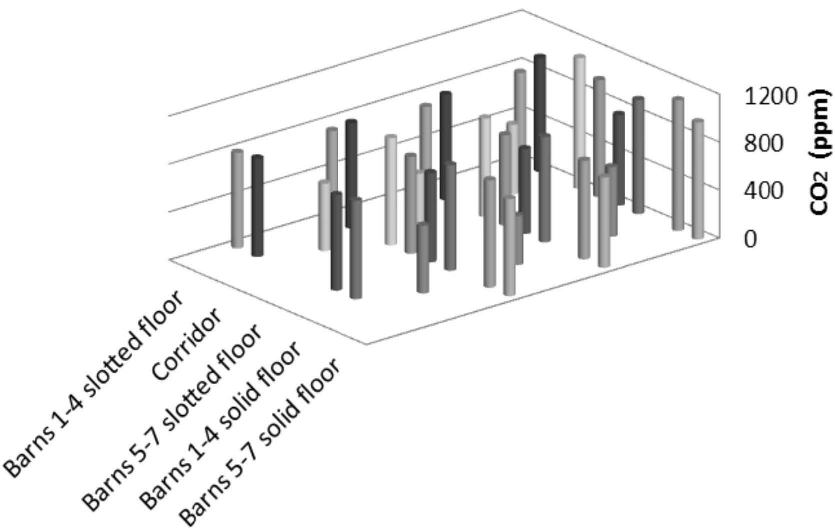


**Figure 3** Distribution of carbon dioxide concentration ($CO_2$) in the pre-fattening barn on the 5 cm height

Figure 3 shows the average concentration of carbon dioxide concentration ($CO_2$) in the pre-fattening barn at 17 different points within a 2-month measuring period 5 cm above the floor. Carbon dioxide showed similar spatial distribution as ammonia, so the highest concentration was again measured above the solid floor of pen 5 (1090 ppm), which was most allocated point from the fan. On the average the $CO_2$ concentration was higher on the solid floor than on the slotted floor, because the carbon dioxide is mainly produced by pig respiration and the animals are indeed lying on the solid floor.

Again, the vacuum fan exchanges the air most efficiently in the corridor, where the lowest $CO_2$ concentration (403 ppm) was measured in the center point. Carbon dioxide is mainly produced by pig respiration while ammonia is released through the bacterial and enzymatic decomposition of nitrogen compounds contained in the excreta, especially in the urine. Legislative upper limit of 4000 ppm $CO_2$ was not exceeded in any part of the barn for two reasons; i) the vacuum fan was appropriate enough to exchange the inside air with the outside one, ii) the maximal $CO_2$ respiration is limited with the body weight of piglets, which in our case did not exceed 22 kg.

**Table 2** Data for the piglets in the experiment

| | Pen 1 | Pen 2 | Pen 3 | Pen 4 | Pen 5 | Pen 6 | Pen 7 |
|---|---|---|---|---|---|---|---|
| Piglets (number) | 10 | 12 | 12 | 12 | 12 | 12 | 12 |
| Total incoming weight (kg) | 49.5 | 102.5 | 136.5 | 54 | 102.5 | 109.5 | 62.4 |
| Total finishing weight (kg) | 197 | 293 | 299 | 255 | 266.4 | 303.5 | 318.5 |
| Feeding days (day) | 55 | 45 | 45 | 45 | 45 | 45 | 45 |
| Total food consummation (kg) | 332.4 | 421.1 | 468.1 | 402.3 | 421.2 | 437.40 | 442.8 |
| Food consumption per piglet (g/day) | 755 | 779 | 866 | 745 | 780 | 810 | 820 |
| Average daily growth per piglet (g/day) | 335 | 352 | 300 | 330 | 349 | 339 | 362 |

*The influence of varying air flows on the ammonia concentrations*

Figure 4 shows the influence of increasing airflow (0.18, 0.27, 0.34, 0.47 $ms^{-1}$) on the average $NH_3$ concentration during the measurements 66 cm above the floor.

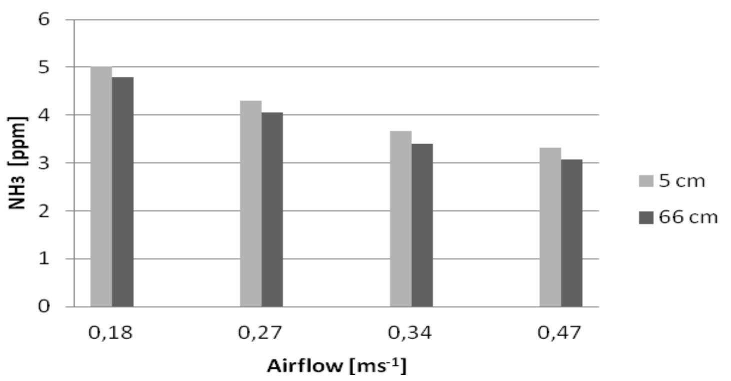


**Figure 4** The average ammonia concentration ($NH_3$) at different airflows

As seen. the rising air exchange decreases $NH_3$ concentration significantly. The maximal $NH_3$ concentration (4.82 ppm) was detected at 0.18 $ms^{-1}$ and minimal (3.08 ppm) at 0.47 $ms^{-1}$ airflow. On that way the latest suggested EU legislative norm was fulfilled. At the airflows 0.34 and 0.47 $ms^{-1}$ the air circulation was significantly higher than in the first two airflows, thus the $NH_3$ concentration decreased even below 4 ppm. However, on the other hand, the maximal air flow rate represents economical hazard, because it does not assure significantly better air quality at higher electricity costs.

## CONCLUSIONS

The results of 2-months experiment in the pre-fattening barn showed appropriate microclimate parameters according to the legislative suggestions which were assured with one vacuum Unitherm 6.3E fan. However, the deep inside analysis clearly showed uneven vertical and horizontal spatial distribution of ammonia and carbon dioxide concentration, mainly caused by the vertical full-walls contraction of the pens and the central fen position on the ceiling.

When heavier group of piglets was growing in the corner pens, the $NH_3$ and $CO_2$ concentration was significantly higher 5 cm and 66 cm above the solid floor then in the middle pens. Beside the higher fodder consumption and excretions production, the main reason represents inefficient air mixing in the corners due to pen’s wall made up of whole plates. Thus, the reconstruction of the barn with installation of an additional fan is foreseen as piglets cannot be placed inside the pens made of pipes. On that way the poor air would be exchanged with the fresh one at slower, but constant airflow rate, which would improve the microclimate. Consequently a steady supply of fresh air with more constant temperature would be ensured, which also improve the health status of animals and lower the stress within animals. Therefore, better feed utilization and increase in growth of piglets might be expected.

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# UTJECAJ RAZLIČITIH KOLIČINA TOKA ZRAKA NA SASTAV PLINOVA U OBJEKTU ZA TOV PRASADI

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*Na svinjogojskoj farmi (Vučja vas, Slovenija) proučavan je utjecaj različitih količina toka zraka postignut sa jednim vakuumskim ventilatorom Unitherm 6.3E na kvalitetu zraka u objektu za gojenje odojaka. U pokusu mjerene su koncentracije plinova $O_2$, $CO_2$, $NH_3$ i $H_2S$ kod porasta brzine zraka (0,18, 0,27, 0,34 i 0,47 $ms^{-1}$) i protoka zraka (89,77, 135,14, 168,91 i 233,49 $m^3h^{-1}$) unutar prostora površine 35,96 $m^2$ i volumena 86 $m^3$. Veličine mjerenih parametra uspoređivane su zakonskim granicama izlaganja. Mjerna mjesta na visini 5 cm i 66 cm iznad tla odabrana su u sedam boksova iznad rešetki te cijelog poda i u hodniku. Najlošiji sastav plina pronađen je iznad cijelog poda i uglovima štale. Najveća koncentracija $NH_3$ (4,12 ± 1,5 ppm) i $CO_2$ (851,03 ± 121,2 ppm) otkrivena je kod najnižeg protoka zraka (89,77 $m^3h^{-1}$) ali još uvijek odgovara zakonodavstvenim propisima. Najvećom brzinom zraka (0,47 $ms^{-1}$) statistički značajno je poboljšana kvaliteta provjetravanja i kvaliteta zraka; $NH_3$ (3,14 ± 1,2 ppm) i $CO_2$ (694,48 ± 89,5 ppm. Rezultati pokusa pokazali su kako bi ugradnja dva ventilatora umjesto jednog bila idealno rešenje, jer bi oba radila kod nižeg protoka zraka sa manje potrošene energije i manjim gubicima topline. To bi također omogućilo dosljednu ventilaciju i bolju kvalitetu zraka u svih dijelovima objekta (uglovima), što je vrlo važno za smanjenje stresa životinja i istovremeno povećanje učinkovitosti tovljenja.*

***Ključne riječi**: farme svinja, ventilator, prasad, sastav plina, amonijak, ugljični dioksid, sumporovodik*

42. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

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# DETERMINATION OF INFLUENTIAL PARAMETERS FOR COMPOSTING OF LIQUID MANURE WITH WHEAT STRAW

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## SUMMARY

*Production of compost from mixture of liquid manure and wheat straw is achievable process. In order to obtain final product of good quality, it is necessary to achieve total control of process. In the production process, essential changes in properties were recorded, compared to initial stage. Organic fertilizer of excellent quality was produced by composting the mixture of liquid manure and wheat straw. Prior to composting, components were mixed in fixed ratio. Production process involves aerobic treatment of mixture, by turning the mass frequently. Mixture of manure and straw was placed on the concrete surface in form of prisms, 3m wide and 1m high. Special machine for mass turning was used. The most important parameters for composting process, and their changes during treatment were monitored (changes in temperature, mass, height, bulk density, moisture content, N content, organic dry matter content, pH level C/N ratio).*

***Key words:*** *liquid manure, straw, aerobic process, compost*

## INTRODUCTION

Composting of mixture that is consisting of liquid manure and crop residues represents a possibility to transform liquid manure into a solid organic fertilizer, outside of the animal housing buildings. This procedure significantly simplifies manure handling process, with advantages such as low energy consumption, savings in storage capacity, and using simpler equipment. At the same time, highly valuable organic fertilizer which is environmental friendly to store and use, is produced.

For the production of compost from a mixture of liquid manure and wheat straw, it is necessary to know the properties of both components, especially when they are joined together (Tomantscher *et al* 2013, Radivojevic 1993) as well as technical - technological parameters of the procedure. The ratio between components is proven to be a parameter of great importance for the success of the process. This ratio directly depends on the consistency of liquid manure and straw adsorption capabilities. Increase of liquid manure consistency causes enhancement of the amount of manure that straw can adsorb. Further increase of adsorption capabilities can be achieved by pre-chopping of straw and by homogenization of the mass in joining procedure.

It was found that the adsorptive capacity of straw is quickly filled, in the first 5 minutes up to 95 %. This means that the process of compounding should last no longer than 5 minutes (Radivojević 1993).

Quantity of straw to be used in process, beside manure consistency, also depends on ratio between nitrogen and carbon (C/N ratio), which should be in the range from 18:1 to 20:1. Dry matter content in the mixture depends on the amount of used straw and was in the range of 15 - 25% (Radivojević 1993, Veeken A. *et al 2002.)*. Formed mixture was subjected to aerobic treatment, with the aim to encourage the development of aerobic microorganisms that break down organic matter. In the first phase, psychrophilic microorganisms were developed. The optimum condition for their growth is temperature of 15 – 20$^{o}$C. In the second phase, at a temperature of 30 – 40$^{o}$C, mesophilic organisms are developed, and in the third phase at temperatures of 50 – 65$^{o}$C a group of thermophilic microorganisms is developed. By appropriate schedule of treatments and maintening of the required aerobic conditions in the mass, mesophilic stage is reached in 24 hours from the beginning of the process.

The maximum achieved temperatures, were maintained up to 1/3 of the time of process duration. During this period, thanks to activity of thermophilic microorganisms, high temperature processes that causes destruction of pathogenic microorganisms, and germination ability of present weed seeds were developed (Bernal M.P *et al.* 2009, Tomantscher *et al* 2013). The process of aerobic care of mixture lasts seven weeks, and during this period twelve treatments were performed. Composting is considered completed at the end of last week, when the temperature of the mass equal to the ambient temperature.

## METHODS

In the composting process were involved liquid manure of natural kind, with 8% of dry matter and wheat straw. The ratio of straw and manure was 1kg:33,3l. Before mixing with manure, straw was chopped, with the following participation of fractions: up to 25 mm 50%, 25 - 35 mm - 20%, 35 - 45mm – 20%, 45 mm and over - 10%.

Compounding of components was performed in a cylindrical vessel with a mechanical mixer and lasted for 5 minutes (Figure 1) (Radivojevic 1993, Külcu R. *et al*. 2004). Formed mixture was placed on concrete surface in prismatic-shape figures, 1m high and 3m wide. Length of prism does not affect the studied parameters, and therefore was not studied.

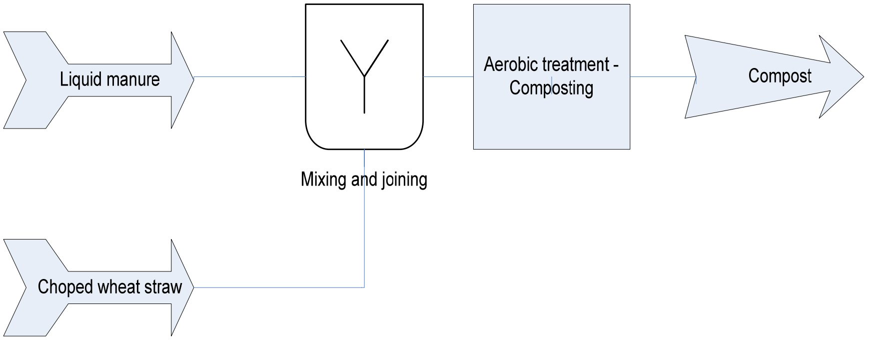


**Figure 1** Scheme of the process

**Figure 2** Self propelled machine Compo Mat 1

Aerobic treatments were performed by a prototype of self-propelled machine named Compo Mat 1 (Figure 2). Working width of machine is 3 meters, height of the tunnel - clearance is 1.5 m. Working body is cylindrical with a diameter of 60 cm, with attached blades. Length of blades is 15 cm, and they are mounted in a fourfold, two-way spiral. Treatment was performed three times in the first week, from second to the sixth week twice a week, and in the seventh week was not performed. Determination of contents of dry matter, ash and organic matter was performed by drying at 105°C in a digester with fan, then by burning at 650$^{o}$C, and cooling in a exicator. Ash content is determined by comparing the difference in mass, and organic matter content was determined by the difference of the percentage of dry matter. Determination of minneral matters, N, $P_2O_5$ and $K_2O$ was carried out by wet burning of sample with a mixture of acids $H_2SO_4$ and $HClO_4$. Nitrogen content was determined by distillation in an alkaline environment, by Kjeldahl method. Phosphorus content was determined calorimetrically over blue molybdenum complex and potassium was determined by flame photometry. pH value was monitored by pH meter with glass electrode. Temperature was monitored by electronic thermometer, with range from -150°C to +150°C, with an accuracy of ± 0.1 degree.

## RESULTS

During the study, the changes in the following parameters were monitored: temperature in the mass, changes in the volume and the height of prisms, average mass density, changes in the content of organic and inorganic matter and pH value.

In the first week of treatment, within 24 hours and immediately after the first passage of machine, the temperature rises. On the fourth day of the process, after the second treatment, the temperature reached 75°C, and with minor fluctuations remained at this level for eleven days. At the level of more than 60°C, which is appropriate for the activity of thermophilic microorganisms, temperature was maintained for three weeks. After that period, a slight downward trend in temperatures is established. The temperature in the mass has reached the ambient temperature in the last week of care (Chart 1).

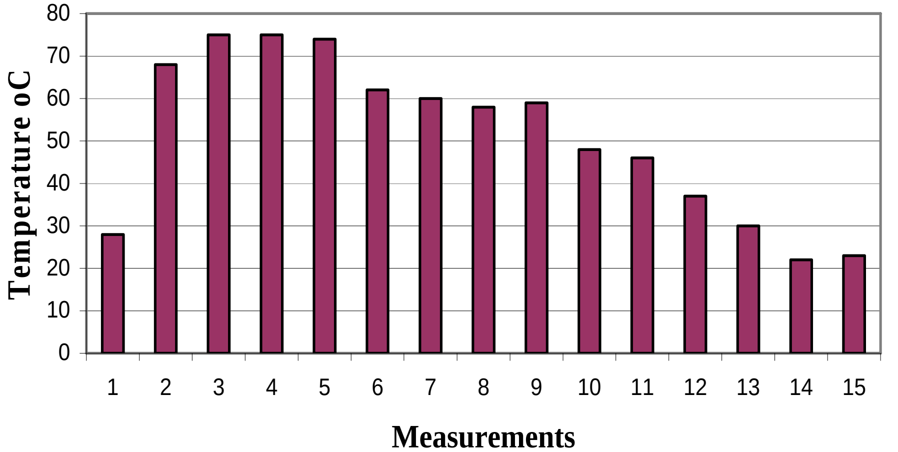


**Chart 1** Changes in temperature of mixture during the process

At the beginning of process, mass of mixture (reduced to $1m^3$ of liquid manure and 300 kg of straw) was 1.3 t. During the treatment, especially to the fourth week, intense weight reduction that has occurred as a result of intense evaporation under the influence of high temperatures was observed. Weight of the finished compost was 0.4 t (Chart 2).

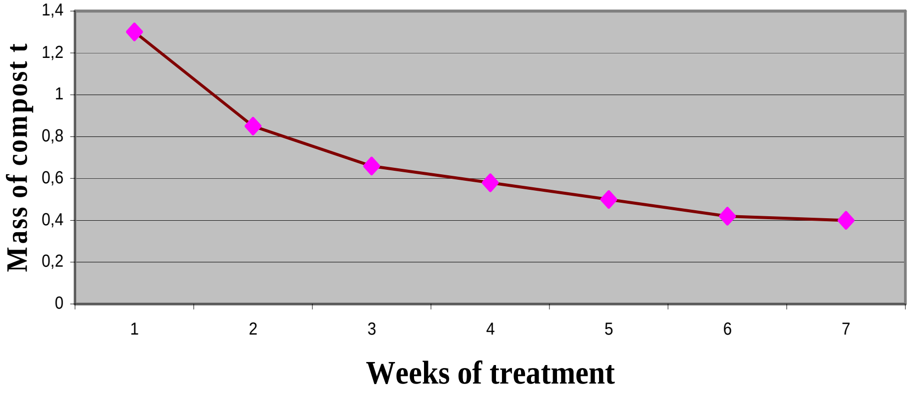


**Chart 2** Changes in compost mass during the process

Height of the prism at the beginning of care was 1m. Losses in weight, also caused volume reduction, therefore a reduction of hight of the prism also. The height is slightly increased after each passage of machines, in the amount about 10% of hight before treatment. This increase is explained by influence of working body, that shakes the mass. Decrease of hight of the prisms calmed down at the end of the fourth week of care. At the end of treatment, the height was 0.5 m (Chart 3).

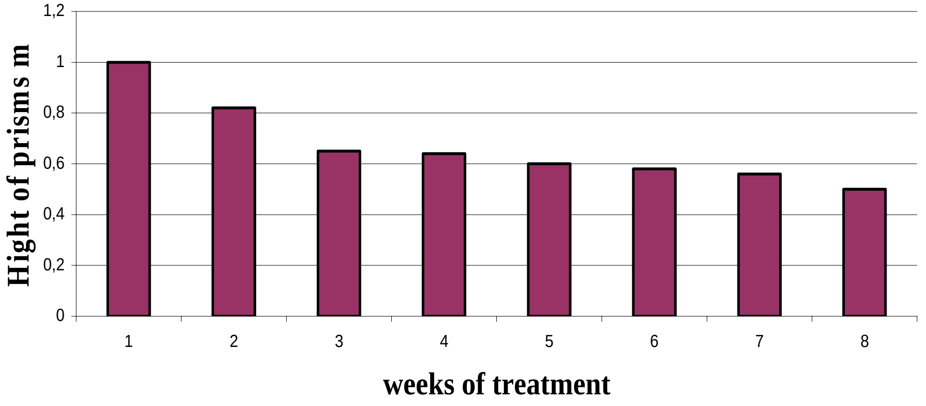


**Chart 3** Changes in prism height during the process

In the process, the average density of the compost also suffered severe changes. Initial average density was 0.4 $t/m^3$ , and the final 0.25 $t/m^3$ . This is explained by high proportion of straw in mixture, that loses moisture during the process (Chart 4).

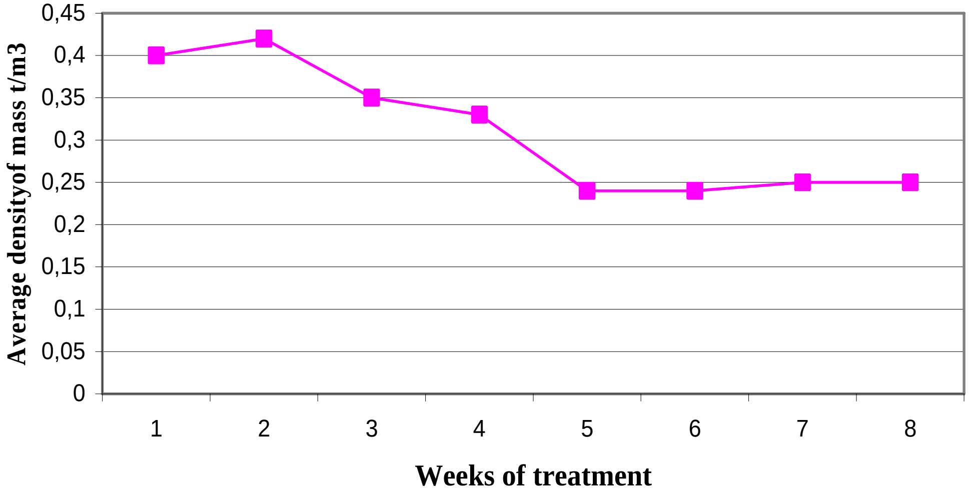


**Chart 4** Changes in avarege density of mixture

Humidity of mixture also suffered changes. At the beginning it was 75%, of that in the first two weeks reduced by the amount of about 3 % per week. In the third week, humidity reduction 5%. Humidity at the end of treatment was about 60% (Chart 5).

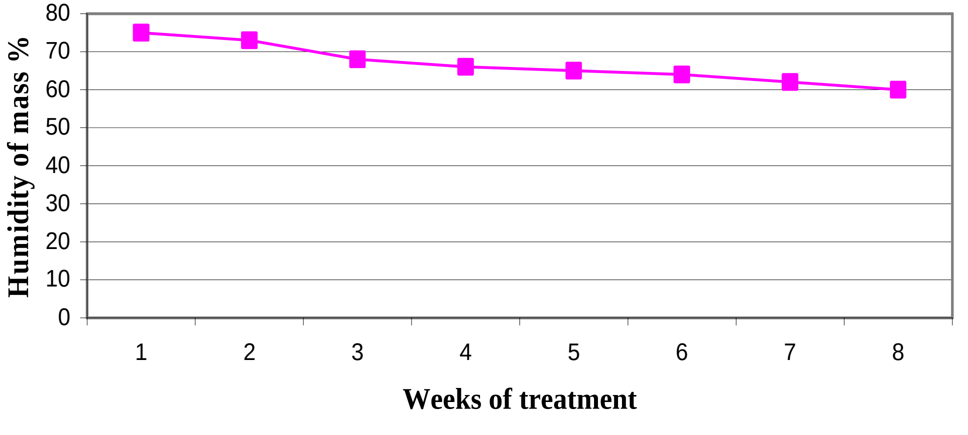


**Chart 5** Changes in humidity of mass during the process

The porosity of the mass in the treatment period increased from an initial 65 % to 83 % at the end of the fourth week of treatment. After stagnating and slightly declining, it comes to 78% at the end of process (Chart 6).

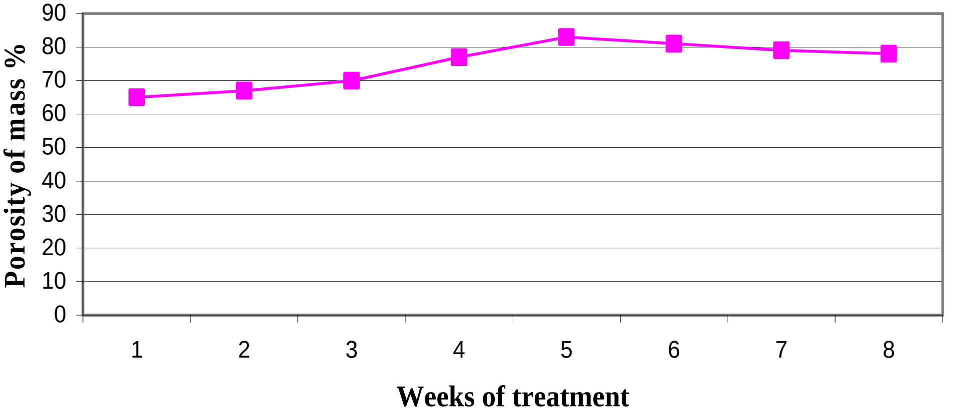


**Chart 6** Changes in porosity of mass during the process

Organic dry matter content generally followed a downward trend. The initial content is 91 % and the final 75%. Certain stagnation was found during the second week of treatment (Chart 7). Before joining and mixing, liquid manure and straw were analyzed on N content. Found quantities of nitrogen from both components and mass portion of 1 $m^3$ of liquid manure and 300 kg of straw was 6 mg/g in fresh mixture. During treatment, the nitrogen content increases in the first three weeks slightly, while in the remaining four weeks, increase ranging from 50 up to 300%. At the end of the last week of treatment the nitrogen content was 11 mg/g. The reason for this phenomenon is the evaporation of water, which increases the concentration of nitrogen in the rest of the mass, as well as partial mineralization organic matter (Chart 8).

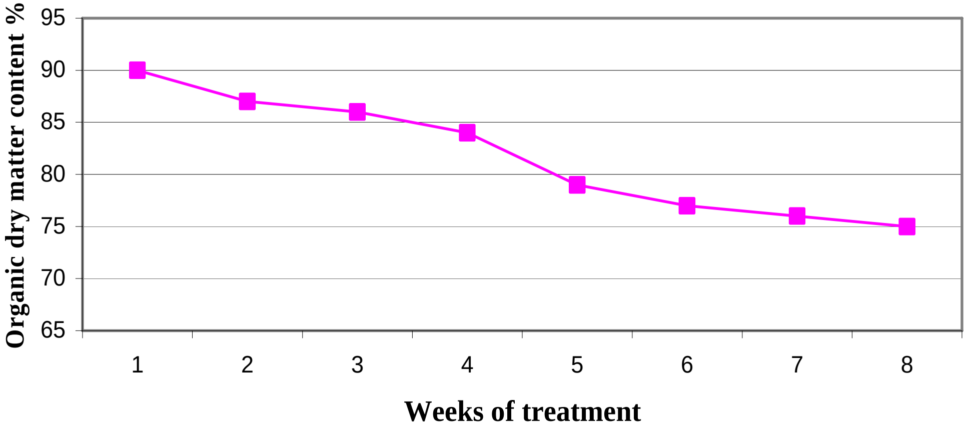


**Chart 7** Changes in organic dry matter content during the process

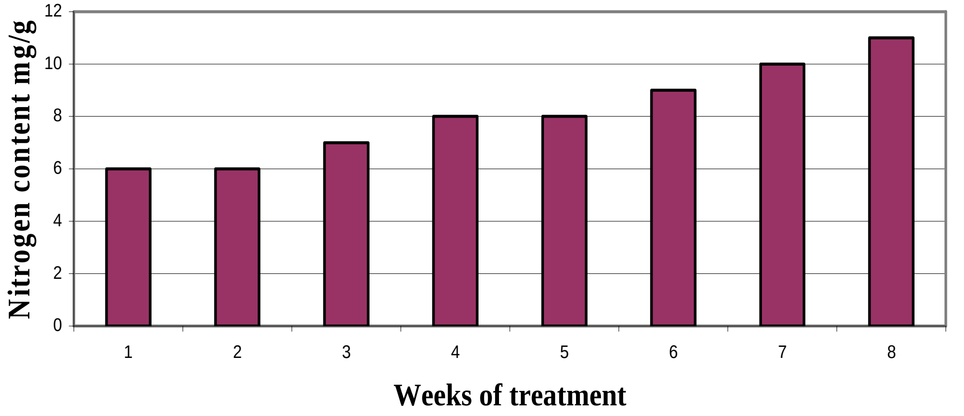


**Chart 8** Changes in nitrogen content during the process

Easily volatile nitrogen compounds are intensely lost in the treatment period. Especially reducing the ammonia content is noticiable. The loss was most pronounced during the first week, and in the second and third week of treatment, it stagnatied. At the end of care there were only a traces of this compounds (Bernal M.P., *et al* 2009, Michel F.C. Jr. *et al*. 2004) . The initial value of the ammonia content was 2.8 mg/g and in the end only 0.2 mg/g (Chart 9). pH value of the mass shows a growing trend, especially at the beginning of care. In the middle of the treatment period, pH value stabilized, and at the end of traetment was on levele of 8.9 (Chart 10).

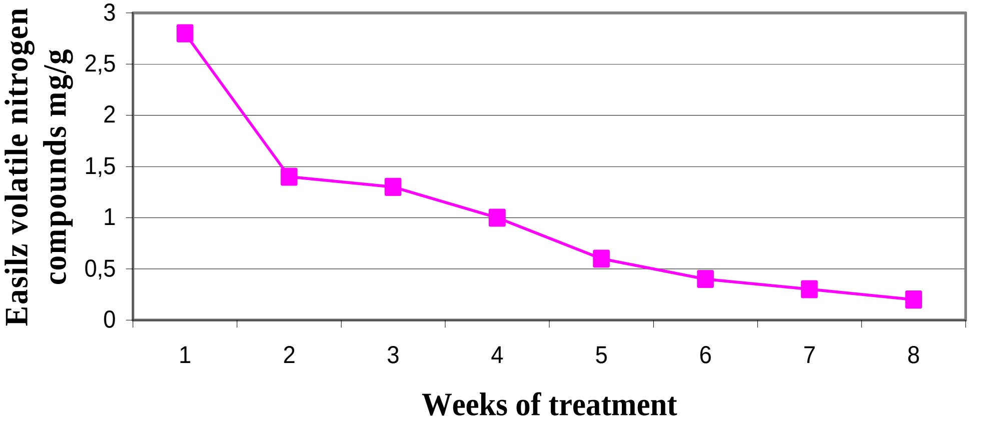


**Chart 9** Changes in easily volatile nitrogen compounds content during the process

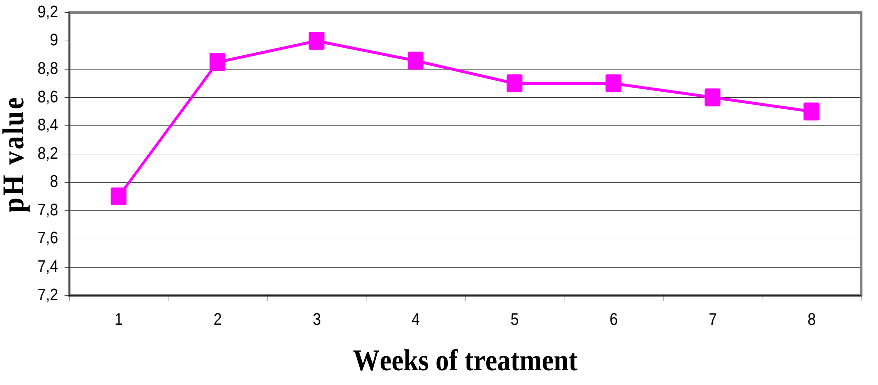


**Chart 10** Changes in pH value during the process

The ratio C/N at the beginning and during the first week of care was at the level of 20:1 to 25:1. Such value of C/N ratio allowed the maintenance of high temperatures in the mixture (Barrington S *et al.* 2002, Huang G.F *et al*. 2004). With the reduction of this ratio, the activity of thermophilic microorganisms is reduced as well. At the end of care, the C/N was 12:1.

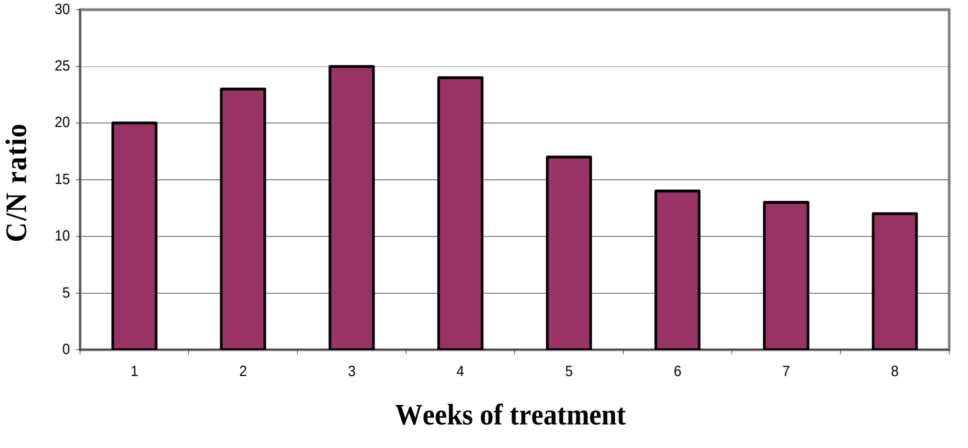


**Chart 11** Changes in C/N ratio during the process

## CONCLUSION

Full transformation of liquid manure in solid manure is possible with the use of an organic residues from crop production. In this case it was wheat straw. Knowing adsorptive capabilities of straw it is possible to make a mixture in which 1 kg of straw adsorbs 5-15 l of liquid manure. The amount of liquid manure that will be adsorbed by straw depends on the consistency of liquid manure and the level of straw preparation.

In controlled process of treatment, under aerobic conditions, notable changes in mixture of liquid manure and straw occur. At the beginning of care, the temperature soars. Weight is reduced by 70 % compared to initial value. Average density is reduced by about 50%, the hight of prisms also about 50%. Organic matter content was significantly reduced compared to the initial state. Porosity of mass increases about 30%. The content of total N is increased, but content of volatile nitrogen compounds is significantly reduced, as well as C / N ratio.

The results obtained in this study are only part of the elements that are important for the process of composting. Every parameter studied in this paper, have significant impact on the overall implementation of technology, and the design and construction of associated facilities for the composting process. These parameters can also affect the choice of appropriate equipment for the preparation and treatment of mass in all stages of the technological process.

## ACKNOWLEDGMENTS

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# ANALYSIS OF SEPARATION CURVES FOR A CONICAL SIEVE WITH A VERTICAL SHAFT AND OSCILLATION MOVEMENT

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**ABSTRACT**

*Separation of granular products on sieves with oscillatory motion can be appreciated with the aid of three curves: distribution curve of material separated for each area of the sieve; cumulative percentage curve of granular material separated on the length of the sieve; cumulative percentage curve of unseparated material on the length of the sieve.*

*If the separation sieve is a conical one with a vertical shaft and alternative oscillatory motion in horizontally plane, separation of granular material is estimated on the base of the cone radius. Depending on the movement kinematic parameters and functional parameters of the sieve, those three separate curves can have different profiles.*

*Thus at a conical sieve with circular apertures were analyzed differences between curves profiles depending on the amplitude and frequency of the oscillation movement and flow of material feed. Sieve was used to separate large impurities from rapeseed, character of material movement on sieve being appreciated by separating profile curves. Distribution curve of material separated on the length of sieve has a similar profile to Gauss curve with or without asymmetry. Character of material movement was appreciated by maximum position of distribution curve on the separation cone radius, using a Gauss function.*

***Key words****: conical sieve, circular oscillate movement, separation curves, Gauss function*

## INTRODUCTION AND LITERATURE REVIEW

Sifting is a way to separate a mixture of particles based on the separation by particle size, in correlation with the number of sieves and the mesh size of each sieve.

Removal of impurities from the stored grain mass and prevent of damage caused by contaminants on seeds quality lead to increase the storage period and reduce losses in storage.

In paper [1], was analyzed the influence of impurities on microbial activity and quality of wheat seeds storage, at a temperature of 30$^{o}$C and relative humidity of 80-90%, in conditions of simulated storage. The results showed that the remaining impurities in the wheat seeds had a negative effect on the quality of storage. It is, so, necessary that impurities to be separated before storing of wheat, to reduce the negative effects during storage of grain.

Separation process on sieve with oscillatory motion has by providing optimal state of sifting imprinted by movement of the sieves and, eventually, a stream of air that passes through the layer of material on the sieve, bottom-up. The separation of through apertures of material on sieve is a complex process influenced by physical properties of the components of a mixture subjected to separation, geometry and surface type of separation, kinematics and functional parameters of the sieve, etc., [5].

The material particle size which must be separated influence the shape and geometric characteristics of the sieve, and way of feeding and the thickness of the material on the sieve can be provided by a uniform feed flow. For a feed flow too high there a risk that in material refused by sieve to find also particles smaller than the apertures that have not met the conditions necessary to pass through these.

The efficiency of the sifting process is influenced by the inclination of the sieves, and by coefficient of friction of the material with its surface, [4,6].

Character of movement of material on sieve and the travel speed directly influences the separation process, these parameters are determined by the kinematic regime of the sieve. In the case of fixed sieves, movement of the particles takes place due to the inclination of the sieve and can be separated only small impurities, without being able to make a proper separation after width or thickness of the particles [2,4].

Description of seed separation on sieves with oscillatory motion can be made stochastic or deterministic.

Stochastic description of the separation process, through mathematical models, is the result of correlation analysis of experimental data with existing distribution functions or laws in mathematical statistics. The intensity of separation of the material along the length of the sieve and the cumulative percentage of material at various distances from the feed point of the sieve is parameters that can be described stochastic [3].

Deterministic description of the process of separation takes into account the main parameters that characterize separation process, and by applying the theory of dimensional analysis and similarity can be determined coefficients of mathematical model, based on data obtained from experiments.

## MATERIALS, METHODS AND PROCEDURES

In order to study the separation of large impurities from rapeseed harvested with combine and the movement of the material on the sieve was used a conical vibrating sieve with circular apertures, suspended by three elastic cables arranged in angle at 120°, both above and below, feeding being made central, through apex of the cone, by a funnel with orifice of ϕ25 mm, having the possibility of adjustment for height to change ring section for flowing between sieve and funnel, [2,3,7].

Actuation of sieve was made eccentric, with an mechanism with oscillating coulisse, at a distance d (adjustable within $d_{min}$ and $d_{max}$) by axis of the cone. Thus, movement of sieve can be considered an alternative circular motion with very small displacements on ar and vertical direction. High impurity content in the mixture of seeds was of 3%, those having sizes of 3-4 mm, separating itself fully over edge of sieve. The main indicator of the quality of separation was losses of seeds and rapeseed character of movement on sieve.

Collection box of sieve is composed of annular alveoli with the following collecting external diameter: 80, 140; 200, 260, 320, 410 and 460 mm. Scheme of principle of sieve and collecting box is shown in fig. 1.

The samples of material were formed at each occurrence from 0.5 kg rapeseed, in addition with 15 g (3%) large foreign bodies, made up of parts of the stems of rape.

Humidity of rapeseed was 7.65-8.05 %, and the parties straw 8.35-8.70% determined by a thermobalance Partner MAC-110, at drying temperature of 105°C. The seeds have a size between ϕ1.5-2.5 mm, (at the rate of more than 90%), determined by sifting with sieve of side apertures of 150 µm, respective 250 µm. For three adjustable distance of the feeding funnel compared to sieve, The feed rate had values 0.020 kg/s, 0.033 kg/s and 0.042 kg/s, in the paper being presented the results of experiments for the highest feed flow. Changed parameters, in research, was the frequency of oscillation of the sieve, through revolution of the actuator with oscillating coulisse, and the amplitude of the oscillation, through position of the joint of liaison arm of mechanism with sieve (distance d, fig.1).

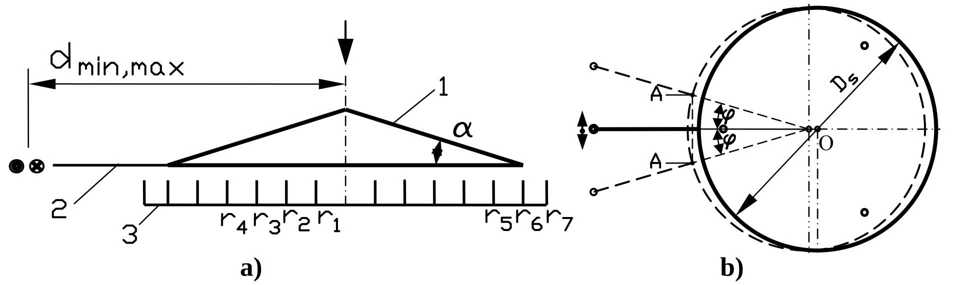


**Fig. 1** Scheme of suspended conical sieve used in experiments; 1. conical sieve with apertures ϕ4.2 mm, 2. actuator arm, 3. collecting box

Conical sieve diameter was 430 mm, and the density of circular orifices on the surface of the separation of 2.25 orificii / cm$^2$ (sieve living area of approximately 31%). The length of suspension wire was 240 mm, at the top and 180 mm, under the sieve.

The amplitude of oscillations, measured at the points A (see fig.1,b), was $A_1$ = 3.58 mm, $A_2$ = 3.74 mm, $A_3$ = 3.91 mm, $A_4$ = 4.10 mm, and the oscillation frequency used in the experiments were 250, 520 and 790 osc./min.

## RESULTS AND DISCUSION

Starting from distribution curve, that presents amount of material collected on a certain length of sieve, can get one from the other two curves which presents either variation of cumulative amount of material separated by sieve apertures, either variation of cumulative amount of material unseparated and transported by to the sieve end or the area discharge.

Curves can be drawn based on the amount of material separated and collected into each alveoli of collecting box, expressed as mass units and as a percentage, being however preferred expression in percentage for a more suggestive presentation of experimental data.

The paper presents results of experiments performed to determine the influence of amplitude and frequency of oscillation on the separating curves profile, at a feed flow, set, of 0.042 kg/s. The material collected under sieve, in the collecting box, was recorded in tables, for each range of collection, both in grams and in percent, the results being presented in Table 1.

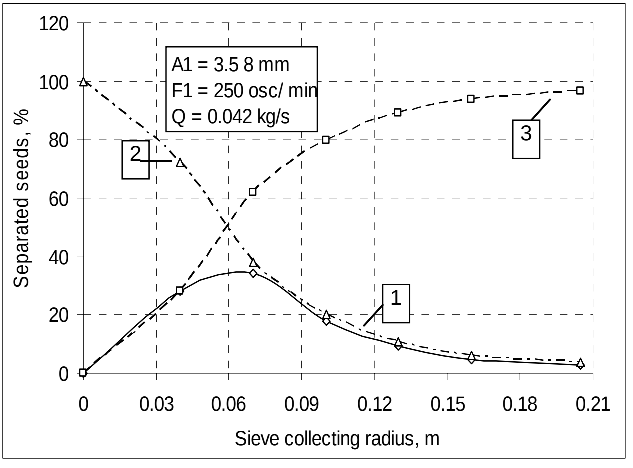


Fig. 2 Separating curves of material on the radius of conical sieve, for amplitude of movement $A_1$=3.58 mm and the frequency of oscillation $F_1$ = 250 osc/min; 1 – distribution curve of the material separated on the sieve length (radius), 2 – curve of cumulative percentage of unseparated material, 3 – curve of cumulative percentage of separated material

Based on the values of the quantities of material collected under the sieve, expressed as a percentage, have been drawn those three separating curves for each experiment and were analyzed differences between the profiles of the curves obtained. These curves are presented graphically in fig. 2, for a specific case, used in experiments. From the analysis of the curves in fig. 2, it is noted that the cumulative percentage of the separate seed under sieve (curve 3), depending on the radius of sieve, tends to 100% (The difference is the loss of seeds beyond the edge of sieve), while the cumulative percentage of seeds unseparated tends to zero, last measured value (and presented on the chart, curve 2) representing seeds collected in the ring last area under the sieve.

**Table 1** Variation of the amount of material collected under the sieve (%), for feed flow Q=0.042 kg/s and four sieve oscillation amplitudes, at different oscillation frequencies

| Nr crt | Q=0.042 kg/s; $M_p$= 500 g | | Sieve range on which it is collected seeds (m) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Amplitude of oscillations | Frequency of oscillations | Separated seeds | 0 | 0.04 | 0.07 | 0.1 | 0.13 | 0.16 | 0.205 | Over sieve |
| 1 | $A_1$= 3.58 mm | $F_1$=250 osc/min | g | 0 | 140 | 170 | 89 | 47 | 23 | 13 | 18 |
| | | | % | 0 | 28 | 34 | 17.8 | 9.4 | 4.6 | 2.6 | 3.6 |
| 2 | | $F_2$=520 osc/min | g | 0 | 100 | 134 | 97 | 86 | 54 | 13 | 16 |
| | | | % | 0 | 20 | 26.8 | 19.4 | 17.2 | 10.8 | 2.6 | 3.2 |
| 3 | | $F_3$=790 osc/min | g | 0 | 142 | 167 | 103 | 49 | 9 | 0 | 30 |
| | | | % | 0 | 28.4 | 33.4 | 20.6 | 9.8 | 1.8 | 0 | 6 |
| 4 | $A_2$= 3.74mm | $F_1$=250 osc/min | g | 0 | 115 | 141 | 92 | 59 | 42 | 21 | 30 |
| | | | % | 0 | 23 | 28.2 | 18.4 | 11.8 | 8.4 | 4.2 | 6 |
| 5 | | $F_2$=520 osc/min | g | 0 | 114 | 141 | 90 | 70 | 39 | 21 | 25 |
| | | | % | 0 | 22.8 | 28.2 | 18 | 14 | 7.8 | 4.2 | 5 |
| 6 | | $F_3$=790 osc/min | g | 0 | 128 | 166 | 95 | 45 | 30 | 9 | 27 |
| | | | % | 0 | 25.6 | 33.2 | 19 | 9 | 6 | 1.8 | 5.4 |
| 7 | $A_3$= 3.91 mm | $F_1$=250 osc/min | g | 0 | 109 | 134 | 95 | 63 | 47 | 19 | 33 |
| | | | % | 0 | 21.8 | 26.8 | 19 | 12.6 | 9.4 | 3.8 | 6.6 |
| 8 | | $F_2$=520 osc/min | g | 0 | 115 | 150 | 88 | 65 | 36 | 20 | 26 |
| | | | % | 0 | 23 | 30 | 17.6 | 13 | 7.2 | 4 | 5.2 |
| 9 | | $F_3$=790 osc/min | g | 0 | 128 | 166 | 95 | 45 | 30 | 9 | 27 |
| | | | % | 0 | 25.6 | 33.2 | 19 | 9 | 6 | 1.8 | 5.4 |
| 10 | $A_4$= 4.10 mm | $F_1$=250 osc/min | g | 0 | 105 | 118 | 99 | 66 | 52 | 17 | 43 |
| | | | % | 0 | 21 | 23.6 | 19.8 | 13.2 | 10.4 | 3.4 | 8.6 |
| 11 | | $F_2$=520 osc/min | g | 0 | 115 | 155 | 90 | 59 | 34 | 19 | 28 |
| | | | % | 0 | 23 | 31 | 18 | 11.8 | 6.8 | 3.8 | 5.6 |
| 12 | | $F_3$=790 osc/min | g | 0 | 134 | 176 | 81 | 48 | 26 | 12 | 23 |
| | | | % | 0 | 26.8 | 35.2 | 16.2 | 9.6 | 5.2 | 2.4 | 4.6 |

Seed distribution curve separated in each of the alveoli of collecting box (density distribution curve) has a similar profile to Gauss curve, with a certain asymmetry (in fig.2 asymmetry is to left).

For motion estimation of seeds on sieve (for possible analysis of the relative motion character or state of sifting existent), were used in the paper only values of the percentages of material that give the distribution curve (curve 1, fig.2).

For these values, represented graphically, were performed regression analyzes on the computer in the program Microcal Origin vers.7.0, of experimental data, with distribution function type Gauss (distribution law commonly used in such analyzes), for which were determined equation coefficients and correlation coefficients $\chi^2$ and $R^2$ (eq. 1),

$$p_X(\%) = y_O + A \cdot \exp\left(-\frac{(x - x_C)^2}{2 \cdot w^2}\right) \; ; \; y_o = 0, \qquad (1)$$

where: $p_x(\%)$ is the proportion of material separated on an interval of distance (range) of sieve.

From the study of charts obtained found that these curves has a maximum positioned at a distance from the feed point of the sieve, which leads to the conclusion that the movement of the material on the separating surface of the sieve can be estimated by the maximum position of the end of sieve (to us sieve center is point where it is done feeding with material).

Thus, coefficient „A" represents the maximum percentage of material collected in boxes under sieve, „$x_c$" is sieve the radius corresponding to the maximum percentage of seeds separated (or the average from the distribution function type Gauss), and „w" is spread compared to maximum position. These coefficients depend on the parameters of adopted work regime, and physical characteristics of the seeds.

As a result, the curves may show some asymmetry of the peak of the curve of material separation on sieve, either of left, either of right, which indicates rapidity or delay which the material was separated.

In Table 2 are presented values of coefficients of the regression equation A, $x_c$ and w, as well as correlation coefficient values $\chi^2$ and $R^2$.

From analysis of data from Table 2 and Fig.3, it appears that, for feed flow Q=0.042 kg/s and the amplitude of oscillation of sieve of $A_1$ = 3.58 mm, with increasing of the frequency from $F_1$ = 250 osc/min to $F_2$ = 520 osc/min, peak position of the distribution curve of material separated on generatrix of sieve (expressed by coefficient value $x_c$ from eq. 1) moving on radius (generatrix) of sieve from the inside to the outside of its (ie from feed to evacuation, from $x_c$ = 0.066 m to $x_c$ = 0.074 m, and then moving back to the feed point ($x_c$ = 0.074 m) at frequency $F_3$ = 790 osc/min, same phenomenon is spending also for amplitude $A_2$ = 3.74 mm (see Table 2).

**Table 2** The coefficients of the regression equation (equation 1), A, w şi $x_c$ and correlations coefficients $\chi^2$ and $R^2$ with experimental data, for the modified kinematic parameters, at feeding flow Q = 0.042 kg/s

| No. sample | Working regime \ Function of type Gauss | | A | $x_c$ | w | $\chi^2$ | $R^2$ |
|---|---|---|---|---|---|---|---|
| 1 | $A_1$ = 3.58 mm | $F_1$ = 250 osc/min | 34.784 | 0.066 | 0.033 | 18.749 | 0.928 |
| 2 | | $F_2$ = 520 osc/min | 27.244 | 0.074 | 0.042 | 26.058 | 0.834 |
| 3 | | $F_3$ = 790 osc/min | 25.737 | 0.077 | 0.045 | 23.861 | 0.833 |
| 4 | $A_2$ = 3.74 mm | $F_1$ = 250 osc/min | 23.728 | 0.082 | 0.049 | 20.659 | 0.832 |
| 5 | | $F_2$ = 520 osc/min | 25.203 | 0.085 | 0.050 | 20.811 | 0.855 |
| 6 | | $F_3$ = 790 osc/min | 26.758 | 0.075 | 0.044 | 26.663 | 0.829 |
| 7 | $A_3$ = 3.91 mm | $F_1$ = 250 osc/min | 28.296 | 0.073 | 0.040 | 26.852 | 0.845 |
| 8 | | $F_2$ = 520 osc/min | 29.555 | 0.071 | 0.038 | 23.807 | 0.871 |
| 9 | | $F_3$ = 790 osc/min | 35.972 | 0.071 | 0.036 | 11.543 | 0.916 |
| 10 | $A_4$ = 4.10 mm | $F_1$ = 250 osc/min | 33.278 | 0.068 | 0.034 | 16.587 | 0.931 |
| 11 | | $F_2$ = 520 osc/min | 34.065 | 0.067 | 0.033 | 18.308 | 0.926 |
| 12 | | $F_3$ = 790 osc/min | 35.283 | 0.065 | 0.031 | 21.235 | 0.919 |

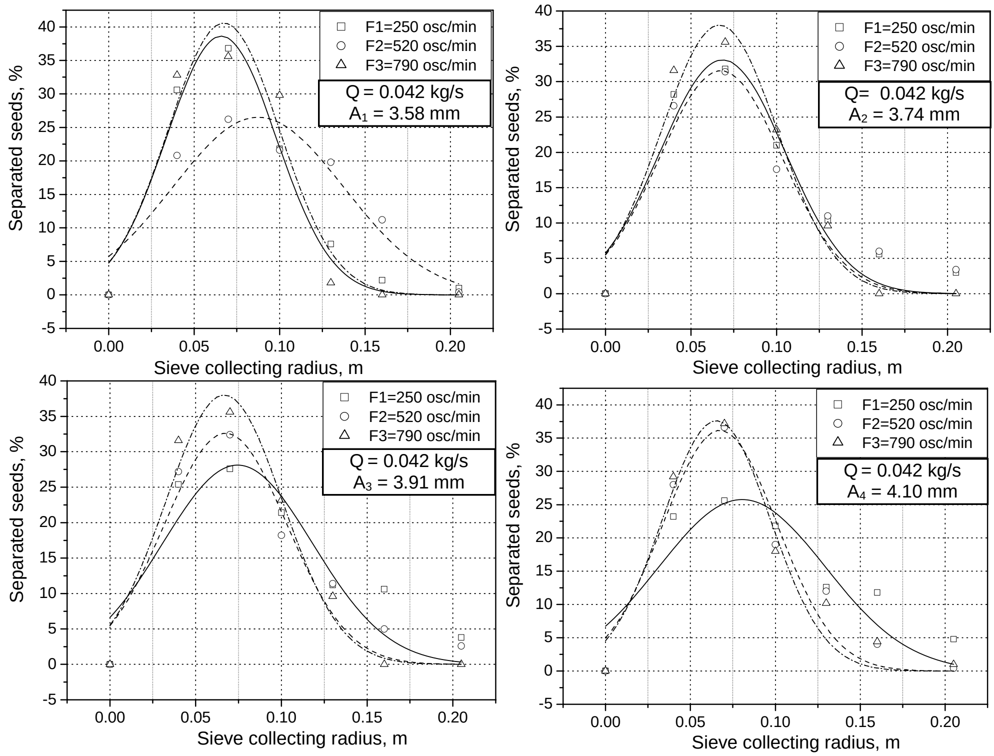


**Fig. 3** Influence of sieve oscillation frequency on the separation process of seeds on conical sieve generatrix, at feed flow Q = 0.042 kg/s, for four oscillation amplitudes of sieve

By increasing the amplitude of oscillation of at $A_3$ = 3.91 mm there is an improving of working process, maximum position of the distribution of separation curve moves on sieve generatrix from the outside to the inside of its (namely from evacuation to feed, from $x_c$ = 0.073 m, for oscillation frequency of sieve $F_1$=250 osc/min, to $x_c$ = 0.071 m for frequencies $F_2$= 520 osc/min and $F_3$ = 790 osc/min). The same phenomenon occurs also for the amplitude $A_4$ = 4.10 mm (see Table 2).

More synthetic, in fig. 4 is observed displacement of position of the maximum of the separation curve with different oscillation frequency for those four amplitudes analyzed at considered feed flow Q= 0.042 kg/s.

In fig. 4 (right) is presented the variation of seed losses for flow rate Q=0.042 kg/s, depending on the amplitude of oscillations and frequency of oscillation of the conical sieve.

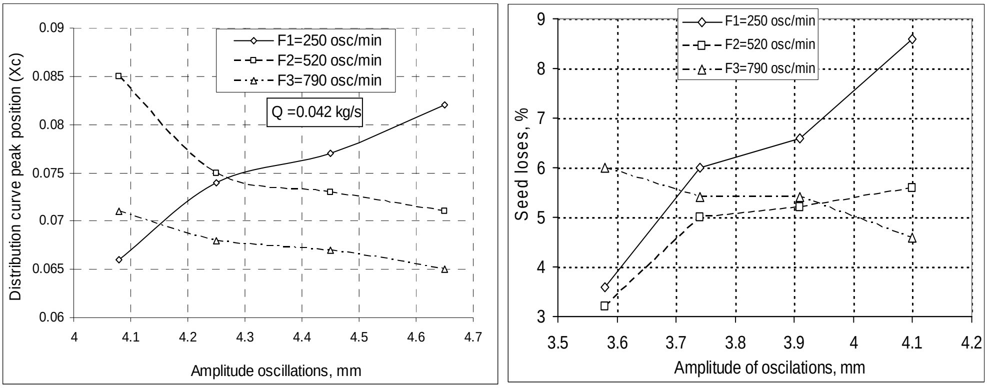


**Fig. 4** Changing the position of maximum of the separation curve based on the amplitude of the sieve oscillations, for the three oscillation frequencies used in experiments

## CONCLUSIONS

Separation of foreign bodies from seesd mixture is done based on differences between physical characteristics of seeds and foreign material (dimensions, aerodynamic properties, coefficient of friction, elastic properties, shape, density,color, etc).

In order to ensure the state of sifting the material on sieve is necessary, either appropriate inclination of sieve, either imprinting a vibratory motion (oscillating) to separation surface.

Vibratory motion is used, in practice, in various fields, including agriculture and food industry, both for the transport of powdery or granular products, and in order to achieve separation processes, that is, to remove impurities from seed mixtures or for sorting after size of vegetal products.

Most mathematical relations proposed by researchers, in the scientific literature, to describe the separation process is based on an number of simplifying assumptions, and process quality assessment takes into account actual ratio between the amount of impurities and initial seeds mass.

Shape of sieves orifices for cleaning and sorting of seeds of agricultural crops is chosen both according to the size by which the separation is done (circular or elongated), and according to the shape of seeds (triangular, square).

The curves of separation of the material along the length of rectangular sieves or on conical sieves radius have an similar profile to Gaussian curve, mean, dispersion and asymmetry of curves depending both on the physical characteristics of material subjected to separation, geometric characteristics of the surface of separation, and of kinematic regime adopted in functioning.

At conical sieve used in experiments, profile of distribution curve, and the maximum of curve to the vertical axis of sieve changes both according to the amplitude of the oscillations and on the basis of the oscillation frequency of sieve, if feed flow remains constant. The correlation of experimental data with Gaussian distribution law is very good, appreciated through very high values of the correlation coefficient $R^2$ (over 0.85 mostly).

At high oscillation frequency, the position of maximum of separation curve approaches to the axis of sieve with increasing of oscillations amplitude, which entitles us to believe that the separation process becomes faster. No experiments were performed above the oscillation frequency that rapeseed not have time to pass through apertures or for amplitudes which will influence the displacement of seeds from a aperture to other.

We believe that the data presented in our paper can be a material of interest to specialists in designing, construction and exploitation of equipment for the separation of impurities from mixtures of cereal grains or other agricultural crops, for choosing optimal parameters of separation regime on conical sieves.

## AKNOWLEGEMENT

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42. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

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Stručni rad
Expert paper

# INFLUENCE OF THE VIBRATION AMPLITUDE ON THE QUALITY OF SHREDDED MEDICINAL VEGETAL MATERIAL SUBJECTED TO SORTING

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## SUMMARY

*In this paper is done a comparative study on the sorting degree of three species of medicinal plants, respectively tutsan (*Hypericum perforatum *L.), yarrow (*Achillea millefolium *L.) and peppermint (*Mentha piperita *L.) in fresh state and dry. Shall be determined the amplitude of vibration of the sorter and is compared the energetic consumption of the sorting process for the three categories of medicinal plants considered for the study. There are presented the results and conclusions.*

***Key words:*** *amplitude of vibration, degree of sorting, energy consumption, medicinal plants*

## INTRODUCTION

The experimental researches were performed in the Laboratory "Technologies in Food Industry" within the National Institute of Agricultural Machinery (INMA) Bucharest during June-August 2013. The three species of fresh and dried medicinal herbs were cut to the dimensions of 5 and 12 *mm*.

The products thus Cut were transported with the help of the inclined conveyor belt, with scrapers and discharged into the feeding hopper of the vibratory sorter and from here, on the upper sieve of this [1]. During the process the energy consumption was monitored with the help of the device CA 8334B.

The sorter was provided with two sets of three sieves with the mesh size of 2.15, 4.00 and 6.30 *mm* for the plants sorting cut to the size of 5 *mm* and with sieves with apertures of

5.00, 8.00 and 13.20 *mm* for the plants cut to the size of 12 *mm*. The inclination angle of the sorter sieves was of 13°20′.

## MATERIAL AND METHOD

To calculate the amplitude of oscillatory motion carried out by the sorter sieves an accelerometer was placed measuring on three axes simultaneously in six important points, respectively in the four corners of the frame and in two symmetrical points in the median plane (Figure 1).

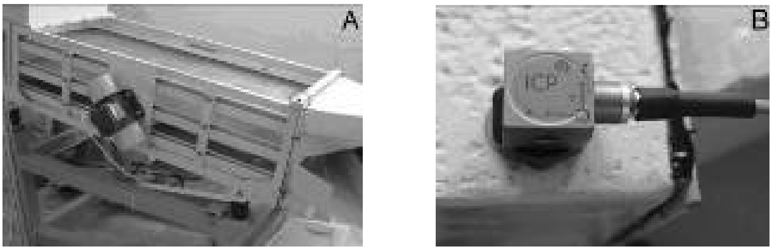


**Fig. 1** Location of the accelerometer on the sieve frame (A), detail (B)

For the measurements there were used:

- piezzoelectric accelerometer with measurement on three axes type 356B20, manufactu-red by PCB Piezotronics USA, having the following main characteristics shown in Table 1;

**Table 1** Technical specifications of the accelerometer type 356B20 [4]

| **Characteristic** | **M.U.** | **Value** |
|---|---|---|
| Sensitivity (± 20%) | *mV / (m/s²)* | 0.1 |
| Measuring range | *m/s² pk* | ± 49.050 |
| Frequency Range | *Hz* | 2...7.000 |
| Resonance frequency | *Hz* | ≥ 55 |
| Temperature range | *°C* | –54…121 |
| The output impedance | *Ω* | ≤ 200 |
| The sensing element | – | ceramic |
| housing material | – | titanium |
| Dimensions | *mm* | 10.2 x 10.2 x 10.2 |
| Mass | *g* | 4 |

- three channels amplifier type 480B21, manufacturer PCB Piezotronics, USA (Figure 2), which carries out the conditioning of signals from the accelerometer and amplifying them in three possible ranges (x1, x10, x100);
- acquisition board on four-channels type NI 9233 manufactured by National Instruments, USA (Figure 3), which converts the analog input signal into a digital signal, signal which is passed further to PC (laptop).

**Fig. 2** Signal Amplifier [4]

**Fig. 3** Four-channel acquisition board [3]

In order to achieve the coupling of the output of the serial acquisition plate to one of the USB inputs of the laptop was used an adaptor type NI USB-9162 produced by National Instruments.

Though were made measurements of the acceleration in six-points on the sorter frame, after studying the resulting graphics, revealed that the differences between them are insignificant and that's why the further study aimed only the the variation of the acceleration in a single point picked in the median plane, in no load and in load.

For data acquisition was used a bloc - chart performed using of LabVIEW software. To achieve the logical scheme was configured the measuring instrument and there were created the graphical recorders. The representation of physical instruments was performed using the existing graphical elements in the library of the graphical programming language LabVIEW.

The sampling period was selected of 0.5 *ms*. The measuring time was 9 seconds for each point, in the graphs in Figure 4, presenting the first 3 seconds of measurement.

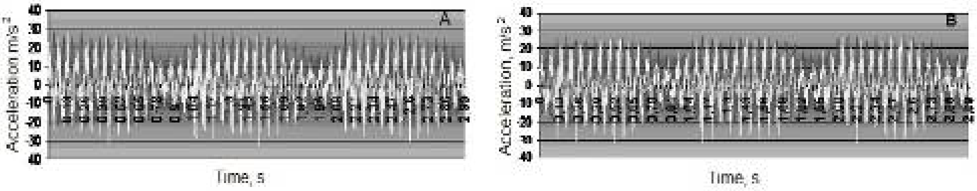


**Fig. 4** The graph of accelerations on the three axes, in no load (A) and in load (B)

The Variation of the acceleration on each axis individually, in no load and in load, within a period of 0.5 seconds, is shown in Figures 5 ... 7.

The analysis of graphics shows that the acceleration decreases in the case of sorter exploitation in load.

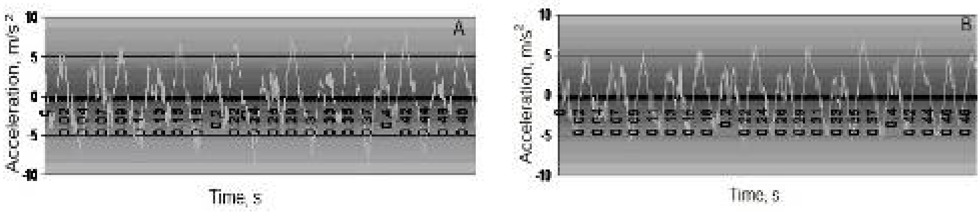


**Fig. 5** The Variation of the acceleration on OX axis, in no load (A) and in load (B)

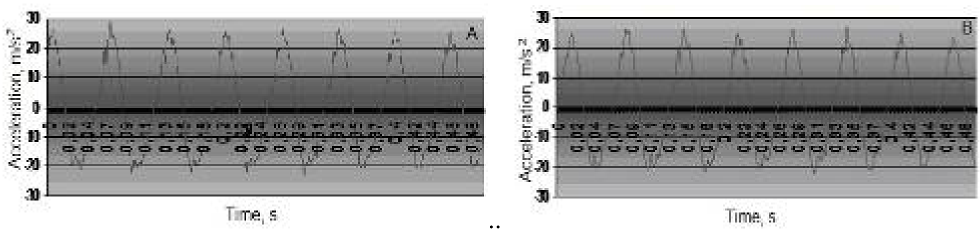


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**Fig. 6** The Variation of the acceleration on OY axis, in no load (A) and in load (B)

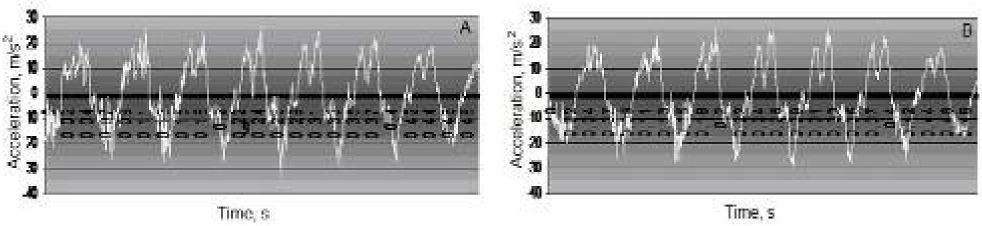


**Fig. 7** The Variation of the acceleration on OZ axis, in no load (A) and in load (B)

For the calculation of the average acceleration of the vibratory sieve on the ox, oy and oz directions in no load, and taking into account the fact that the measuring range was of 0.5 *s* at a frequency of 16 *Hz*, have been used in the formulas:

$$\overline{a}_{x\max g} = \frac{1}{16} \cdot \sum_{1}^{16} \left| a_{x\max g} \right| = 7.05 \ m/s^2, \tag{1}$$

$$\overline{a}_{y\max g} = \frac{1}{16} \cdot \sum_{1}^{16} \left| a_{y\max g} \right| = 23.96 \ m/s^2, \tag{2}$$

$$\overline{a}_{z\max g} = \frac{1}{16} \cdot \sum_{1}^{16} \left| a_{z\max g} \right| = 24.88\ m/s^2, \tag{3}$$

where: $\overline{a}_{x\max g}$, $\overline{a}_{y\max g}$, $\overline{a}_{z\max g}$ represents the average of the maximum accelerations on the directions ox, oy and oz, within the considered range, in no load. Maximum amplitude on the three directions, in no load is calculated with the relations:

$$A_{xg} = \frac{\overline{a}_{x\max g}}{\omega^2} = \frac{\overline{a}_{x\max g}}{4\pi^2\nu^2} = \frac{7{,}05}{4\pi^2 \cdot 16^2} \cong 0.7\,mm, \tag{4}$$

$$A_{yg} = \frac{\overline{a}_{y\max g}}{\omega^2} = \frac{\overline{a}_{y\max g}}{4\pi^2\nu^2} = \frac{23{,}96}{4\pi^2 \cdot 16^2} \cong 2.37\,mm, \tag{5}$$

$$A_{zg} = \frac{\overline{a}_{z\max g}}{\omega^2} = \frac{\overline{a}_{z\max g}}{4\pi^2\nu^2} = \frac{24{,}88}{4\pi^2 \cdot 16^2} \cong 2.46\,mm. \tag{6}$$

Similarly, calculating the average acceleration of the vibratory sieve on the directions ox, oy and oz in load, were obtained the following values for the maximum amplitudes:

$$\overline{a}_{x\max s} = 5.55\,m/s^2;\ A_{xs} = 0.55\,mm, \tag{7}$$

$$\overline{a}_{y\max s} = 22.99\,m/s^2;\ A_{ys} \cong 2.27\,mm, \tag{8}$$

$$\overline{a}_{z\max s} = 19.89\,m/s^2;\ A_{zs} \cong 1.97\,mm, \tag{9}$$

where: $\overline{a}_{x\max s}$, $\overline{a}_{y\max s}$, $\overline{a}_{z\max s}$ represents the average of the maximum accelerations on the directions ox, oy and oz, within the considered range,, in load, and $A_{xs}$, $A_{ys}$, $A_{zs}$ - the maximum amplitudes on the three directions, in load.

Following the calculations it was found that the real amplitudes of the oscillations on the oy and oz directions are within the prescribed literature values respectively from 1 to 6 mm.

## RESULTS AND DISCUSSIONS

To determine the material shredding quality were prepared the tables 2 ... 4 with the masses of the four types of varieties obtained after sorting. based on the data were drawn and the diagrams representing the degree of sorting obtained for the two cutting lengths of 5 and respectively 12 *mm*.

**Table 2** The sorting degree of millefolli Herb, plant fresh and dry, cut at 5 and 12 mm

| Cutting length, *mm* | The sorting degree on sizes, *mm* | Mass of the sorted products, *g* | | The sorting degree, *%* | |
|---|---|---|---|---|---|
| | | Fresh Yarrow | Dry Yarrow | Fresh Yarrow | Dry Yarrow |
| 5 | over 6.30 | 28.20 | 8.70 | 11.28% | 10.12% |
| | over 4.01 up to 6.30 | 118.40 | 46.80 | 47.36% | 54.42% |
| | over 2.16 up to 4.00 | 82.30 | 26.30 | 32.92% | 30.58% |
| | under 2.15 | 21.10 | 4.20 | 8.44% | 4.88% |
| | Total, *g* | 250.00 | 86.00 | 100% | 100% |
| 12 | over 13.20 | 21.00 | 6.70 | 8.40% | 7.36% |
| | over 8.01 up to 13.20 | 71.50 | 25.80 | 28.60% | 28.35% |
| | over 5.01 up to 8.00 | 124.10 | 48.80 | 49.64% | 53.63% |
| | under 5.00 | 33.40 | 9.70 | 13.36% | 10.66% |
| | Total, *g* | 250.00 | 91.00 | 100% | 100% |

**Tabel 3** The sorting degree of Menthae Herb, plant fresh and dry, cut at 5 and 12 mm

| Cutting length, *mm* | The sorting degree on sizes, *mm* | Mass of the sorted products, *g* | | The sorting degree, *%* | |
|---|---|---|---|---|---|
| | | Fresh peppermint | Dry peppermint | Fresh peppermint | Dry peppermint |
| 5 | over 6.30 | 25.50 | 7.80 | 10.20% | 8.21% |
| | over 4.01 up to 6.30 | 103.60 | 50.20 | 41.44% | 52.84% |
| | over 2.16 up to 4.00 | 90.20 | 30.70 | 36.08% | 32.32% |
| | under 2.15 | 30.70 | 6.30 | 12.28% | 6.63% |
| | Total, *g* | 250.00 | 95.00 | 100% | 100% |
| 12 | over 13.20 | 26.30 | 3.90 | 10.52% | 4.02% |
| | over 8.01 up to 13.20 | 68.70 | 26.90 | 27.48% | 27.73% |
| | over 5.01 up to 8.00 | 125.70 | 50.60 | 50.28% | 52.16% |
| | under 5.00 | 29.30 | 15.60 | 11.72% | 16.09% |
| | Total, *g* | 250.00 | 97.00 | 100% | 100% |

**Tabel 4** The sorting degree of hyperici Herb, plant fresh and dry, cut at 5 and 12 mm

| Cutting length, *mm* | The sorting degree on sizes, *mm* | Mass of the sorted products, *g* | | The sorting degree, *%* | |
|---|---|---|---|---|---|
| | | Fresh tutsan | Dry tutsan | Fresh tutsan | Dry tutsan |
| 5 | over 6.30 | 23.60 | 5.60 | 9.44% | 5.83% |
| | over 4.01 up to 6.30 | 109.70 | 53.40 | 43.88% | 55.63% |
| | over 2.16 up to 4.00 | 90.50 | 28.60 | 36.20% | 29.79% |
| | under 2.15 | 26.20 | 8.40 | 10.48% | 8.75% |
| | Total, *g* | 250.00 | 96.00 | 100% | 100% |
| 12 | over 13.20 | 21.30 | 4.50 | 8.52% | 4.25% |
| | over 8.01 up to 13.20 | 60.70 | 28.40 | 24.28% | 26.79% |
| | over 5.01 up to 8.00 | 123.40 | 54.70 | 49.36% | 51.60% |
| | under 5.00 | 44.60 | 18.40 | 17.84% | 17.36% |
| | Total, *g* | 250.00 | 106.00 | 100% | 100% |

Measuring in no load power variation was performed and on the medicinal plants sorter, using the same apparatus. The active power value read on the device scale (obtained by the internal integration algorithm), as well the average, resulted from the calculations after raising of graphics was about 304 *W* (Figure 8).

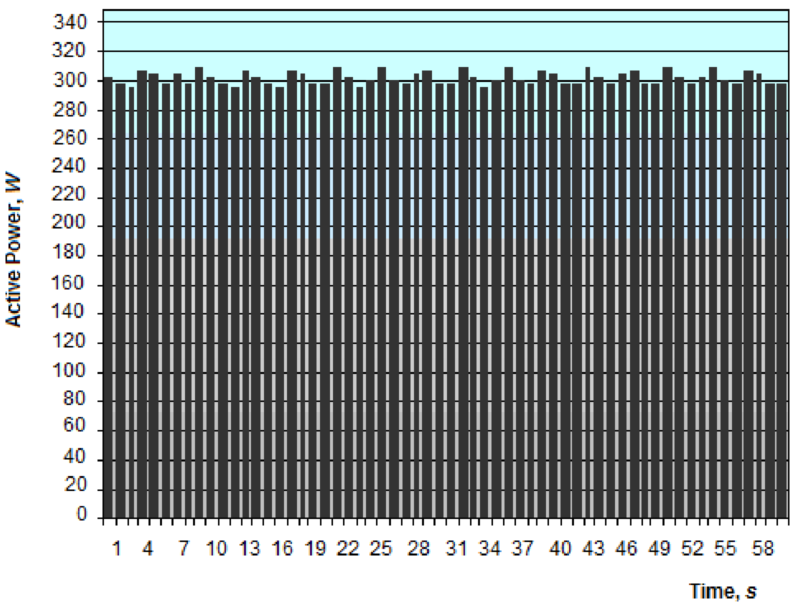


**Fig. 8** Measurement of power variation of vibratory sorter in no load

The active powers measured were very close as value for all the species of medicinal plants (Figure 9), the amount of energy consumed for the separation on sorts of sizes being higher for the fresh herbs, this being due to the more extensive duration of the sorting process, in comparison with the ones dried [2].

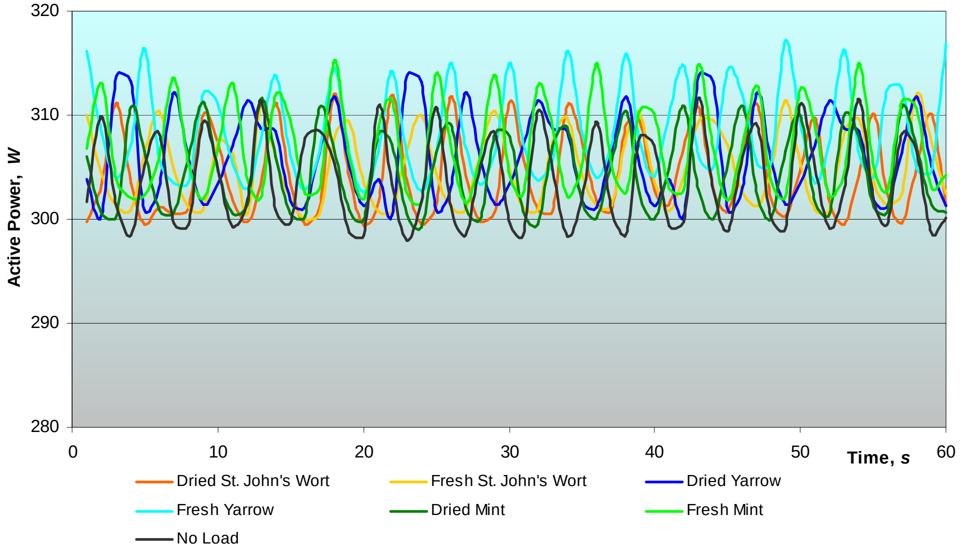


**Fig. 9** Variation in time of the active powers, in the sorting process

The active power has the appearance from the Figure 10 because the sorter actuation is provided by two engines with eccentric, and these present periodic variations in the absorbed current.

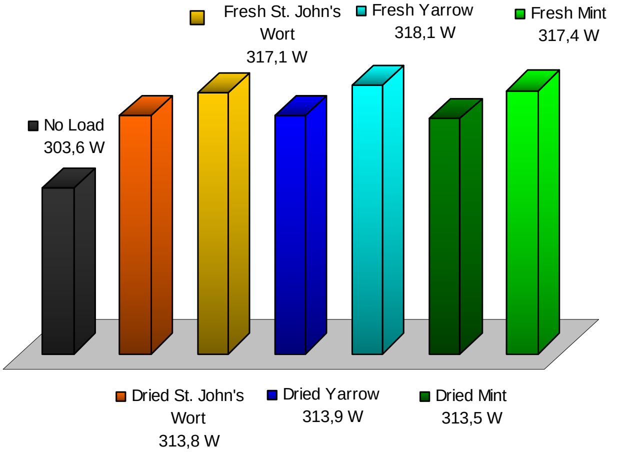


**Fig. 10** Average values of active powers in the sorting process

## CONCLUSIONS

An important conclusion of the experimental researches is that even though the measured active powers were very close as value for all the plants, the amount of energy consumed for the separation on sorts of sizes was higher for the fresh herbs. This was because these needed a longer sorting duration in comparison with the dried ones, with implications on the increase in energetic consumption.

Also, it is found that the active energy associated only of the sorting process represents between 3.16 ... 4.56% of the total active energy consumed under load.

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Original scientific paper

# ISSUES RELATING THE MECHANICAL DAMAGES PRODUCED BY THE IMPACT LOADING OF THE FRUITS

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## SUMMARY

*In this paper, we are experimenting a direction of research that concerns the study of the reaction to the impact of the fruit in order to assess the degree of injury and developing mathematical models that achieves its correlation with the level of impact, allowing prediction of injuries due to impact and, more specifically, through susceptibility index of injury from impact defined by the kinetic energy dissipated in the collision (or initial kinetic energy) or the impact maximum force, in which the probability of injury of fruit when the first contused tissue appear does not exceed a certain threshold (e.g., typically 10%, after certain standards).*

*Based on data obtained from experiments, using one of the specialized programs Table Curve or Microcal Origin, were tested a few logistical functions, and a Rosin-Rammler function, with experimental data and the nonlinear regression constants have been determined by logistical coefficients C, C1 , m, μ, and α, n, and the corresponding correlation coefficients, R2, which determine compliance functions tested with experimental data through their value as close to the unit.*

*Experiments were performed on a batch of 108 apples, 3 varieties of apples, and the data processed partly in the form of the mean value ($\overline{X}$) and standard deviation squared value (σ) of the fruit mass (m), initial kinetic energies impact (Eci) at the 4 levels of impact velocity (vi), together with the number of damages percentage probabilities (p%), similar to the percentage share of the fruit of the injured in the mass of fruit to each group were structured in the form of tables, they can thus be used for estimation of the index of susceptibility to damages in the impact.*

***Key words**: apple, impact, viscoelastic, mathematical model, impact characteristics, initial kinetic energies, damages percentage probabilities, index of susceptibility*

## INTRODUCTION

In the chain of activities after the harvest, for the fresh fruit of agricultural production, they suffer from a chain of packing-transport operations (handling)-storage-sorting, an important element is the operation of temporary storage or long, or for marketing purposes, or to preserve.

Are intensified concerns both in the world and in Romania, for the development a method (which may become standard) to determine an value of reaction to the collision of fruits, well defined, strived to achieve very important data and helpful in choosing the optimal working schemes of technical systems for sorting-packing-handling, in improving and enhancing their constructive, in design, as well as in the areas of genetic improvement, selection of varieties, in the techniques of crop growth and development, the choice of post-harvest treatment of fruits, [1].

Thus was developed and founded the theoretical concept of susceptibility value of damage from impact, a more appropriate size that expresses the damage through impact to be covered in evaluations, the natural variability of physical and mechanical characteristics of the fruits, through the probabilistic interpretation of the phenomenon of impact damage, [1].

The damage degree of the fruits and fruit injured share in technical systems for handling, transport and sorting-packing, depends on the maturity degree of fruits and the conditions for growth and development in orchards, complexity and constructive and functional parameters of the technical system, the type and its working arrangements, time of operation (before or after a period of storage).

An important direction of research that concerns the study of the reaction to the impact of the fruits in order to assess the degree of damage and developing mathematical models that achieves its correlation with the level of impact, allowing prediction of damages due to impact.

A matter of importance for the assessment of damage due contusion tissue of fruit flesh, either through the volume bruised, either by the diameter of contusion mark visible on surface of the fruit, either by specific kinetic energy absorbed or kinetic energy available from which appear first bruise (crushed) cell invisible to the eye (which can be found at 1,5-2,5 mm below fruit epicarp, [2]), either by the susceptibility value to damage from impact (defined by kinetic energy at the beginning of the impact when appear first tissues bruised or kinetic energy to which the predicted probability of damage to fruit does not exceed 0,1 or 0,05 ), either by the degree of damage appreciated in probability that the fruit does not contain more than a certain number of points of bruised or a contusion area, [1,3,4].

## THEORETICAL ELEMENTS

In the last time are developed methods of assessing the degree of damage to fruit to impact stress using susceptibility value of damage from impact with a method that involve the kinetic energy at impact which does not exceed a certain value accepted of probability of injured fruits.

More general, susceptibility value of damage at impact of fruits are the value who characterizes the limit level of impact for which the predicted probability of damage is equal to a fixed value (5% or 10 %), [5,6,7]. The index of susceptibility to damage from impact of fruit is a new concept which has in view natural fluctuation of development conditions and functional parameters for installations taken into account by introducing into mathematical models of the concept of probability. This approach was also covered in a series of recent work [1,3,4)], being offered several types of mathematical models. Of these we notice that the model the most appropriate, with superior results in practical use is the probabilistic law which is a logistical type with two parameters which gives the probability of damage fruits according of initial kinetic energy of the impact, as the follow equation, [1,4,5]:

$$p = \frac{\exp\left(C + m \cdot E_{ci}\right)}{1 + \exp\left(C + m \cdot E_{ci}\right)}, \tag{1}$$

where p is probability of damage (expressed as decimal); $E_{ci}$ - initial kinetic energy of the impact (J); C,m - logistical constants.

Thus, in the work (1,4), been assessed level of impact on which appear first bruises of tissues, it has been determined the correlation between the probability of damage and the kinetic energy at impact and it has been assessed (estimated) the susceptibility value at damage from collision for apples.

The experiments have used Jonathan apples, and they were carried out at the laboratory of processes and equipment for primary processing of agricultural products "from the Department of agricultural machinery to the Faculty of Biotechnical systems engineering of the “University Politehnica of Bucharest”. For performing the impact of fruits we have used pendulum method using a pendulum-type device (calibrated for measurements), and produced in the laboratory.

Data obtained from experiments on a lot consisting of 36 fruits, under the averages form ($\overline{X}$), and root mean square standard deviations (σ) of the fruits mass and for four levels of initial kinetic energy of the impact to the 4 levels of impact velocity, together with percentage probability of damage treated by percentage share of injured fruit mass are represented in fig. 1, where the sample was represented by logistic curve (1) where the parameters C and m have been determined through non-linear regression of experimental data.

Variation of probability of damage for impact of apples as described by the relation (1) in relation to the experimental dates is shown in figure 1, in which it was extrapolated the validity of field relation.

We highlight the deficiency of relation (1) in which $E_{ci}$ = 0 is obtained $p = \frac{\exp C}{1 + \exp C} \neq 0$ and logically should have been that p = 0. To remove this deficiency in the work [4], the author substantiates its theoretical and experimental, it propose a relation of logistic type, more general, like:

$$p = \frac{1-\exp(-\mu X)}{1+\exp(C-\mu X)}, \qquad (2)$$

where X is the value of the threshold level physical impact probably; μ, C – logistical.

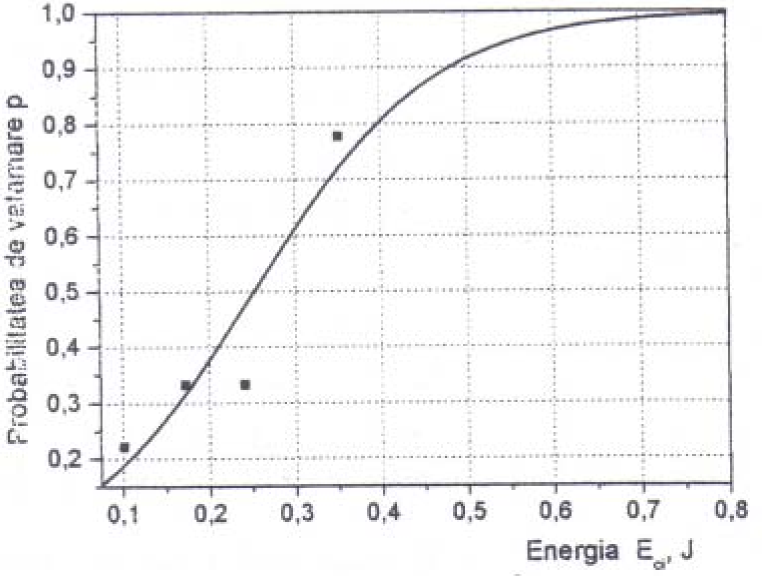


**Figure 1** Logistic curve consistent with experimental data for Jonathan apples [3]

It is to be noted that in rel. (2), for X = 0 is obtained p=0, which satisfy logical requirement. Equation (2) describes better the probabilistic calculation susceptibility to damage from collision of fruits.

Research carried out in [1,4], on a practical way for the evaluation of the probability of damage at apples impact as a function of initial kinetic energy of the impact, for the variety Jonathan, have revealed that they can be satisfactorily described by a logistic equation with two parameters form the relationship (1), and significantly more accurately can be described by the relation (2) in which $X = E_{ci}$, and c and μ are properly logistic parameters.

The equation can be useful in the work of the design of technical systems of pick-packaging of apples, as well as in the activity of rational use of them, by defining the term of susceptibility value to damage from impact, a measure which expressed more appropriate and further explained the impact damage, by introducing into an appreciation of natural variability of the physical characteristics and mechanical of the fruits, through the interpretation by probabilistic way of the impact damage phenomenon.

## METHODS, RESULTS AND DISCUSSION

*Testing models for analysis the susceptibility at impact of fruits*

A direction of research refers to experiments which affects the study of the behaviour impact of the fruit in order to assess the extent of damage and the development of mathematical models which carries out its correlation with the level of impact, allowing predict damages from impacts.

One of the modes of appreciation of damages due to fruit flesh contusion tissue by impact value is by susceptibility of impact damage, as defined by the limit of kinetic energy dissipation to impact (or initial kinetic energy), or the maximum force of the impact, in which the predicted probability of damage to fruit when appear first contusion tissues does not exceed a certain limited percentage (e.g. as a rule 10 %, according to certain standards).

This is why we will present, in the following, the use of equation in practical situations, applying to experiments carried out in the context of this paper. According to the data of the literature, [1,4,5,6], is used, two laws of probability - logistic type, with two parameters which associating percentage p(%) of the injured fruit, the probability of damage from impact, according of the impact level, appreciated by $E_{ci}$ of the form:

$$p(\%) = \frac{1 - \exp(-\mu E_{ci})}{1 + \exp(C - \mu E_{ci})} \cdot 100 \tag{3}$$

şi

$$p(\%) = \frac{\exp(C_1 + mE_{ci})}{1 + \exp(C_1 + mE_{ci})} \cdot 100 \tag{4}$$

where $E_{ci}$ - initial collision kinetic energy (J) C, m, μ - constant logistics.

Because the configuration of the actual experimental curves, p(%) =f($E_{ci}$), for the probability of damage depending on the intensity of the impact ($E_{ci}$), has the sigmoid form, a third relationship, used in determining the probability of damage is a Rosin-Rammler equation:

$$p(\%) = (1 - e^{-\alpha E^{n}{}_{ci}}) \cdot 100 \tag{5}$$

Basis on data obtained from experiments using one of the specialized programs Table Curve or Microcal Origin, have been tested both equations, logistical functions ((3), (4)), as well as the function of Rosin-Rammler (eq. 5), with the experimental data and by the nonlinear regression constants it has been determined the logistical constant C, $C_1$, m, μ, and α, n, and the corresponding correlation coefficients $R^2$, which determine compliance of the tested equations with experimental data through their value as close to the unit. Results of analyses of the impact damage for testing are given in table 1.

Data obtained from experiments on batch consisting of 108 apples, are partially processed under the form of the average value ($\overline{X}$) and standard deviation squared value ($\sigma$) of the fruit mass (m), of initial kinetic impact energies (Eci) at the 4 levels of impact velocity (vi), together with the number of damage percentage probabilities (p%), similar to the percentage share of the fruit of the injured in the mass of fruit to each group, are presented, synthesis, in table 1.

**Table 1** Average values ($\overline{X}$) and the average deviations quadratic standard ($\sigma$) of the masses (m), the initial kinetic energy ($E_{ci}$) for the four levels of impact velocities ($v_i$), as well as percentage weightings (p) of the injured fruits, for all 3 varieties of apples

| Variety of apples | $V_i$ (m/s) | m(g) | | $E_{ci}$ (J) | | Damages share |
|---|---|---|---|---|---|---|
| | | Average value | σ | Average value | σ | p(%) |
| Jonathan | 1,04 | 105,91 | 12,3 | 0,0572 | 0,0067 | 100 |
| | 0,83 | 108,36 | 13,5 | 0,0373 | 0,0047 | 89 |
| | 0,67 | 109,16 | 29,4 | 0,0245 | 0,0067 | 67 |
| | 0,5 | 100,31 | 14,2 | 0,0125 | 0,0018 | 11 |
| Idared | 1,04 | 120,1 | 20,5 | 0,0649 | 0,0111 | 100 |
| | 0,83 | 126,03 | 17,5 | 0,0434 | 0,0060 | 77,8 |
| | 0,67 | 139,5 | 19,9 | 0,0313 | 0,0045 | 55,6 |
| | 0,5 | 145,2 | 30,3 | 0,0181 | 0,0038 | 44,4 |
| Golden Delicious | 1,04 | 128,4 | 14,9 | 0,0694 | 0,0081 | 100 |
| | 0,83 | 113,3 | 12,1 | 0,039 | 0,0042 | 89 |
| | 0,67 | 119,2 | 14,6 | 0,0267 | 0,0033 | 77,8 |
| | 0,5 | 120,4 | 20,3 | 0,015 | 0,0025 | 33,3 |

With these data were tested by nonlinear regression with experimental data, three types of the equations proposed, obtaining values of the coefficients and correlation coefficient $R^2$, the values that are presented in table 2.

**Table 2** Values of the coefficients C, $C_1$, m, μ and α, n and the correlation coefficient for the eq. (3) - (5)

| Variety | Coefficient | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | μ | C | $R^2$ | $C_1$ | m | $R^2$ | α | n | $R^2$ |
| Jonathan | 196,6 | 4,2 | 0,987 | -4,44 | 206,04 | 0,986 | 21755 | 2,694 | 0,984 |
| Idared | 55,05 | 0,54 | 0,92 | -1,57 | 65,32 | 0,948 | 94,36 | 1,31 | 0,919 |
| Gold.Delic | 136,4 | 2,45 | 0,98 | -2,84 | 146,9 | 0,983 | 1670,8 | 1,966 | 0,982 |

For this three apple varieties tested, we have plotted the equations obtained in connection with the experimental data in figure 2-10, showing that any of the equations (3) to (5), may be used for the estimation of the susceptibility value to damage at the impact. The usefulness of equations set refers to the estimated values for the susceptibility value ($E_{ci}$ minimum) for the threshold of 10% fixed for the probability of damage (assimilated with the share (%) of the injured fruits). These values are presented in table 3, for the 3 varieties of apples and for those 3 mathematical models used.

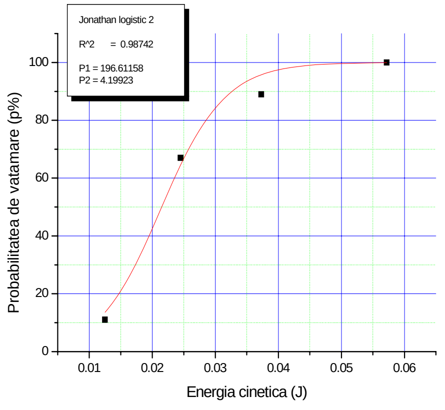


**Fig. 2** Logistics function according ec. (3)

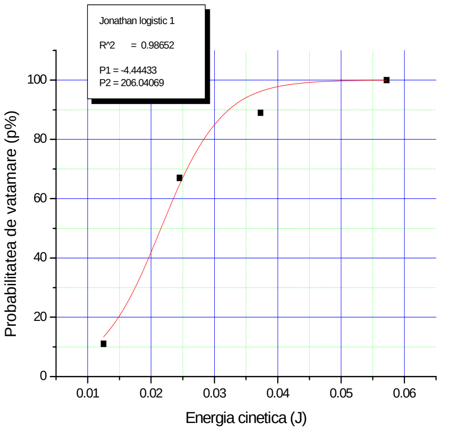


**Fig. 3** Logistics function according ec. (4)

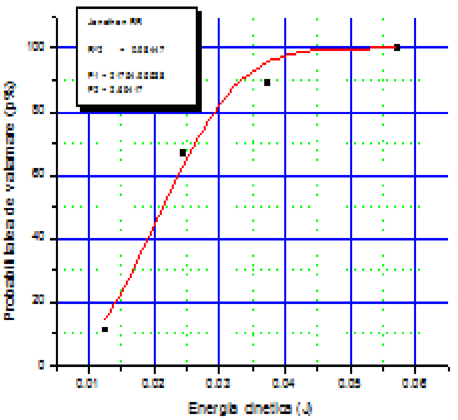


**Fig. 4** Equation Rosin – Rammler according eq. (5)

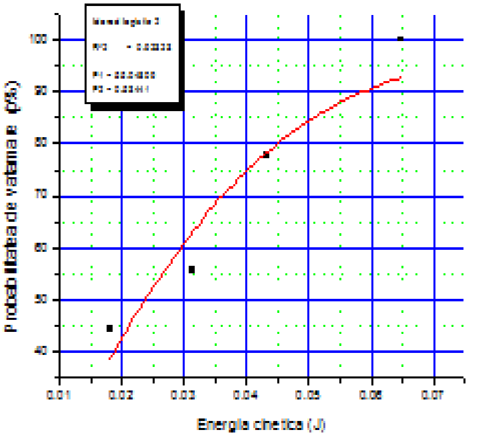


**Fig. 5** Logistics function according eq. (3)

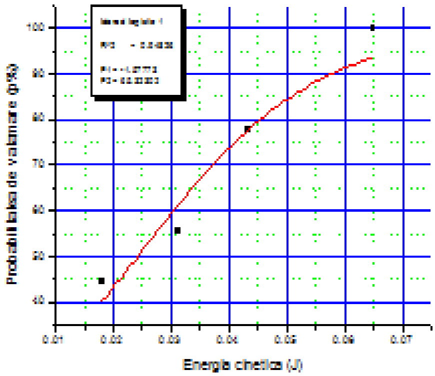

**Fig. 6** Logistics function according eq. (4)

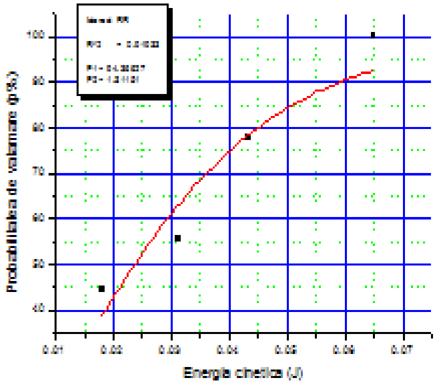

**Fig. 7** Equation Rosin–Rammler according eq. (5)

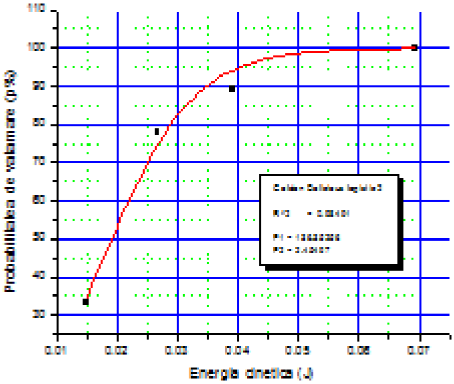

**Fig. 8** Logistics function according eq. (3)

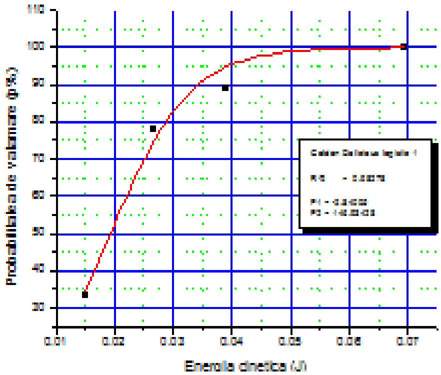

**Fig. 9** Logistics function according eq. (4)

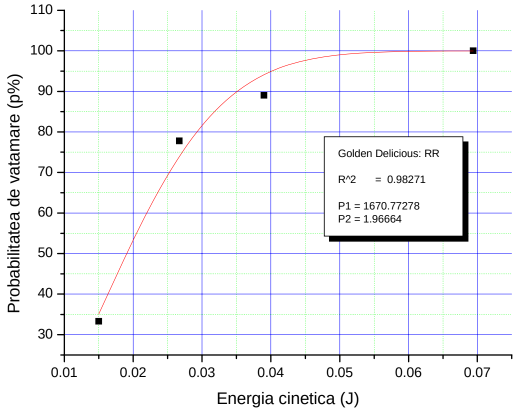


**Fig. 10** Equation Rosin – Rammler according eq. (5)

**Table 3** The values of $E_{ci}$ minim (J) corresponding to a threshold of damage of 10% for this 3 mathematical models

| Variety | The value $E_{ci}$ minim (J) | | |
|---|---|---|---|
| | eq. 3 | eq. 4 | eq. 5 |
| Jonathan | 0,0109 | 0,0109 | 0,0106 |
| Idared | 0,0048 | -0,0096 | 0,0056 |
| Gold.Delic | 0,0064 | 0,0044 | 0,0073 |

## CONCLUSIONS

It is observed that, for the Jonathan variety, susceptibility index values are not significantly different. Also the 3 varieties have different sensitivities to damage, most noticeably being the Idared, and most resistant to damage by impact is the Jonathan. The data in table 3 are useful to estimate average velocity collision so that the probability of damage of fruit does not exceed the recommended threshold of 10%, [5,7]. So for Jonathan variety, for apples with medium masses m = 100 g, and the index of susceptibility to damage from impact, $E_{ci\ min}$ = 0,0109 J min (see tab. 3) yields a minimum velocity of impact of 0,22 m/s, in order not to damage probability of damage of 10%. (Note: it was considered valid ec. (3) and for the values of the velocities out of the direction between 0,5-1,04 m/s, the validity of the model (3) with the coefficients determined from testing with experimental data (see tab. 2)).

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Original scientific paper

# BURGERS MODEL TESTING TO RHEOLOGICAL BEHAVIOR OF APPLES FOR STRAIN COMPRESSION

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## SUMMARY

*In this paper it is present a method to determening experimenthal of relaxation time at compression static strees for apple, with maintaining their integrity. We emphasize the theoretical foundations of the method using the creep test through consideration of linear viscoelastic behaviour of objects described by physical model of rheological Burgers.We found a mathematical model and correspon-ding reological equation, describing the behavior of apples at compression static strees.It is presents the results of the tests for three local apples varieties: Idared, Jonathan, Golden Delicious and is tested the mathematical model of rheological behaviour with experimental data. These data are useful in assessing the du-ration of storage in height known by imposing the distortion coefficient for geometrical form β or if make one's mark the storage time can determine the appropriate height of the crates for storage.*

***Key words****: apple, compression, storage, storage time.*

## INTRODUCTION

In the chain of activities after the harvest, for exploitation of the fruits - agricultural production, in fresh condition, an important element is the process of temporary or long storage. The packages used in this activity, need to keep the original quality of the fruit, namely the maintaining unchanged the characteristic geometric shape.

The fruits of the last lines are subjected to static compressive loading at constant load from the weight of the fruit in the upper ranks, corresponding of the equation force – strain, parameter of the creep phenomenon from mechanical engineering. That's why it should taken into account that the dimensions of the packaging does not exceed certain limits because the place of the fruit over these limits may cause defects affecting their quality and class.

Limiting and even avoiding mechanical defects can be done through useful recommendations in designing and choosing the appropriate package according to the category of fruit ripeness and the duration and conditions of storage.

In this context were expected theoretical and experimental research for the compression behavior of some varieties of apples for the establishment the systems for optimal storage.

In the beginning the study were carried out based on fruit are homogeneous materials and isotropic with linear elastic behavior [4,5,7]. Mathematical models have been developed concerning the contact stresses, strain and the size of the contact spot at the action of an compression force based on the elastic contact Hertz theory in order to assess the mechanical damage of the fruits through contusion of the cell tissue of their [4,7,9].

This facts allowed to development an adequate mathematical models as well as more consistent with reality and on the basis of which to provide a concrete conditions, either mechanical injury level caused by storage in certain packages, either by imposing the maximum admissible level of damages or defects related to error from geometrical shapes or to select the corresponding appropriate packages [1,9,10].

Lately there have been thorough research by consideration of the fruits as anisotropic and inhomogeneous material with viscoelastic behavior [2, 3, 9] (as a first approximation, linearly viscoelastic) a situation closer to the real behavior of the fruit [1, 10].

On this basis the standard methodologies have been developed for testing at compression and to determination the mechanical characteristics (Young elasticity module, deformability, force - strain curve, breaking point, the maximum stress) of apples [12].

In this context the objective of this paper is to development of a mathematical model for describing the behaviour at static compression of apples (considered linear viscoelastic materials) represented by the Burgers model and applying the results to predict the height of the packaging to ensure the avoidance of damages for storage - depositing durations.

## THEORETICAL ASPECTS

The fruits are biological materials, and for that reason they don't react to stress, in a purely elastic way, their reaction combining a elastic and viscoelastic behavior.

The tests regarding the compression behavior of apples have highlighted through the force-strain curves response, that the effect of the time of application of the force and strain velocity, has practical importance for the creep of fruit under static load [9,11].

During storage, the fruit are subjected to static loads for extended periods of time, strain and damage can appear from pressure, far below the required standard at compression tests. To get more detailed data about creep (strain) of fruits, has developed a technique so that continuous strain under static load can be registered in time.

In order to find appropriate rheological equation of the apple behavior at the static compression loading, while maintaining its integrity in accordance with the Burgers mecanical model, was used for the same model, instead of specifics strain and streses, forces and strains according to Fig. 1, with the following notations: δ-strain; K- strenght of the arch (representing the ideal elastic element); η*-viscosity pneumatic device damping (represents the ideal viscous element).

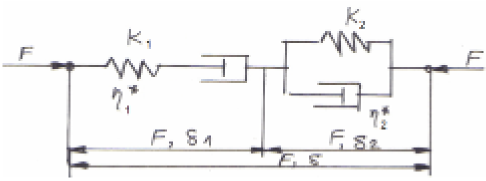



**Fig. 1** The Burgers physical model to describe behavior in compression of whole apple

In the paper [6] the authors presented in detail the development of the mathematical model of apple strain at static compression with maintaining the integrity of the fruit. We reproduce the main equations from this paper, [6], that will be used in the present paper.

The body (fruit) represented by the Burgers model, subjected to the action of a compression force, F = $F_0$ = const. will be take on a strain in time, which will produce, in accordance with the principle of superposition effects, according to the equation:

$$\delta = \frac{F_0}{K_1} + \frac{F_0}{\eta_1^*} t + \frac{F_0}{K_2}\left(1 + e^{-\frac{t}{T_i}}\right) \tag{1}$$

If after a period of time ($t_1$) to maintain a constant strength $F_0$, it produces a strain $\delta(t_1)$ which is obtained from the eq. (1) by substituting $t = t_1$, there has been a total discharge by removing the $F_0$ and in consequently a elastic delayed recurrence according to the equation:

$$\delta = \frac{F_0}{K_1}\left(1 - e^{-\frac{t_1}{T_i}}\right) e^{-\frac{t}{T_i}} + \frac{F_0}{\eta_1^*} t_1 \tag{2}$$

where t is measured from the moment of strength $F_0$.

In this equation if we make $t \to \infty$ we obtained:

$$\delta = \delta_1 = \frac{F}{\eta_1^*} t_1 \tag{3}$$

representing the remanent strain of the body after removing the action of constant strength $F_0$ during $t_1$.

$$T_r = \frac{\eta_1^*}{K_1} \text{ and } T_i = \frac{\eta_2^*}{K_2}$$

where: Ti-time delay (slow down) (in the Kelvin model); Tr-relaxation time (Maxwell model), and the next steps in given hereafter.

Obs: Eq. (1) and (2) of strains variation over the delayed elastic strains and elastic return after total discharge it's obtain by customization the solutions of the constitutive rheological equation as differential form of the Burgers model (fig. 1) [6,11]:

$$T_i \ddot{\delta} + \delta = \frac{T_i}{K_1} \ddot{F} + \left( \frac{1}{K_1} + \frac{T_i}{T_r K_1} + \frac{1}{K_2} \right) \dot{F} + \frac{1}{K_1 T_r} F$$

In [6,11] indicates that $T_r$ and $T_i$ expressed by the equations above have the same meaning to these terms express from the Burgers model by Young module of elastic elements and the dynamic viscosity of viscous elements of the Maxwell and Kelvin-Voigt component that compose the model.

After experimental pegging-out of the strains in time for a constant strength known F = $F_0$ = const., shall be tested according to the type of equation (1) with the experimental data, once it is put in the form:

$$\delta = Y = a - be^{-ct} + dt \tag{4}$$

$$a = \frac{F_0}{K_1} + \frac{F_0}{K_2}; \qquad b = \frac{F_0}{K_2}; \qquad c = \frac{1}{T_i}; \qquad d = \frac{F_0}{\eta_1^*}$$

where the coefficients a, b, c, d are obtained by linear regression from eq. (4) with the experimental data.

Knowing the coefficients a, b, c, d, using the notations are determined the dimensions $K_1$, $K_2$, $\eta_1$*, $\eta_2$ *, $T_i$ and $T_r$. These metrics are useful in the evaluation of remanent strains $\delta_1 = \delta_r = \frac{F_0}{\eta_1^*} t_1$ that allows either the storage duration $t_1$ assessment that does not exceed an imposed amount δr, either the evaluation of compression strength $F_0$ for a imposed length $t_1$ and a acknowledged remanent deformation δr required for rating the height of packaging for storage.

We defined the coefficient of geometric shape distortion $\beta = \frac{\delta_r}{2R}$(R-radius of the fruit) [4,8] and then:

$$\delta_r = \frac{F_0}{K_1 T_r} t_1 = 2\beta R \text{ we obtain the, } t_1 = \frac{2\beta R K_1 T_r}{F_0} \tag{5}$$

Using the equation (5) to evaluate the storage length t1 of apples for known height packages or allowing the evaluation of the compression strength F0 established itself the distortion coefficient β. If it is necessary the storage length t1 is determined the height of the container for storage.

## MATERIAL, METHOD AND EQUIPMENTS

As a biological material for experiments have been used local apple varieties Idared, Golden Delicious and Jonathan, fig. 2. We used fruit having masses between 85 and 136 g and diameters between 47 and 75 mm

Fig. 2 Views of apples in orchard

In order to carry out the tests of static stress creep compression of apples it was developed a device for testing the compression (D.T.C.) whose diagram is shown in Fig. 3a. In fig. 3 (b, c) are presented the views of the device ready for making measurements. It acts on apple with a static compression request by pressing, with a constant load, either a flat rigid plate fig. 3 (c) or any other half apple fig. 3 (b) and the strain was measured using a comparator clock at different moments of time at the beginning of loading.

To measurement of remanent strain at static loading of medium and long term, there has been presented schematically a device (A.M.D) in Fig 4.(a, b).

As can be seen from Figure 4 (a) on the system board arranges, without being attached to the plate, around the central axis 6 equilateral triangles made of a stiff plywood. Under each triangle will set 3 apples, of approximately equal diameters. The device must meet the requirement to achieve a stable system, so that there is no displacement of loads or samples during the test. This has led to the use of an arrangement of three fruits of approximately equal diameters, arranged at the corners of an equilateral triangle. On each triangle will set three weights of the same mass, (8) a weight for each fruit under triangle.

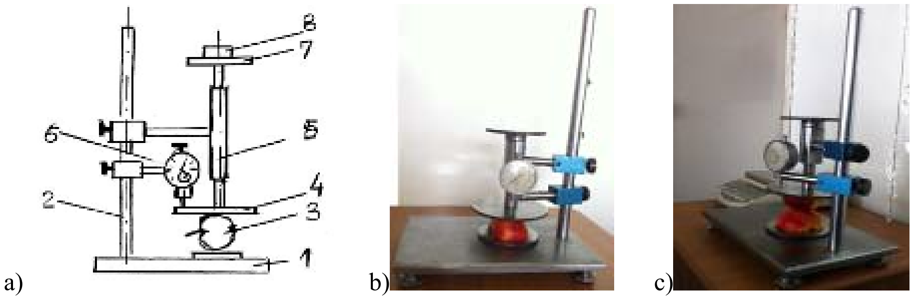
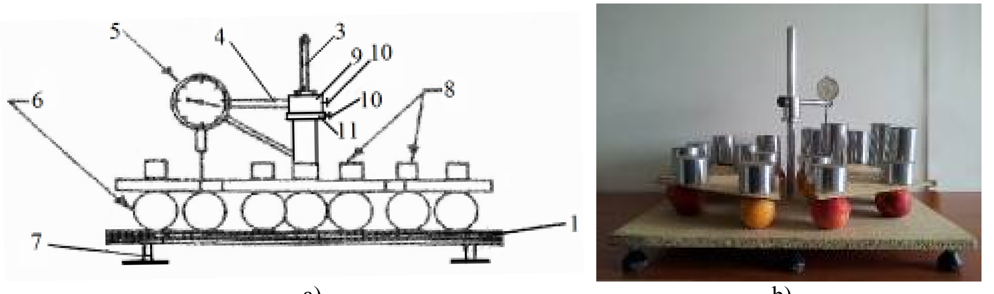



Fig. 3 The device diagram for testing the creep compression of apples (D.T.C.) 1- baseplate; 2-support; 3- apple; 4- press rigid plate; 5 - stabilizer; 6-clock comparator; 7- platen; 8-load weight

In order to avoid rolling apples under static load they were fastened with a small nail caught in the base plate.

Were used weights of 850, 1000, 1250, 1500, 1750, 2250 grams. The six triangles were arranged around the central axis, so their centers of gravity to be located along the circle described by the clock comparator rod.

The strain as the arithmetic mean of the three apples deformation was measured directly in the center of gravity of the triangle.




a) b)

**Fig. 4** Device for measuring the strains of fruit at static loading (AMD) a- the scheme; 1-baseplate; 2-equilateral triangle; 3-central shaft; 4-arm support; 5-clock comparator; 6-fruits; 7-screws for horizontally fixation; 8-weights; 9-sleeve; 10-screw; 11-ring mounting b-view during operation

In order to assess the storage time, using data from tests of short duration, it has sought to extend the test experiments of creep, extends the duration of the test of creep from 2 hours and 40 minutes to 40 hours, with measurements on our device (D.T.C.), fig. 3.

To measure the remanent strain at static stress for a medium and long length has been used A.M.D. device (fig. 4). The measured values were compared with the estimated values.

To verify the accuracy of the test using the expressions obtained using data from experiments made on A.T.C. device- Fig. 3 of 2 hours and 40 minutes for long period of time of experimentation, extended up to 40 hours on A.M.D. device, fig. 4.

After applying the masses over the fruits were read and noted indications from clock comparator at intervals laid down previously and timed : 2 hours; 2.6 hours; 4 hours; 8 hours; 16 hours; 20 hours; 24 hours; 32 hours; 40 hours.

At the end of the test, the weights were carefully removed, leaving the triangles it over the apple and the indications from the clock comparator were recorded again at that point, these representing the remanent strains of the fruits after 40 hours of loadingt. Data obtained were used in the mentioned tests.

## RESULTS AND DISCUSSION

In order to test the Burgers model for rheological behavior of apples strain to compression (portion of the creep strain-time curve) at increase of duration of the strain, we extrapolated the data obtained from the experience of 2 hours and 40 minutes at longer durations, namely 16, 20, 24 and 40 hours.

The values of the coefficients a, b, c, d from the eq. 4, obtained from trials with data from experiments (2 hrs and 40 min.), for the three apple varieties corresponding to strenght F = 12.5; 15 and 17.5 N, from our data [6,8] are presented in table 1.

**Table 1** The values of the coefficients a, b, c, d from eq.4 [6,8]

| Variety | Strenght | Values of the coefficients | | | |
|---|---|---|---|---|---|
| | | a | b | c | d |
| Idared | F=12,5 N | 0,00066 | 0,00016 | 0,00237 | 0,0000000170 |
| | | 0,00067 | 0,00017 | 0,00868 | 0,0000000083 |
| | F= 15N | 0,00078 | 0,00019 | 0,00232 | 0,0000000278 |
| | | 0,0009 | 0,00028 | 0,00273 | 0,0000000175 |
| | F=17,5 N | 0,00081 | 0,00024 | 0,00329 | 0,0000000172 |
| | | 0,00087 | 0,00023 | 0,00314 | 0,0000000218 |
| Jonathan | F=12,5 N | 0,00071 | 0,00015 | 0,0017 | 0,0000000292 |
| | | 0,00073 | 0,00018 | 0,00341 | 0,0000000372 |
| | F= 15N | 0,0008 | 0,00019 | 0,00294 | 0,0000000250 |
| | | 0,00091 | 0,00024 | 0,00182 | 0,0000000363 |
| | F=17,5 N | 0,00079 | 0,00019 | 0,00258 | 0,0000000279 |
| | | 0,00085 | 0,00027 | 0,00647 | 0,0000000279 |
| Golden Delicious | F=12,5 N | 0,00101 | 0,00042 | 0,00212 | 0,0000000519 |
| | | 0,00136 | 0,00068 | 0,0013 | 0,0000000390 |
| | F= 15N | 0,00115 | 0,00042 | 0,00229 | 0,0000000416 |
| | | 0,00125 | 0,00044 | 0,00249 | 0,0000000464 |
| | F=17,5 N | 0,00103 | 0,00031 | 0,00297 | 0,0000000353 |
| | | 0,00115 | 0,00037 | 0,00304 | 0,0000000236 |

With eq. (4) for the coef. a, b, c, d from table 1 have been assessed, the strain of the 3 varieties of fruits at compression strenght for 12.5, 15 and 17.5 N and for durations of strenght for 16, 20, 24 and 40 hours, which were compared to measured values. More meaningful data are presented in table 2.

**Table 2** The values of the strains calculated vs. those measured

| Variety | Strenght | Fruit code | Time (hours) | Strain δ Calculated (mm) | Strain δ as measured (mm) | error * (%) |
|---|---|---|---|---|---|---|
| IDARED | F = 12,5 N | I.1.1.1.1. + I. 2.3. | 16 | 1,562 | 1,56 | 0,10 |
| | | | 20 | 1,79 | 1,72 | 4,18 |
| | | | 24 | 2,02 | 1,81 | 11,73 |
| | | | 40 | 2,94 | 2,62 | 12,36 |
| | | I.1.1.1.2. + I. 2.9. | 16 | 1,15 | 1,16 | -1,22 |
| | | | 20 | 1,26 | 1,26 | 0,37 |
| | | | 24 | 1,38 | 1,37 | 0,99 |
| | | | 40 | 1,86 | 1,82 | 2,14 |
| | F = 15 N | I. 1.1.2.3. + I. 2.4. | 16 | 1,85 | 1,85 | 0,10 |
| | | | 20 | 2,14 | 1,94 | 10,30 |
| | | | 24 | 2,43 | 2,08 | 16,73 |
| | | | 40 | 3,58 | 2,84 | 26,05 |
| | | I.1.1.2.4. + I.2.10. | 16 | 1,82 | 1,8 | 1,15 |
| | | | 20 | 2,07 | 1,96 | 5,53 |
| | | | 24 | 2,32 | 2,12 | 9,24 |
| | | | 40 | 3,31 | 3,1 | 6,67 |
| | F = 17,5 N | I.1.1.3.5. + I.2.5. | 16 | 1,70 | 1,7 | 0,07 |
| | | | 20 | 1,95 | 1,88 | 3,70 |
| | | | 24 | 2,19 | 1,94 | 13,29 |
| | | | 40 | 3,19 | 2,87 | 11,15 |
| | | I.1.1.3.6. + I.2.2.11 | 16 | 2,12 | 2,06 | 3,10 |
| | | | 20 | 2,44 | 2,39 | 1,98 |
| | | | 24 | 2,75 | 2,72 | 1,13 |
| | | | 40 | 4 | 3,84 | 4,17 |
| JONATHAN | F = 12,5 N | J.1.1.1.1. + J.2.3. | 16 | 1,92 | 1,89 | 1,56 |
| | | | 20 | 2,22 | 2,18 | 1,92 |
| | | | 24 | 2,52 | 2,34 | 7,88 |
| | | | 40 | 3,73 | 3,2 | 16,69 |
| | | J.1.1.1.1. + J.2.9. | 16 | 1,92 | 2,19 | -12,34 |
| | | | 20 | 2,22 | 2,41 | -7,80 |
| | | | 24 | 2,52 | 2,5 | 0,97 |
| | | | 40 | 3,73 | 3,48 | 7,29 |
| | F = 15 N | J.1.1.2.3. + J.2.10. | 16 | 2,22 | 2,19 | 1,44 |
| | | | 20 | 2,52 | 2,39 | 5,49 |
| | | | 24 | 2,87 | 2,56 | 11,98 |
| | | | 40 | 4,25 | 3,69 | 15,15 |
| | | J.1.1.2.4. + J.2.4. | 16 | 2,55 | 2,45 | 4,20 |
| | | | 20 | 2,96 | 2,78 | 6,69 |
| | | | 24 | 3,37 | 3,01 | 12,26 |
| | | | 40 | 4,2 | 4,19 | 0,24 |
| | F = 17,5 N | J.1.1.3.5. + J.2.11. | 16 | 2,18 | 2,18 | 0,11 |
| | | | 20 | 2,53 | 2,42 | 4,46 |
| | | | 24 | 2,87 | 2,58 | 11,38 |
| | | | 40 | 4,25 | 3,79 | 12,13 |
| | | J.1.1.3.6. + J.2.5. | 16 | 2,45 | 2,43 | 0,96 |
| | | | 20 | 2,85 | 2,68 | 6,57 |
| | | | 24 | 3,26 | 2,79 | 16,79 |
| | | | 40 | 4,86 | 3,98 | 22,11 |

| | | | | | | |
|---|---|---|---|---|---|---|
| GOLDEN DELICIOUS | F = 12,5 N | G.1.1.1.15 + G.2.3. | 4 | 1,70 | 1,70 | 0,19 |
| | | | 8 | 2,10 | 1,89 | 11,45 |
| | | | 24 | 3,72 | 2,78 | 33,78 |
| | | | 32 | 4,53 | 3,54 | 27,84 |
| | F = 15 N | *G.1.1.2.1. + G.2.4.* | 4 | 1,46 | 1,48 | -1,29 |
| | | | 8 | 1,92 | 1,96 | -1,96 |
| | | | 24 | 3,76 | 3,13 | 20,36 |
| | | | 32 | 4,68 | 3,86 | 21,41 |
| | | G.1.1.2.4. + G.2.4. | 4 | 1,53 | 1,48 | 3,57 |
| | | | 8 | 2,06 | 1,96 | 5,39 |
| | | | 24 | 4,19 | 3,13 | 34,17 |
| | | | 32 | 5,26 | 3,86 | 36,33 |
| | F = 17,5 N | G.1.1.3.6. + G.2.5. | 4 | 1,42 | 1,30 | 9,07 |
| | | | 8 | 1,70 | 1,59 | 7,29 |
| | | | 24 | 2,86 | 2,74 | 4,30 |
| | | | 32 | 3,43 | 3,42 | 0,41 |
| | | G.1.1.3.6. + G.2.11. | 16 | 2,28 | 2,28 | 0,09 |
| | | | 20 | 2,57 | 2,56 | 0,39 |
| | | | 24 | 2,86 | 2,74 | 4,31 |
| | | | 40 | 4,01 | 3,98 | 0,75 |

* Error (%)= $[(\delta_c - \delta_m)/\delta_m]x100$

Analyzing data from table 2 it can be seen that most errors are positive, theoretical values are higher than the actual values which allows us to state that the theoretical values calculated are satisfactory compared to real measurements values.

There has been a comparative presentation in the form of graphs of estimated strains with coef. a, b, c, d determined from data in the experiences of short duration (2 hours and 40 minutes) toward those measured with the A.M.D. device, for the longer period, namely: 16, 20, 24 and 40 hours, as can be seen from the graphs shown in fig. 5 – 9.

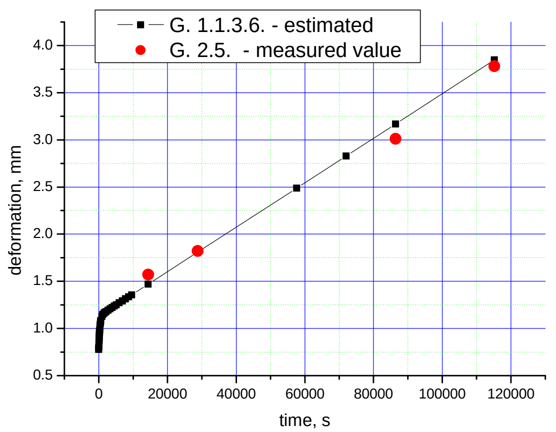



**Fig. 5** The curve for deformation δ (t) in function of time for Golden Delicious to $F_0$ = 17,5 N

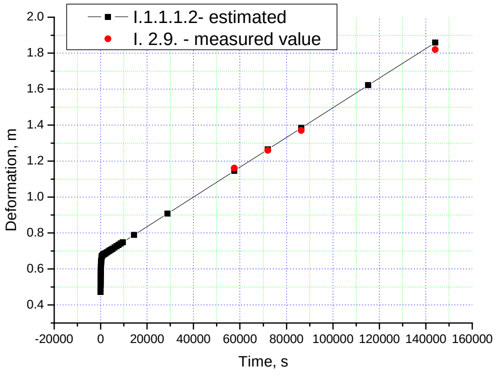



Fig. 6 The curve for deformation δ (t) in function of time Idared to $F_0$ = 12,5 N

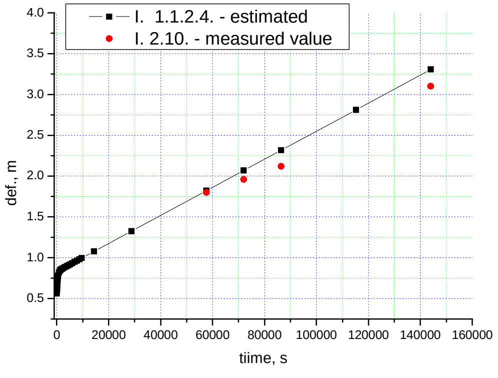



Fig. 7 The curve for deformation δ (t) in function of time for Jonathan to $F_0$ = 12,5 N

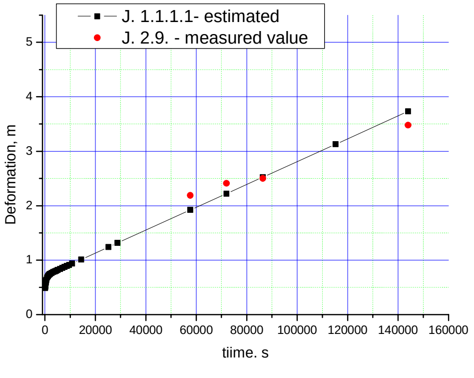



Fig. 8 The curve for deformation δ (t) in function of time for Jonathan to $F_0$ = 17,5 N

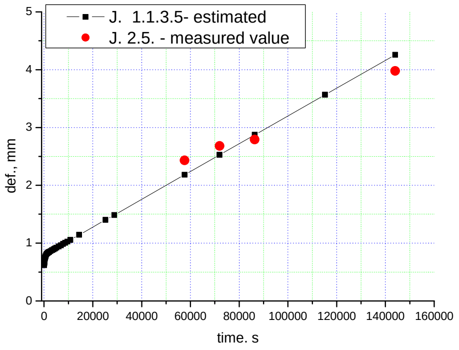



Fig. 9 The curve for deformation δ (t) in function of time for Idared to $F_0$ = 15 N

As can be seen from the graphs shown in fig. 5-fig. 9 estimated values differ in most cases insignificant in the measured values which substantiates the fact that data obtained from short period experiments can be used with good results for extended periods compared to these measurements are very close to the calculated values, sometimes they even lovingly dub it.

## CONCLUSIONS

The apples being biological materials can be considered from the point of view of the response to the compression strains as materials with linear viscoelastic behavior, represented by the Burgers model, were replaced by specific strains with strength and deformations of the testing fruit.

The variation of the static compressive strains of apples with maintaining their integrity can be described by the eq.(1) that was arranged in the form of eq.(4) for testing with experimental data. The coef. a, b, c, d of the eq.(4) for 3 varieties of apples are given in table 1.

We tested the equations (4) for the coef. a, b, c, d obtained from short period experiments (2 hours 40 min) and it can be extended and applied with good results at long period of times (over 40 hours).

The obtained data are useful in assessing the duration of storage of apples in packages of known dimensions.

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42. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

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Prethodno priopćenje
Preliminary communication

# USING OF LOGISTIC FUNCTION FOR THE ANALYSIS OF GRANULOMETRIC CHARACTERISTICS OF PRODUCTS FROM THE TECHNOLOGICAL FLOW OF A CEREAL MILL

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## ABSTRACT

*Cereal seeds are considered biological granular products whose dimensions are subject to distribution laws of Gaussian type, normal law, logistic law or Euler functions. As these, products obtained by grinding of seeds with hammer mills or roller mills follow also similar distribution laws.*

*To verify and support this assertion, in the paper is presented the analysis of variation curves of wheat seeds dimensions subjected to grinding in a flour mill with capacity of 100 t / 24 h, as well as grist intermediate products resulted at roller mills but also of products resulted from sifting and sorting of these within plan sifter compartments.*

*Because the number of grist and fractions sorted at plansifter compartments is very high, in the paper is presented only the products resulted on the circuit (technological flow) of Break 1, from seeds to flour.*

*The experimental data were subjected to regression analysis on the computer, using the logistic function with two parameters, ascertaining for all products analyzed a very high degree of correlation ($R^2 \geq 0.98$ for most of the products) which entitles us to believe that this function can be used to estimate the dimensions and granulometric characteristics of the other products on the technological flow of the mill.*

*The data presented can be of interest to specialists in the designing, construction and exploitation of equipments in the technological flow of cereal mills.*

***Key words***: *roller mills, cereal seeds, grist, flour, particle size-distribution, logistic function*

## INTRODUCTION AND LITERATURE REVIEW

In milling units grinding and sifting are complementary operations, after each grinding operation is performed a sorting on fractions operation (sifting) of grist intermediate products. Reducing the size of wheat seeds and grist intermediate products is made in the passages of technological flow of the unit, a technological passage being formed from a roller mill and a plan sifter compartment. Although sifting is a familiar and simple operation, within her occur a number of variables (grist stratification on the sieve, the relative velocity of the particles on the surface of the sieve, revolution of equipment, etc.) that can lead to erroneous assessment of the process, [9,13].

Sorting on fractions on the technological flow of the milling plant is carried out with plan sifters. They are made up of several compartments within which the sifting frames overlapping are arranged in several packages. At each compartment packages of breakage passage is obtained at least a refusal (break) and a sifting.

This can be directed to the next frame package or can be removed out of compartment and collected separately or transmitted to a technological passage.

Dunst, semolina and breaks are fractions that reenter into the grinding and sorting on fractions process until all endosperm fractions are processed into flour.

Plan sifters are actuated through eccentric mechanisms which allow performing of a plane-circular translation movement, any point on the sieve describing a circle of radius equal to the eccentricity of actuating mechanism, [7, 11, 14].

From specialty literature, [3, 4, 5, 9, 10, 12], most important factors that influence the efficiency of sifting are: the size and shape of the grist particles, the amount of material that reaches on the surface of the sifting frame, characteristics of sifting surface, relative movement of the material on the sifting surface, and kinematics of equipment. Thus, choice of fabric (textile or metal) and of fabric aperture size for plan sifter compartment sieve is based on the dimensional characteristics of the grist particles that get into compartment, [2]. Also, the movement of the particles on the sifting surface depends on the zone of feeding with material, as well as the size of apertures of the sieve, [1, 8].

Distribution by size of small seeds was the subject of several scientific papers published in specialty literature. Determining the distribution by size of granular materials is carried out, commonly, with special apparatus provided with overlapping sieves, sieve selection being made in descending order, from top to bottom, according to the particle size of the mixture, so that on the topper sieve remains a percentage of about 5 – 10 %. The following sieves is selected from the range of sieves of the sieve shaker, so that the size of their apertures to be in a geometric progression of ratio $\sqrt{2}$.

In our paper we shall synthetically present the distribution by size of particles from fraction resulted at plan sifter compartment C1 in breakage phase of wheat in a milling plant with capacity of 100 t/24 hr., from Romania.

## MATERIALS, METHODS AND PROCEDURES

In figure 1 are presented intermediate products that are sorted in the plan sifter compartments in wheat breakage phase of a milling plant.

Technological flow diagram of wheat breakage phase for mentioned milling plant is presented in fig. 2.

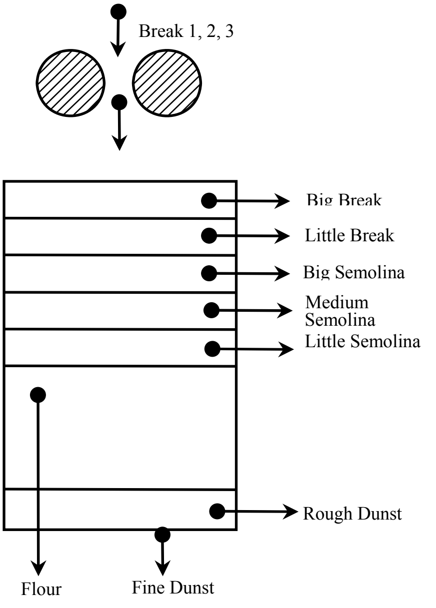


**Fig. 1** Intermediate products that results at a breakage technological passage

In this phase, breakage diagram includes six technological passage, of which five are equipped with grinding machines (with fluted cylinders), and a compartment is intended for classification of semolina fractions (divisor). Diagram has three finishers of bran for the recovery of flour from fractions with high content in shell, and two semolina machines for cleaning and classification of fractions with a high content of endosperm. Characteristic to breakage phase, the six plansifter compartments have relatively large number of packages intended for sifting of refusals. Refusals are made up of products derived from grinding seeds and leaks with fluted cylinders.

The paper analyzes the grist of Break 1 (from the diagram) that reaches in plansifter compartment C1.

Plansifter compartment C1 has at the top a set of seven frames of metal fabric with large apertures (no. 20), in correlation with the distance between the roller mills of the technological passage. These sieves extract large particles (refusals and semolina). Metal sieves are used for sifting of refusals for not wear out and deteriorate very quickly. Also, material that was grinded at this passage (Break 1) and feeds plansifter compartment C1, was sorted into fractions according to the inside diagram of the compartment (see fig. 2).

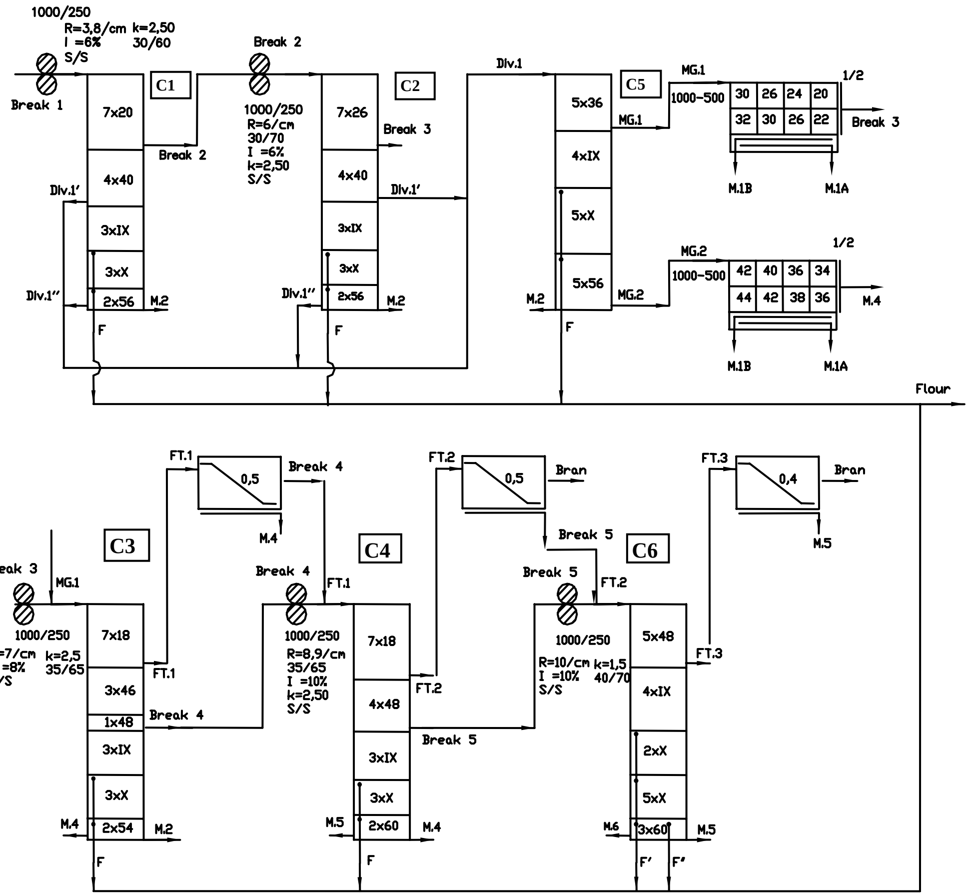


Fig. 2 The flow diagram of the wheat breakage phase in a milling plant with the capacity of 100 t / 24 h: C1 ÷ C6 – plansifter compartments; Break 1 ÷ Break 5 – breakage technological passages; DIV1 – divisor (sorting compartment); MG1, MG2 – semolina machines; FT 1 ÷ FT 3 – bran finishers; M.1A, M1B, M 2 ÷ M6 – reduction technological passages; F – flour, [15]

Recently textile fabrics have been replaced with plastic fabrics. For technological diagram of the analyzed mill, equivalence between sieve number and mesh size of it (as are indicated in the diagram) is shown in Table 1.

**Table 1** Equivalence between sieve number and aperture size

| Sieve number | 18 | 20 | 26 | 36 | 40 | 46 | 48 | 50 | 54 | 56 | 60 | VIII | IX | X | XI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Aperture size | 1.17 | 1.05 | 0.78 | 0.52 | 0.47 | 0.39 | 0.37 | 0.35 | 0.32 | 0.31 | 0.28 | 0.18 | 0.17 | 0.15 | 0.13 |

Sifted material of the first package of compartment reaches on the surface of sieves from the second package (no. 40), his refusal being directed to Break 2, where is subjected to a new grinding, composing a new set of fractions that are sorted in the plansifter compartment C2. Package II of sieves consists of four metal sieves number 40. Refusal of this package is directed to compartment C5 of sorting (divisor), and sifted material reaches on the surface of package III.

Central packages, of compartment, III and IV, denoted by roman numerals, are intended for sifting of flour. This is extracted from the material that reaches from the package II. Refusal of package III (with frames no. IX) reaches on the surface of the first frame of the package IV (with frames no. X) and sifting of this package is a second quality flour. From grist that reaches on the package IV one side is sifted (flour F2) and a part is rejected and get on the first frame of the package V.

Last package of two frames (no. 56) separating and extracting from endosperm particles of smaller size (dunsts) which are routed to the reduction passage M2. Refusal of package V reaches at compartment C5 of sorting (divisor), of plansifter.

For the particle size distribution of material fractions obtained at plansifter compartment C1 were used samples of 100 g taken from the input, respectively outputs of compartment. These were sifted on a set of five overlapping sieves with apertures of different sizes mounted on a classifier ANALYSETTE 3 SPARTAN, subjected to a vibratory motion at amplitude of 2 mm, for 3 minute, according to the methodology presented in other papers, [6, 16].

Based on results from particle size analysis performed with classifier with sieves was tested by nonlinear regression analysis in program Microcal Origin vers. 7.0, the correlation of experimental data with distribution law of logistic type with two parameters, for the cumulative percentage of material refused by the sieve of classifier.

Logistic type with two parameters distribution is defined by the relation:

$$R(x) = 100 \cdot \frac{e^{\alpha+\beta x}}{1+e^{\alpha+\beta x}} \tag{1}$$

where: R($x$) mass percentage share of the fraction with particles bigger than x (don't pass through the sieve with size x); x - apertures size sieve by which particles have passed; α and β – logistics experimental coefficients.

## RESULTS AND DISCUSION

Grist fractions sorted and separated by sieves of plansifter compartment C1 are composed of particles with sizes between a minimum value and a maximum value, within the mixture distribution by size being characterized by different distribution laws. Also, even a certain fraction obtained at a package of sifting sieves, in plansifter compartment has a different size distribution with dimensions very different of the particles between aperture sizes of sieve which have been sifted and the sieve that refused them (on who remained unseparated). It should be noted that grist particles presents mechanical characteristics and different composition, being extracted from different morphological areas of seeds (from outside to inside).

Sieve size used in the experiments and the weight fractions of material on each sieve for the separated the material are shown in Table 2.

**Table 2** Weight values p (%) of grist on sieve of classifier and weight values R (%) for grist products collected at input and the five outputs of plan sifter compartment C1

| x [mm] | C1 Entrance | | x [mm] | C1 Break2 | | x [mm] | C1 Div1' | | x [mm] | C1 Div1" | | x [mm] | C1 F | | x [mm] | C1 M2 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | p [%] | R [%] | | p [%] | R [%] | | p [%] | R [%] | | p [%] | R [%] | | p [%] | R [%] | | p [%] | R [%] |
| 0.000 | 53.30 | 100.00 | 0.000 | 3.10 | 100.00 | 0.000 | 2.50 | 100.00 | 0.000 | 5.70 | 100.00 | 0.000 | 0.50 | 100.00 | 0.000 | 11.00 | 100.00 |
| 0.710 | 10.80 | 46.70 | 0.710 | 6.40 | 96.90 | 0.180 | 8.90 | 97.50 | 0.125 | 10.80 | 94.30 | 0.045 | 15.00 | 99.50 | 0.090 | 18.80 | 89.00 |
| 1.000 | 14.50 | 35.90 | 1.000 | 35.00 | 90.50 | 0.250 | 12.90 | 88.60 | 0.180 | 18.60 | 83.50 | 0.063 | 25.80 | 84.50 | 0.125 | 28.00 | 70.20 |
| 1.400 | 5.90 | 21.40 | 1.400 | 19.30 | 55.50 | 0.400 | 26.80 | 75.70 | 0.250 | 24.80 | 64.90 | 0.090 | 29.30 | 58.70 | 0.180 | 5.60 | 42.20 |
| 2.000 | 9.80 | 15.50 | 2.000 | 28.40 | 36.20 | 0.630 | 38.60 | 48.90 | 0.315 | 29.60 | 40.10 | 0.125 | 23.90 | 29.40 | 0.200 | 23.50 | 36.60 |
| 2.800 | 5.70 | 5.70 | 2.800 | 7.80 | 7.80 | 0.710 | 10.30 | 10.30 | 0.400 | 10.50 | 10.50 | 0.160 | 5.50 | 5.50 | 0.250 | 13.10 | 13.10 |
| Mean diameter, [mm] | | 0.98 | Mean diameter, [mm] | | 1.76 | Mean diameter, [mm] | | 0.55 | Mean diameter, [mm] | | 0.29 | Mean diameter, [mm] | | 0.10 | Mean diameter, [mm] | | 0.17 |

As can be seen from the analysis of data from table 2, at each fraction is a percentage of material with dimensions under the side (opening) of apertures of sifting frames aperture, which means that the sifting is incomplete, even if the number of frames is quite large. However, average particle size of the fraction C1–Break 2 is of 1.76 mm, much larger than opening of sieves aperture of the respective package (1.05 mm). This shows that here is obtained parts of seed with dimensions large enough which must returned to the grinding process to the passage Break 2.

At second package of frames of plan sifter compartment C1, opening of aperture fabric is of 470 μm (fabric 40), but the average particle size of the fraction C1-DIV1' is of 0.55 mm, that is slightly larger than the opening of apertures. It is noted (Table 2) that here are particles smaller than the size of apertures remained unseparated (at least a percentage of 10.3%).

Fraction C1-DIV1" of plan sifter compartment C1 consists of sieve frames refusal no. 56 (with aperture 0.31 mm), after from sifting the second package consisting of particles passed through sieve no. 40 (with aperture 0.47 mm) was extracted flour F (with particle of mean sizes 0.1 mm). This fraction along with fraction C1-DIV1' is routed together to sorting compartment DIV1 (compartment C5). Average particle size of the fraction DIV1", from compartment C1, is of 0.29 mm (equal to that of opening of sieve apertures that refused them, demonstrating that even here sifting is incomplete).

It is noted, however, that the last fraction of plan sifter compartment has a high content of shell which is situated in upper layers of the material on frames, so it is recommended that it does not separate through apertures, even if its size are approximately equal to particles of endosperm, to be disposed of in a semolina machines (due to plan sifter movement is achieved stratification of the mixture components by density).

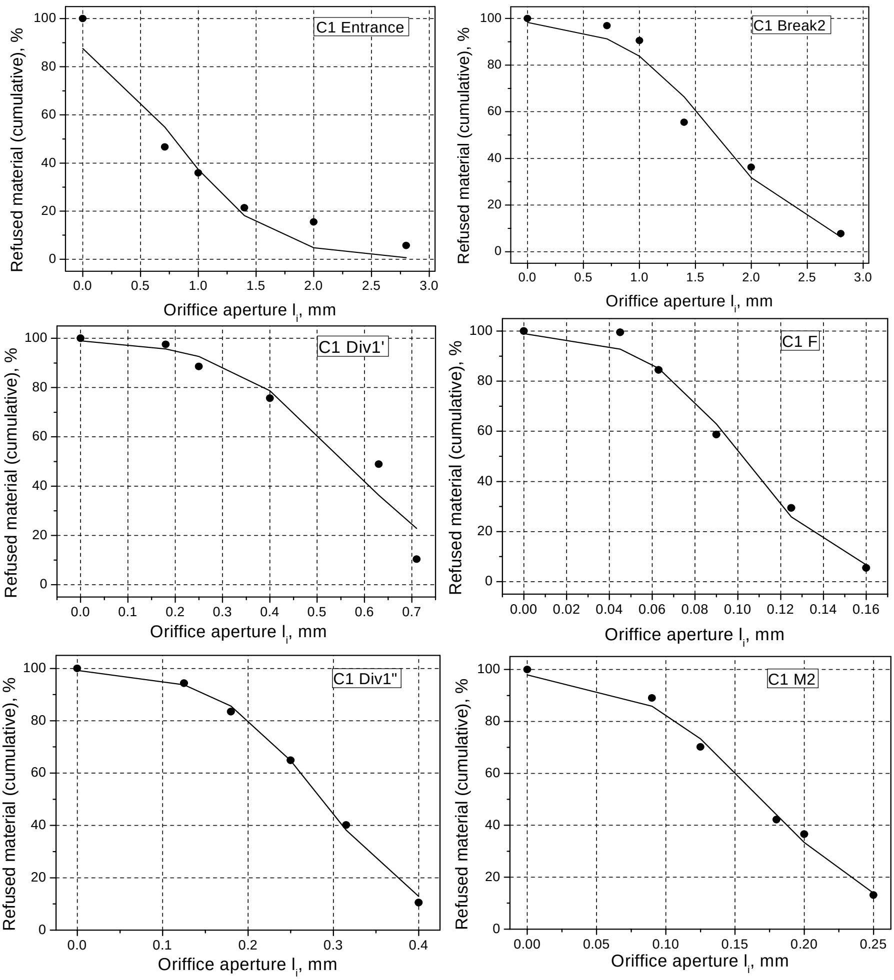


Fig. 3 Size distribution curves, R(%), given by equation (1) and experimental points for fractions sorted at plansifter compartment C1

Correlation with experimental data is given by the coefficient $R^2$ shown in Table 3, along with coefficients of correlation function. They depend on the working conditions and the degree of fineness of the grist, as well as the differential speed between of grinding rollers.

Table 3 The values of correlation coefficients $R^2$, $\alpha$ and $\beta$ from equations (1)

| Grist fractions | $\alpha$ | $\beta$ | $R^2$ |
|---|---|---|---|
| C1 Entrance | 1.954 | -2.474 | 0.935 |
| C1 Break 2 | 4.057 | -2.411 | 0.967 |
| C1 Div1’ | 4.569 | -8.147 | 0.943 |
| C1 F | 4.591 | -45.146 | 0.990 |
| C1 Div1” | 4.801 | -16.770 | 0.998 |
| C1 M2 | 3.848 | -22.707 | 0.993 |

x – side of sieve apertures, mm.

As can be seen of charts from figure 3, are fractions having most of particles with dimensions to the minimum value of sieve aperture of classifier, but there are components that have particles with medium sizes to maximum values of sieve apertures used in granulometric analysis.

The allure and character of regression curves are in correlation with obtained experimental data, being either concave or convex, or with central inflection point depending on the amount of material collected on each sieve of the classifier.

## CONCLUSIONS

Conduct of the wheat breakage technological process in a milling plant is very important for all technological flow of the milling plant, having a significant influence on the degree of flour extraction, without any excessive grinding of the seeds shell.

Distribution by size of particles from grist fractions, in plansifter compartment, for wheat breakage technological phase, has been tested with logistic with two parameters distribution law, very often used in particle size analysis of granular mixtures.

For all plansifter compartments of a milling plant, from wheat breakage phase is important to know the average particle size of the separated fractions, distribution by size and physical composition of their because it reenters into the grinding process, and structural characteristics of flutes of the roller mills, as well as roller mills functional parameters must be correlated with these.

In the case of the first tehnological passage of wheat breakage phase of a milling plant granulometric distribution can be described, with the best results by logistic with two parameters type law ($R^2 \geq 0.935$).

Particle size distribution law used in paper shows a very good correlation with experimental data regarding the size of particle fractions at the entrance and five outputs of the plansifter compartment C1 from the wheat breakage phase. Knowing the average size and distribution by size, as well as other physical characteristics of the particles of grist fraction is, simultaneously, requirements in choosing of sifting frames fabrics from plansifter compartments, from input in the compartment and until the output of each fraction of material.

The data presented can be important for all specialists and workers in the field of wheat milling, for the first phase of the technological process, that of breakage.

## AKNOWLEGEMENT

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# POTATO PROCESSING INTO FRIED PRODUCTS – AN EFFECT OF GROWING TECHNOLOGY ON ACRYLAMIDE PRECURSOR CONTENT IN POTATO TUBERS

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## SUMMARY

*In three-year field trials reducing sugar (RS) and asparagine (Asn) content was measured in raw potatoes, fried chips from three potato varieties grown with four variants of nitrogen and sulphur fertilization. RS content was statistically affected by year and variety. In dry and warm year the lowest RS content was determined. All studied factors, i.e. year and also variety and fertilization variants had a statistical important effect on Asn content. The relation of Asn and year is opposite than for RS, significantly the highest content was found in year with highest rainfall deficit. The results indicate tendency to higher Asn and also acrylamide contents with increased rates of nitrogen fertilizers. Sulphur fertilizer did not positively influence decrease of Asn content as referred several data from literature.*

*Based on trial results the relation was calculated between acrylamide precursors and acrylamide final content in fried chips. Whereas in case of RS content linear dependence was confirmed, in case of Asn content did not detect any dependence.*

***Key words**: Potato processing, acrylamide, reducing sugar, asparagine, chips, yield, starch*

## INTRODUCTION

In recent ten years, during potato processing into fried products an extraordinary attention has been paid to acrylamide content, which is potentially carcinogenic to human health. Reducing sugars and free amino acid asparagine are acrylamide precursors (Torborg et.al. 2004). Processing contaminant acrylamide is generated by reaction of these compounds. Although the European Commission did not set any limits for acrylamide, Commission Recommendation No. 2007/331/EC on the monitoring of acrylamide levels in food was issued.

Acrylamide (AA) was accidentally discovered in foods in April 2002 by scientists in Sweden when they found the chemical in starchy foods, such as potato chips, French fries, and bread that had been heated (production of acrylamide in the heating process was shown to be temperature-dependent).

An EFSA statement in 2005 noted that there may be a potential health concern with acrylamide, which is known to be both carcinogenic and genotoxic.

Member EU States were requested to perform a three-year monitoring of acrylamide levels and submit data to EFSA. In 2010, the Commission recommended that Member States should continue annual monitoring. The Commission prescribed indicative values in its recommendation on the monitoring of acrylamide levels in food. For example, 600 µg/kg was prescribed for French fries for direct consumption and 1 000 µg/kg for potato chips. In 2011, the Commission recommended that Member States carry out investigations in cases where the levels of acrylamide in food exceed the prescribed indicative values.

The Confederation of the Food and Drink Industry (CIAA) developed a ‘toolbox’ containing tools that can be used selectively by food producers in line with their particular needs to lower acrylamide levels in their products.

In addition to the technology of food production the “Toolbox”, updated in 2011, also involves not completely clarified effects of cultural practices. It is specifically mentioned that suggests that the impact of farming practices (e.g. fertilizer regimes) may have an effect on amino acid ratios in potatoes. Sulphur deprivation may alter the ratio of free Asn: total free amino acids in a tuber and that this ratio is potentially of greater significance to AA formation in potatoes than previously thought: in particular in the Asn: Gln ratio (Food Drink Europe Acrylamide Toolbox, 2011).

Optimal amino acid ratio in potato has been so far not established.

## METHODS

Between 2007 and 2009 a field trial was established in Potato Research Institute Havlíčkův Brod, Valečov Research Station, directed to study of year, variety and nitrogen and sulphur fertilization effect on acrylamide precursor content, i.e. RS and Asn and acrylamide content.

Valečov Research Station is situated in potato production region under conditions of typical mildly gleyed cambisol, with medium heavy soil and loamy to sandy topsoil. The altitude of the locality is 460 m, annual mean temperature is 7,0 °C and annual amount of rainfall is 652 mm.

Three varieties for chips production were involved into the trial. These varieties were bred for low accumulation of RS during storage:

Pirol (medium early German variety)

Lady Claire (medium early Dutch variety)

Crispy (medium early Dutch variety)

Fertilization variants involved nitrogen and sulphur levels, following rates were used:

- 40 kg N/ha (N1)
- 160 kg N/ha (N2)
- 40 kg N/ha + 40 kg S/ha (NS1)
- 160 kg N/ha + 40 kg S/ha (NS2)

The trial was established in three replications, using randomized blocks, plot area was 27,9 $m^2$ (96 hills/plot).

After the harvest standard yield and quality characteristic were determined. RS content was determined using HPLC method with a refractometric detector. From each variant a sample was taken and after slicing each tuber from the sample was divided based on following scheme: a part for sugar content analysis, a part for Asn level analysis and a part for frying. During the frying tests temperature curve of oil bath was measured for each fried batch. Samples were analysed for AA using LC-MS. Asn content was measured using HPLC with a fluorescence detector. Analysis of variance and Tuckey test was used for statistical assessment.

## RESULTS AND DISCUSSION

Obtained results are summarized in Table 1.

**Potato yield** was statistically significantly affected only by variety (Fig. 1). The highest yield was recorded for Pirol (46,9 t/ha) compared to Lady Claire (41,0 t/ha) and Crispy (37,4 t/ha). It is interesting that year and fertilization had no significant effect. Although especially trends of year effect showed positive effect in 2008 (on average 44,8 t/ha), when highly above-normal rainfalls (due to rainfalls in June and July) and normal temperatures were determined compared to the year 2009 (41,2 t/ha) with increased temperature and also rainfalls as regard as long-term normal and the year 2007 (39,3 t/ha), which was characterized by strong and long-term moisture deficit and high temperature.

Detailed weather progress is given in Table 2. The findings are completely not in accordance with results by many authors (Vokal et al., 2013), who mention year effect as the strongest factor; however, not always statistical significance is reached among studied years.

**Table 1** Effect of variants on studied indices

| Year | Variety | Fertilization | Studied index | | | | |
|---|---|---|---|---|---|---|---|
| | | | Potato yield (t/ha) | Starch content (%) | RS content (%) | Asn content (mg/kg) | AA content (μg/kg) |
| 2007 | Lady Claire | N1 | 34.50 | 19.8 | 0.020 | 2.68 | 514 |
| | | N2 | 37.99 | 17.8 | 0.020 | 3.86 | 613 |
| | | NS1 | 33.52 | 19.8 | 0.020 | 2.89 | 688 |
| | | NS2 | 37.75 | 19.3 | 0.030 | 3.51 | 607 |
| | Crispy | N1 | 46.76 | 19.3 | 0.025 | 3.00 | 846 |
| | | N2 | 46.07 | 17.6 | 0.012 | 3.96 | 1111 |
| | | NS1 | 40.00 | 19.3 | 0.014 | 3.00 | 844 |
| | | NS2 | 44.80 | 18.5 | 0.019 | 3.77 | 775 |
| | Pirol | N1 | 33.00 | 19.0 | 0.011 | 2.10 | 536 |
| | | N2 | 38.92 | 18.2 | 0.014 | 3.10 | 586 |
| | | NS1 | 36.44 | 19.2 | 0.016 | 2.06 | 471 |
| | | NS2 | 42.41 | 18.9 | 0.014 | 2.95 | 565 |
| 2008 | Lady Claire | N1 | 37.28 | 17.3 | 0.032 | 1.76 | 635 |
| | | N2 | 38.32 | 15.3 | 0.036 | 1.99 | 489 |
| | | NS1 | 37.00 | 16.5 | 0.036 | 2.11 | 628 |
| | | NS2 | 37.00 | 15.4 | 0.038 | 2.15 | 625 |
| | Crispy | N1 | 39,31 | 17,3 | 0,045 | 2,19 | 1166 |
| | | N2 | 45.69 | 15.3 | 0.055 | 2.84 | 1054 |
| | | NS1 | 41.02 | 16.5 | 0.043 | 2.32 | 1071 |
| | | NS2 | 40.39 | 15.4 | 0.071 | 2.23 | 1324 |
| | Pirol | N1 | 44.07 | 19.5 | 0.061 | 1.43 | 951 |
| | | N2 | 55.82 | 17.3 | 0.071 | 2.29 | 1567 |
| | | NS1 | 53.39 | 18.5 | 0.049 | 2.02 | 1716 |
| | | NS2 | 51.45 | 18.1 | 0.058 | 2.19 | 924 |
| 2009 | Lady Claire | N1 | 44.33 | 19.2 | 0.087 | 1.62 | 923 |
| | | N2 | 43.78 | 17.6 | 0.057 | 2.65 | 683 |
| | | NS1 | 46.05 | 19.1 | 0.075 | 1.81 | 735 |
| | | NS2 | 47.63 | 17.9 | 0.070 | 2.39 | 658 |
| | Crispy | N1 | 25.57 | 15.8 | 0.161 | 2.66 | 1321 |
| | | N2 | 25.73 | 15.3 | 0.185 | 3.62 | 1410 |
| | | NS1 | 26.48 | 16.0 | 0.166 | 2.92 | 1389 |
| | | NS2 | 27.57 | 15.7 | 0.194 | 3.41 | 1453 |
| | Pirol | N1 | 53.54 | 19.2 | 0.063 | 1.26 | 2125 |
| | | N2 | 51.85 | 17.6 | 0.118 | 2.13 | 3000 |
| | | NS1 | 49.37 | 19.1 | 0.085 | 2.10 | 2712 |
| | | NS2 | 52.44 | 17.9 | 0.100 | 2.22 | 4731 |

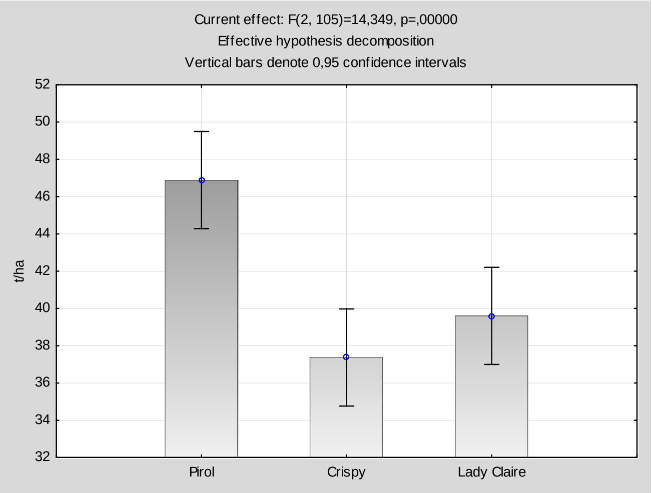


**Fig. 1** Effect of varieties on potato yield

**Table 2** Differences of temperatures and rainfalls during trial years from the long-term (70 year) mean

| year | parameter | month | | | | | |
|---|---|---|---|---|---|---|---|
| | | April | May | June | July | August | Sept. |
| 2007 | temperature (°C) | 2.7 | 3.2 | 3.1 | 1.4 | 1.7 | -1.0 |
| | rainfalls (mm) | -41.8 | -16.8 | -27.0 | -4.6 | -28.8 | 92.9 |
| 2008 | temperature (°C) | 0.7 | 1.9 | 2.2 | 1.1 | 1.0 | -0.4 |
| | rainfalls(mm) | 8.8 | -1.8 | 10.0 | 38.2 | -6.0 | -9.2 |
| 2009 | temperature (°C) | 4.7 | 1.5 | -0.4 | 1.9 | 1.8 | 2.3 |
| | rainfalls(mm) | -33.4 | 1.9 | 19.6 | 6.9 | 27.6 | -23.4 |

Similarly, variants with increased N fertilization (160 kg N/ha) tendentiously had higher yield compared to variants of 40 kg N/ha, sulphur fertilization was not reflected in potato yield.

**Starch content** was statistically significantly affected by year (Fig. 2), variety (Fig. 3) and fertilization variant (Fig. 4). In dry and warm year 2007 highest starch content was found (18,9 %). From varieties the highest starch content was recorded for Pirol (18,5 %). The results of variant effect confirm standard finding and negative effect of increased N rate. Sulphur fertilization had no effect on starch content.

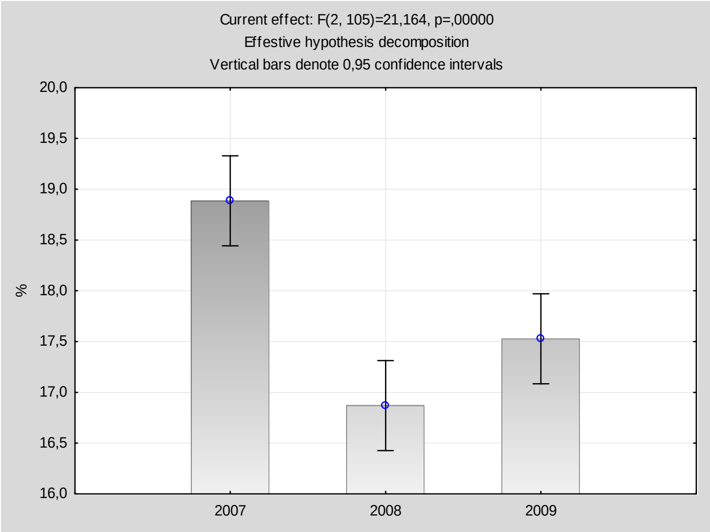


**Fig. 2** Effect of year on starch content

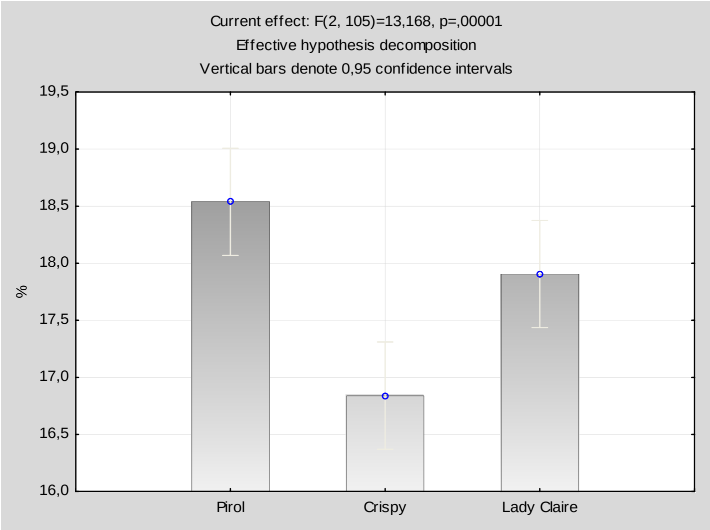


**Fig. 3** Effect of variety on starch content

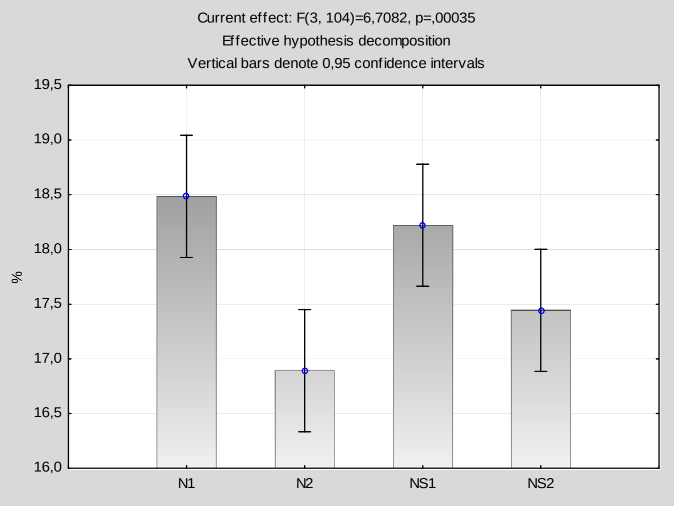


**Fig. 4** Effect of fertilization on starch content

**Reducing sugars (RS)** are important acrylamide precursors. Within the trial their content was statistically significantly affected by year (Fig. 5) and variety (Fig. 6). In dry and warm year lowest RS content was determined, the lowest content was recorded for Lady Claire compared to Crispy. Amrein et al. (2003) refer to the importance of variety, that acrylamide content in potato products could be substantially reduced especially by selection of cultivar possessing low RS concentration.

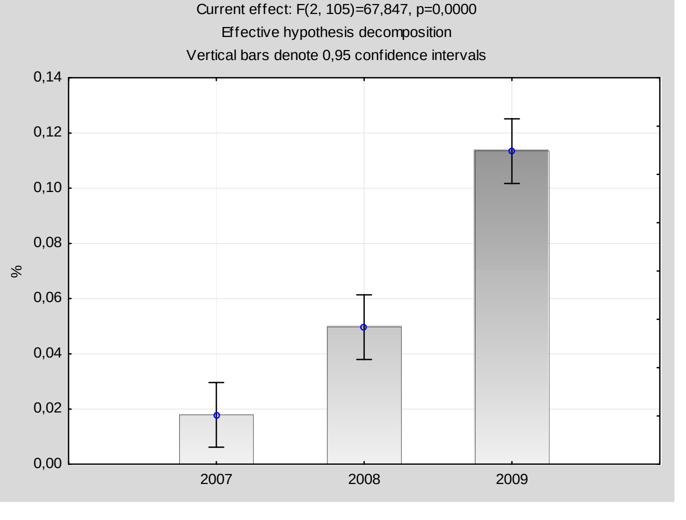


**Fig. 5** Effect of year on RS content

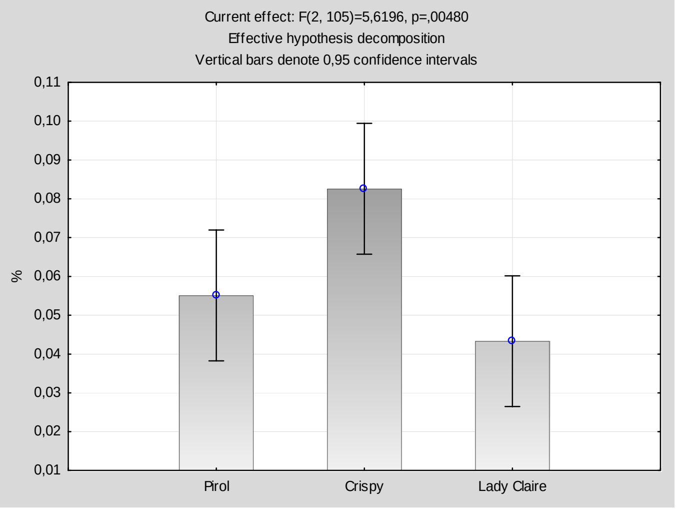


**Fig. 6** Effect of variety on RS content

**Free amino acid asparagine (Asn) content** was statistically significantly affected by all studied factors, i.e. year (Fig. 7), variety (Fig. 8) and fertilization variants (Fig. 9). The relation of Asn and year is opposite than for RS, the content was significantly highest in year with the highest rainfall deficit (2007 The variety effect was identical as for RS and variant effect was statistically significant only for nitrogen rates. Increased nitrogen rates significantly increased Asn values. Sulphur rates had no significant effect.

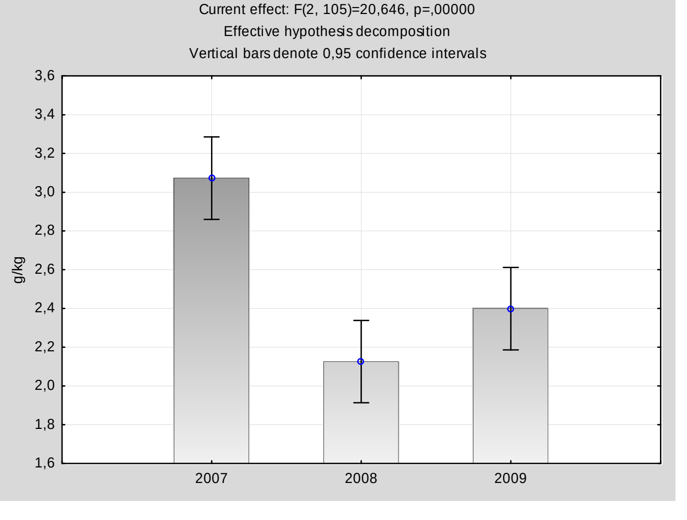


**Fig. 7** Effect of year on Asn content

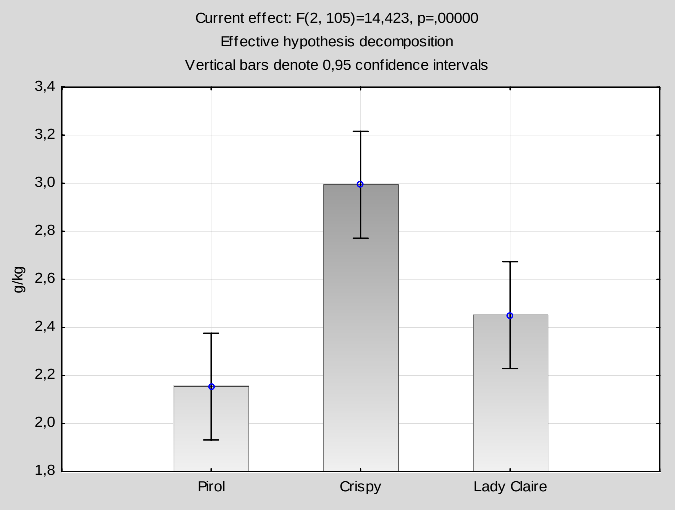


**Fig. 8** Effect of variety on Asn content

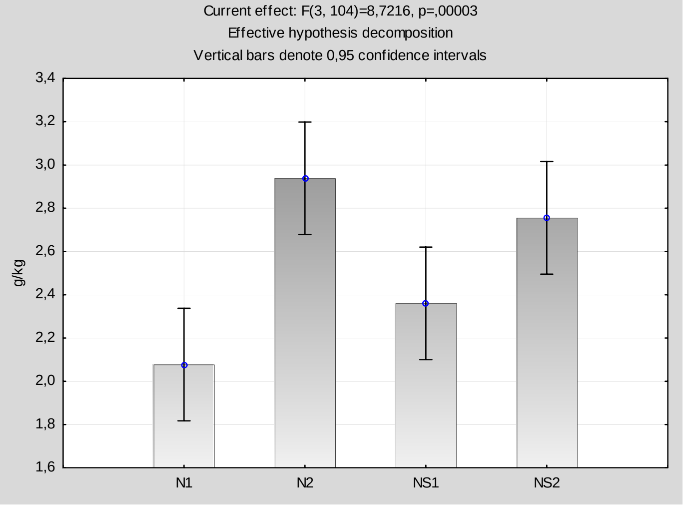


**Fig. 9** Effect of fertilization on Asn content

*Acrylamide content*

The results show that year affected AA content similarly as for RS, i.e. the lowest content in 2007 and the highest in 2009. Within the tested varieties no trend of significant effects of RS and Asn was found, in case of N fertilization effect it was found that for increased N rates tendency of higher AA content is determined. This finding corresponds to the results of Muttucumaru, et al. (2013), who studied effect of N fertilization in 15 varieties and found acrylamide increase in response to N increase in 13 varieties; however, reduction was found in two varieties. On contrary, S fertilization reduced RS concentrations in their trials compared to our results.

Based on trial results a relation was calculated between acrylamide precursors and acrylamide final content in fried chips (Figs. 10 and 11). Whereas in case of RS content linear dependence was confirmed, in case of Asn content the dependence was not detected.

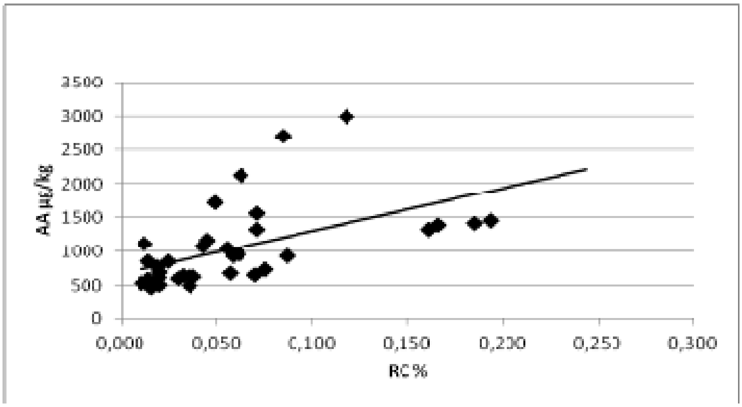


**Fig. 10** Relation between RS content in tubers and AA content in chips

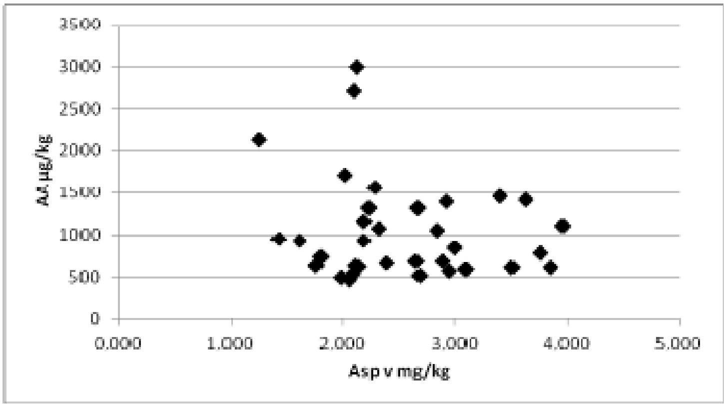


**Fig. 11** Relation between Asn content in tubers and AA content in chips

## CONCLUSIONS

The dependence of RS content in tubers and AA content in fried products, namely chips was confirmed.

Year and variety had the highest effect on RS content. In dry and warm year the lowest RS content was found.

Asparagin is referred as an important acrylamide precursor (in our trials no relation was confirmed). Asparagine content was statistically significantly affected by all studied indices. The relation between Asn and year was opposite than for RS, the content was significantly the highest in the year with highest rainfall deficit (2007). The effect of variety was similar as for RS. Variants with increased nitrogen rate had significantly higher Asn values. Sulphur rate were not significantly expressed.

## ACKNOWLEDGEMENTS

The results of the study were obtained within the research plan MSM6010980701 and QI101A184.

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42. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

UDC 631.374:633.1
Stručni rad
Expert paper

# AUTOMATIC CONTROL OF A CEREAL CONVEYOR BANDS

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## SUMMARY

*PLC's (Programmable Logic Controllers) are today the most common technical solution applied to industrial command circuits, due to some obvious advantages like simplicity, flexibility, liability and no maintenance. This monitoring and control solution is extremely used in industry, civil engineering and transportation, but not very used in agriculture. This paper presents an original technical solution concerning that type of control used for all electrical equipment used on a classic conveyor sequence in agriculture, based on a Möeller PS4 industrial PLC. The cereal conveyor is simulated in the Power Apparatus Laboratory in Timisoara by using a dedicated stand made by ELWE. Hardware as well as software belonging to this application are shown. The main result is that PLC could be implemented as a modern and effective technical solution for monitoring and control of agricultural processes. It could be easily applied for the refurbishment of existing conveyors in all storage areas.*

***Key words:*** *Control, cereal conveyor, PLC*

## INTRODUCTION

Monitoring and control of all industrial processes is an important issue in our era. During the last few years we assist to an increased number of control equipments based on PLC's. PLC's (Programmable Logic Controllers) are today the most common technical solution applied to such equipments due to some obvious advantages:

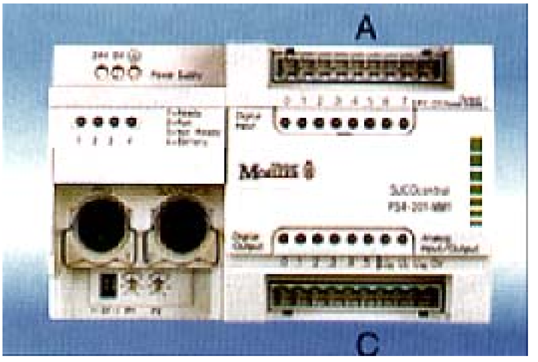


**Figure 1** The PS 4-201 PLC basic type

When the price of all classic electrical equipment replaced is higher than PLC's price, this piece of equipment becomes even economically justified, being cheaper than the old parts changed [2]. In fact, a PLC is a small industrial computer specialized in simultaneously treatment of both combinational and sequential logic instructions. It is equipment which allows connections between a large number of inputs and another large number of outputs.

It simulates the classical wire structure by using logical ports disposed in a flexible and complex structure. Figure 1 shows us such a PLC type PS4-201 MM1 produced by the German manufacturer Klöckner MOELLER, belonging to the Low Voltage Equipment Laboratory of the POLITEHNICA University of Timisoara.

Used equipment has 6 digital inputs (marked with an A) and 8 digital outputs (marked with a C). All digital inputs and outputs are 24 V DC and maximum current of 100 mA. This current allows enough power to control a semiconductor device, relay or micro-contactor connected to that output [2], [3]. It also disposes of two analogical inputs and one analogical output all offering an array of 0 - 12 V DC at maximum 100 mA. This PLC disposes of a serial RS 232 communication port which allows program downloading from an external program source (PC or panel). It also has a RS 485 serial communication connector used for PLC connections and an extension module connector for multiplying all the inputs and outputs needed. According to IEC 1131-3, it accepts all languages compatible with:

- **IL** (Instruction list);
- **LD** (Ladder Diagram);
- **FB** (Function Block).

## METHODS FOR IMPLEMENTING THE PROCESS

The process controlled by this sequence is a normal conveyor belt used for cereal transport, located in each storage areas. The most important aspect is the refurbishment of existing equipment, without any considerable modification.

*Conveyor band panel description*

Figure 2 shows the main application panel for this conveyor band sequence. As we notice in Figure 2, this panel refers to an agricultural conveyor band sequence made of 3 different segments called **Band1**, **Band2**, **Band 3**, each of them driven by a squirrel-cage induction motor. Those engines are directly connected to the power supply network by using 3 main contactors called **K1**, **K2** and **K3**.

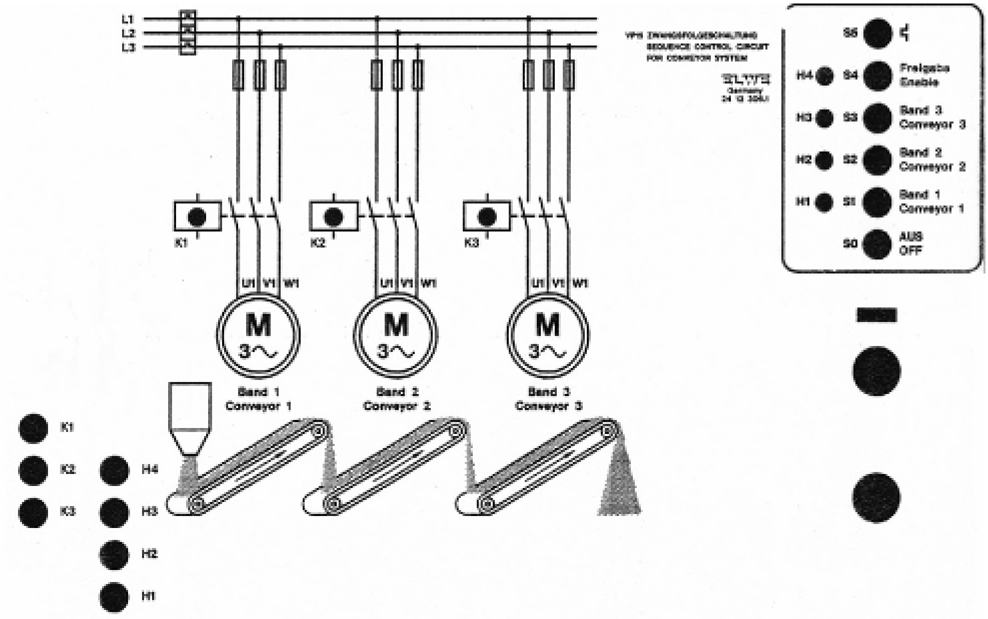


**Figure 2** Conveyor bands sequence; Monitoring and control panel

The cereal grains are loaded on the first conveyor segment in order to be transported to the storage area at the end of the third segment. The proper functioning of the 3 contactors is shown by 3 LED's located on the panel. On the up-right corner of the same panel, there is a button set used to activate all PLC inputs (process outputs). They are:

- **S0** is the STOP button;
- **S1** is the button used to start the first segment in manual mode;
- **S2** is the button used to start the second segment in manual mode;
- **S3** is the button used to start the third segment in manual mode.
- **S4** is the start button for the automatic sequence.
- **S5** is the button reserved to simulate a fault caused by an overload.
- There are 4 other LED's located in the same area:

- the **H1** LED indicates the appropriate operation of **Band 1**, no matter manual or automatic mode.
- the **H2** LED indicates the appropriate operation of **Band 2**, no matter manual or automatic mode.
- the **H3** LED indicates the appropriate operation of **Band 3**, no matter manual or automatic mode.
- the **H4** LED indicates the appropriate operation of all equipment in automatic mode. When it flickers, a fault is detected.

*Conveyor band control sequences*

The control algorithm is, as follows:

- The conveyor band sequence starts automatically when pressing the **S4** button**.** Automatically mode selection is confirmed by the **H4** LED.
    - Then, after 2 seconds (time for feeding the start point with cereal grains), the first segment, **Band 1**, starts by activating the **K1** contactor**.** This situation is indicated by the **H1** LED showing the operational status of the first engine.
    - After 5 seconds from **Band 1**'s start through the **K1** contactor, (the necessary time for all cereals to pass through that segment), the second segment will be activated, through the **K2** contactor. The function status of the **K2** contactor is indicated by the **H2** LED.
    - After another 5 seconds from **Band 2** through **K2**, (the necessary time for all cereals to pass through that segment), the third segment will be activated, through the **K3** contactor. The function status of the **K3** contactor is indicated by the **H3** LED.
    - During service, for each segment, **K1**, **K2**, **K3** and **H1**, **H2**, **H3**. LED's will rest on. The **H4** LED will indicate automatic mode selection.
- **Band 1**, starts independently from the others (in manual mode) when pressing the **S1** button. The **K1** contactor will be connected as well as the corresponding LED indicator **H1**.
- **Band 2**, starts independently from the others (in manual mode) when pressing the **S2** button. The **K2** contactor will be connected as well as the corresponding LED indicator **H2**.
- **Band 3**, starts independently from the others (in manual mode) when pressing the **S3** button. The **K3** contactor will be connected as well as the corresponding LED indicator **H3**.
- Those operations are not permitted when the automatic mode is selected. One, two and even all three conveyor band segments could operate simultaneously during manual mode, depending on the given control modes.
- All equipment stops when the **S0** button is pressed, no matter the operational mode.

- If the automatically mode is selected, all engines running at that time will be disconnected through the **K1**, **K2**, **K3** contactors. The corresponding LED's **H1**, **H2**, **H3** and, obviously, **H4** will be shut off.
- It the manual mode is selected, all engines running at that time will be disconnected through their dedicated contactors. The corresponding LED's will be shut off.
- Overload simulation is made by pressing the **S5** button.
- That fault could occur no matter if automatic or manual mode is active.
- All segments running will be shut down. The corresponding LED's will be shut off, as well as, of course, all active contactors.
- The **H4** will blink during 15 seconds, time needed for short engine and relay cooling, indicated fault mode.
- No re-connections are permitted during this period.
- After 15 seconds manual or automatically mode selection is permitted.

## RESULTS AND DISCUSSIONS

After describing all functional requirements for the conveyor band, the necessary control program write into the **Sucosoft S40** dedicated language, which does all those operations through the PLC, is shown below.

```
VAR  (variable declaration section)
K2 AT %Q0.0.0.0.2 : BOOL ;
K1 AT %Q0.0.0.0.1 : BOOL ;
K3 AT %Q0.0.0.0.3 : BOOL ;
S1 AT %I0.0.0.0.1 : BOOL ;
S2 AT %I0.0.0.0.2 : BOOL ;
S3 AT %I0.0.0.0.3 : BOOL ;
S0 AT %I0.0.0.0.0 : BOOL ;
S4 AT %I0.0.0.0.4 : BOOL ;
S5 AT %I0.0.0.0.5 : BOOL ;
avarie : TP ;
stav : BOOL ;
p1 : TP ;
p2 : TP ;
p3 : TP ;
avarie : TP ;
stav : BOOL ;
p1 : TP ;
p2 : TP ;
p3 : TP ;
timp1 : TIME := t#2s ;
timpav : TIME := t#15s ;
timpsem : TIME := t#0.5s ;
nosemn : TP ;
stpor1 : BOOL ;
stpor2 : BOOL ;
stpor3 : BOOL ;
timp2 : TIME := t#5s ;
timp3 : TIME := t#5s ;
semn : TP ;
stsemn : BOOL ;
stnosemn : BOOL ;
man1 : BOOL ;
po1 : BOOL ;
auto : BOOL ;
oprire : BOOL ;
H1 AT %Q1.1.0.0.1 : BOOL ;
H2 AT %Q1.1.0.0.2 : BOOL ;
```

```
H3 AT %Q1.1.0.0.3 : BOOL ;
H4 AT %Q1.1.0.0.4 : BOOL ;
man2 : BOOL ;
man3 : BOOL ;
END_VAR
```

## Main program section

```
ld      S4
r       oprire
ld      S4
andn    avarie.q
s       H4
s       auto
st      stpor1
cal     p1(in:=stpor1,pt:=timp1)
ldn     p1.q
and     auto
andn    oprire
andn    avarie.q
s       k1
s       H1
st      stpor2
cal     p2(in:=stpor2,pt:=timp2)
ldn     p2.q
and     auto
andn    oprire
andn    avarie.q
and     k1
s       k2

s       H2
st      stpor3
cal     p3(in:=stpor3,pt:=timp3)
ldn     p3.q
and     auto
andn    oprire
andn    avarie.q
and     k1
and     k2
s       k3
s       H3
ld      S0
s       oprire
ld      oprire
and     auto
r       k1
r       k2
r       k3
r       H1
r       H2
r       H3
r       H4
ld      S5
st      stav
st      stsemn
s       oprire
r       k1
r       k2
r       k3
r       H1
r       H2
r       H3
r       H4
cal     avarie(in:=stav,pt:=timpav)
cal     semn(in:=stsemn,pt:=timpsem)
ld      avarie.q
and     semn.q
s       H4
ld      avarie.q
andn    semn.q
r       H4
st      stnosemn
cal     nosemn(in:=stnosemn,pt:=timpsem)
ld      avarie.q
andn    nosemn.q
st      stsemn
```

```
cal     semn(in:=stsemn,pt:=timpsem)
ld      S1
r       auto
r       H4
r       oprire
ld      S1
andn    avarie.q
andn    auto
andn    oprire
s       k1
s       H1
s       man1
ld      S2
r       auto
r       H4
r       oprire
ld      S2
andn    avarie.q
andn    auto
andn    oprire
s       k2
s       H2
s       man2
ld      S3
r       auto
r       H4
r       oprire
ld      S3
andn    avarie.q
andn    auto
andn    oprire
s       k3
s       H3
s       man3
ld      S0
s       oprire
ld      oprire
and     man1
r       H1
r       k1
ld      oprire
and     man2
r       H2
r       k2
ld      oprire
and     man3
r       H3
r       k3
```

## CONCLUSIONS

PLC's are fully recommended for monitoring and control of such equipment located in agricultural areas. A small program sequence introduced to a PLC could replace many electrical devices involved in classic structures, reducing equipment costs. It could increase safety and liability of all units involved at a lower maintenance cost, with interchanging possibilities. No major changes have to be made in the control scheme in order to apply this technical solution. The program sequence could be easily verified virtually. It is totally suitable for agriculture equipment due to the simplicity of operation process too.

It could be applied without major changes to all existing equipment, as a refurbishment, updating and energy saving effect.

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42. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

UDC 634.635:697.329
Prethodno priopćenje
Preliminary communication

# DESIGN AND PERFORMANCE EVALUATION OF A SOLAR CONVECTION DRYER FOR DRYING FRUITS AND VEGETABLES

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## SUMMARY:

*This article describes the design, construction, and performance evaluation of a natural-convection, solar dryer capable of producing dried fruits and vegetables likely to be used in semi-subsistence farms in Romania. Experiments were done at ICDIMPH – Horting, using plum during the summer and autumn of 2013. A sorption isotherm was developed for the Tuleu Gras and Anna Spath plums variety to determine target levels of moisture content needed to achieve required levels of water activity. Performance evaluation revealed cabinet temperatures between 32.0°C and 45.5°C during sunlight hours depending on airflow and loading conditions. Damper restriction was shown to effectively control flow rates to adjust temperatures within the dryer. Operating capacity of the dryer was 10,0 kg of fresh plum slices per 48 h, lowering the moisture content from 85.7% to 18% for Tuleu Gras and and 84.3% to 18.2% for Anna Spath, under a continuous mode of operation. The experiments have allowed obtaining some values for the parameters of the dehydration process, which ensure a minimum duration of the process itself.*

***Key words**: plums dehydration, dehydration, drying.*

## INTRODUCTION

Romania has a temperate continental climate with Mediterranean influences in the south west, which allows the cultivation of different varieties of fruits and vegetables. Horticultural production structure includes 35% vegetables and melons, 35% potatoes, 17% fruits and 13% grapes.

Compared to EU horticulture production, Romania has average productions consists of 9.3% plums, 3.6% apples, 2.2% cherries, 1.0% other fruits, 22.8% vegetables and melons, 17 9% cabbage, 12.3% eggplant, 4.9% onion, 2.1% tomato and 3.0% other vegetables. For apple, carrot, onion, potato storage is possible for a long period of time (4-6 months) in the controlled atmosphere or cold conditions. A number of fruits (plums and apricots) and vegetables (tomatoes, eggplant, peppers) have a short period of keeping fresh, but for long-term storage can be used drying / dehydration.

Increased demand for natural foods, healthy with a small cost, linked to the need to diversify the products made in semi-subsistence farms, in order to achieve sustainable development, make solar drying a useful alternative for sales and storage fruits and vegetables. For sustainability and climate change concerns it is important to use renewable sources of energy as much as possible.

Alternatively, solar drying has shown considerable potential in prolonging product shelf life while significantly reducing both the product volume and weight. This helps minimize packaging, storage, and transportation costs (Chaudhri et al., 2009). Using the method solar drying in the semi-subsistence farms, is income generating potential by increasing the value of the product.

## METHODS

The experiments was developed in 2013, on a solar dryer (fig.1) designed and built at ICDIMPH-Horting Bucharest. This dryer features an indirect, solar heating component and a separate drying chamber which houses five product trays. The two components were designed to be detachable for easier maintenance and mobility as needed. Solar collector, built of timber is rectangular shape (L = 1980 mm, w = 600 mm, h = 110 mm, v = 0.130m$^3$), lined at the inside with black painted steel sheet. Area of 1,188 m$^2$, exposed to sunlight is made of transparent plastic.

Drying cabinet of solar convection dryer is rectangular shape (L = 1000 mm, w = 800 mm, h = 430 mm, v = 0.334 m$^3$). Inside drying the products are placed on five removable stainless steel grills. Air flow is adjusted by opening or closing the chimney section.

The loading capacity of the solar dryer was designed as 1,5 – 2,5 kg/grill, depending on the specific weight of the raw material

This drying system was adopted to avoid direct exposure of product to solar radiation. Direct exposure to solar radiation was avoided since discoloration, surface cracking, inadequate internal drying, and undesirable temperature rises in the top layer would otherwise diminish product quality (Sreekumar et al., 2008). Indirect solar dryers also exhibit improved efficiency (Chen et al., 2009) and are capable of drying larger quantities than direct-mode dryers (Buchinger and Weiss, 2002).

The performance was specifically evaluated in terms of collector efficiency (eq. 1), and drying efficiency (eq. 2) assuming steady state conditions using the thermodynamic properties recorded during operation of the solar dryer.

Overview Drying cabinet Solar collector

**Fig. 1** Constructive aspects of the dryer

$$\eta_{collector} = \frac{GC_p\left(T_0 - T_i\right)}{I} \tag{1}$$

$$\eta_{system} = \frac{WL}{IA} \tag{2}$$

where:

- G = mass flow rate or air per unit collector area ($kgm^{-2}s^{-}1$);
- Cp = specific heat of air ($kJkg^{-1}K^{-1}$);
- $T_o$ = collector outlet temperature (°C);
- $T_i$ = inlet temperature (°C);
- I = total solar energy incident upon a plane per unit time ($Wm^{-2}$);
- W = weight of water evaporated from product, experimentally determined (kg);
- L = latent heat of vaporization of water at exit air temperature ($kJkg^{-1}$);
- A = aperture area of collector ($m^2$).

The two plum cultivars came from the collection of Research Institute for Fruit Growing, Pitesti.

Fruit appearance and the arrangement of fruits on the grill is shown in Figure 2.


**Fig. 2** Fruits

## RESULTS AND DISCUSSION

Variation of temperature in the drying enclosure, depending on load is shown in Figure 3, taking into account the ambient temperature.

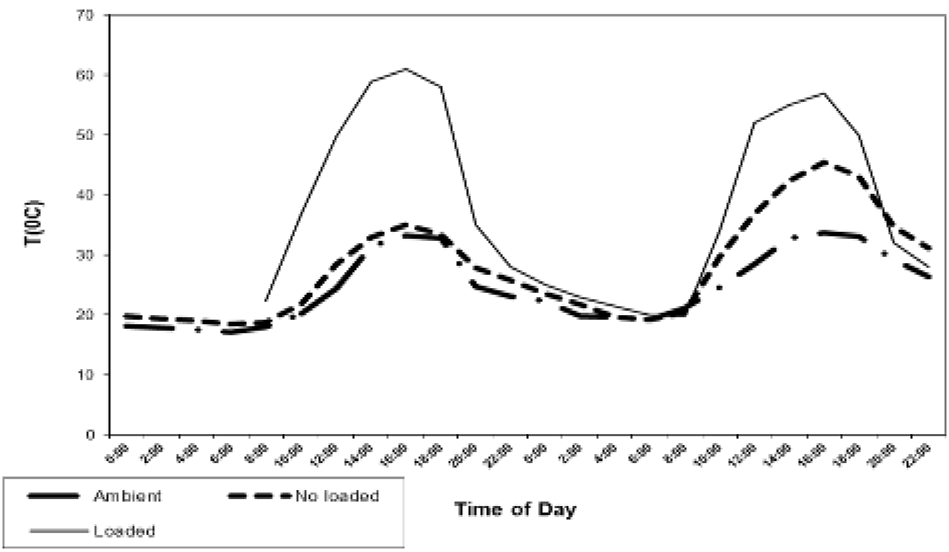


**Fig. 3** Average cabinet temperatures within solar dryer for trials with and without load compared with ambient temperatures

The maximum temperature is reached with unloaded dryer in the first and second day respectively $61^{0}$C and $57^{0}$C. If fruit load, maximum reached temperature is $35.5^{0}$C on the first day and $45^{0}$C the second day. The difference of $10^{0}$C is due to enlargement of the air circulation; reduce humidity and temperature accumulated in fruits.

Fruit moisture variation on the five grills during drying is shown in Figure 4.

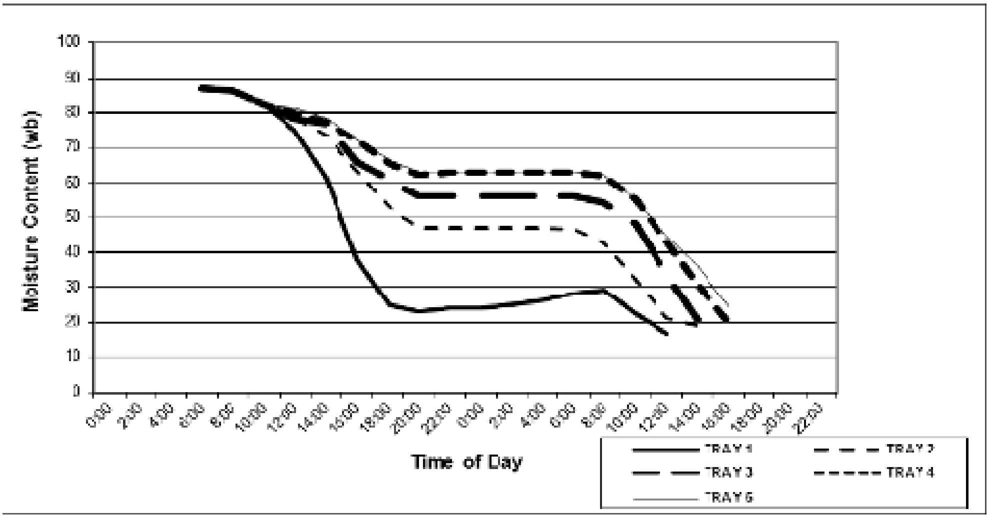


**Fig. 4** The moisture content of the plums slices initially loaded trays solar drying for two days. The initial conditions were with Tray 1 positioned at the bottom and Tray 5 positioned on the top. Newly added trays in the continuous mode of operation are omitted from this

Drying rates slowed at nightfall and generally remained constant until morning. Slight increases in moisture content overnight were found to have negligible effects on product quality.

In figure 5 are shown dried half- fruits from varieties Tuleu gras and Anna Spath.


Fig. 5 Dried half-fruits

| Cultivars | Finale moisture [%] |
|---|---|
| TULEU GRAS | 23,37 |
| ANNA SPATH | 16,16 |

## CONCLUSIONS

Presented solar dryer is capable of drying out fruits and vegetables subsistence farms due to the affordable cost.

The temperature inside the dryer made possible to obtain quality products at a low cost price.

Thus, this dryer was found to be efficient and technically feasible for producing dried plums slices with the utilization of a widely available natural energy resource.

The disadvantage of using this dryer is that it can be utilized only in summer to fruits and vegetables reached mature during this period.

In 80% proportion the dehydrated products existing in the Romanian market come from imports. Due to current conditions and the absence of the performing technologies is required the modernization and optimization of the specific dehydration technologies, which can ensure the obtaining of competitive local products (for plums), competitive for both internal market and for export.

## ACKNOWLEDGEMENTS

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42. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

UDC 664.69:664.761
Stručni rad
Expert paper

# THE MONITORING OF ENZYME ACTIVITY OF LIPOXYGENASE ON FLOUR OBTAINED FROM DURUM WHEAT (*TRITICUM DURUM* DESF.) AND FROM COMMON WHEAT (*TRITICUM AESTIVUM* L.) USED FOR MANUFACTURING OF PASTA PRODUCTS

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## SUMMARY

*This study presents the enzyme activity of lipoxygenase on flour obtained from Triticum durum wheat and from Triticum aestivum wheat used for manufacturing of pasta products. The determination of the rheological characteristics of the flour and dough is obtained by alveographic and consistographic methods. The tests results show that the addition of lipoxygenase decreases the time of kneading the dough. On the dough sample from flour obtained from Triticum durum wheat it can be seen that the enzyme preparation based on lipoxygenase is used to obtain pasta products with improved color and gloss and is also used to reduce the drying time of noodles, improves surface appearance and mechanical stability of noodles and pasta, and reduces raw material costs. The dough sample from flour obtained from Triticum aestivum wheat shows only a small improvement by increasing of the time at which it reaches the maximum pressure and also in the tolerance and stability of the dough, but the softening at 250 and 450 seconds is quite high compared with the sample F durum.*

***Key words**: lipoxygenase, wheat, flour, pasta, alveograph method, consistographic method.*

## INTRODUCTION

Pasta products are foods prepared from different types of flour and water, with or without the addition of other food materials such as enzymes. They are high food value farinaceous products based not only on their energy intake, given the increased content of carbohydrates and fats, but also the value of all components, representing shapes that are easily assimilated by the human body and high content of vegetable protein and nutrients.

Technological characteristics of flour and nutritional value of pasta are the following variables: flexibility, water retention capacity, maximum strength, extensibility, nutritional value and energy value. In order to improve these variables, the various additives and are placed in the technology of manufacturing of pastas.

Enzymes applications have grown to be a common practice in manufacturing of pasta products with advantage of being considered as natural additives. The enzyme activity of lipoxygenase is being used in pasta products to improve the flour and dough-handling properties. Flour obtained from Triticum durum wheat has the best characteristics due to high content of gluten.

Lipoxygenase oxidizes polyunsaturated fatty acids during kneading dough. Hydroperoxides formed can oxidize sulfhydryl groups of gluten proteins and thus may be beneficial in forming gluten network of the dough. [1] This addition of lipoxygenase also decreases the time of kneading the dough. Enzyme preparation based on lipoxygenase is used to obtain pasta products with improved color and gloss and is also used to reduce the drying time of noodles, improves surface appearance and mechanical stability of noodles and pasta, and reduces raw material costs. It positively influences the quality of final products by increasing tolerance to prolonged cooking, cooked pasta firmness and helps reduce oil uptake of fried instant pasta.

## METHODS

*Samples preparation*

Materials used for the preparation of the samples are flour type 550 from Triticum durum wheat and from Triticum aestivum wheat, salt, water, yeast and lipoxygenase enzymes.

The enzyme preparation used is: EMCEdur – enzyme preparation which contains lipoxygenase enzyme; doze: 100-500g/100kg flour; description: enzyme complex to enhance boiling and chewing properties; properties: creates a firmer structure, reduces loss through boiling and lightens the colour.

Each sample of 250g of flour is mixed with a solution of salt, yeast and enzyme preparation in a laboratory mixer 15 min to form dough. The amount of water was adjusted according to the water absorption capacity of flour. The water absorption process starts and the formation of the dough takes places by the transfer of the proteic content characteristics into the gluten chain. The fermentation represents a complex enzymatic process, especially of amylolitic hydrolysis of the carbon hydrates and of gluten proteolysis. [2]

The first two dough samples MARTOR durum and MARTOR aestivum contained 95% flour, 1.7% salt, 1.7% yeast and does not have any enzymes.

The third and fourth dough sample F durum and F aestivum contained 95% flour, 1.7% salt, 1.7% yeast and 150g/100kg enzymes preparation which contain lipoxygenase.

Each dough sample is divided in five circular consecutive dough patties which are rested 20 min in the alveograph in a temperature-regulated compartment at 25 °C. Each dough patty is tested individually and the result is the average of the five dough patties.

*Methods of analysis*

The determination of the rheological characteristics of the dough was obtained by alveographic and consistographic method. The alveographic method relies on measuring the resistance to biaxial stretch under air pressure of a dough sample prepared in standard conditions.

The dough patty is placed on the alveograph, witch blows air into it. The dough patty expands into a bubble that eventually breaks. The pressure inside the bubble is recorded as a curve on graph paper. The alveograph determines the gluten strength of dough by measuring the force required to blow and break a bubble of dough. The results include P Value, L Value, and W Value. Stronger dough requires more force to blow and break the bubble (higher P value). A bigger bubble means the dough can stretch to a very thin membrane before breaking. A bigger bubble indicates the dough has higher extensibility; that is, its ability to stretch before breaking (L value). A bigger bubble requires more force and will have a greater area under the curve (W value).

From the alveogram the following indicators were obtained:

- P Value is the force required to blow the bubble of dough. It is indicated by the maximum height of the curve and is expressed in millimeters (mm). It is also known as the viscosity or the value of maximum pressure that is in relationship to the resistance of the deforming dough (mm H2O)
- L Value is the extensibility of the dough before the bubble breaks. It is indicated by the length of the curve that begins from the origin until the perpendicular point that corresponds to decreasing pressure due to rupture of air bubble and is expressed in millimeters (mm).
- G Value is the expansion index G being the average of the expansion index on the graphic of cellules and corresponds to breaking the abscise L, G =2.226L, where L – air volume ($cm^3$) used to stretch the dough under bubble form.
- P/L Ratio is the balance between dough strength and extensibility. It is the rapport of configuration of the curve.
- W Value is the area under the curve. It is a combination of dough strength (P value) and extensibility (L value) and is expressed in joules. It represents the action of deformation of the dough, based on a gram of dough, evaluated at 10 E – 4 joule, calculated as follows: W= 1.32 x (V/L) x S, where V- air volume in $mm^3$; L- the average abscise at breaking point in mm; S- surface of the curve, $cm^2$.
- Ie – elasticity index, represents the rapport between the measured pressures, expressed in mm $H_2O$ to form bubbles after the insufflations of 200 $cm^3$ of air in dough form, that correspond to a length L of 40 mm or an index of expansion G from 14,1 and the maximum of the curve P: Ie%= P200/Pmax.[3]

The Consistographic method is used to determine the consistency of dough and water absorption capacity of flour and observing changes in the process of kneading dough.

The equipment used to determine consistogrames is Alveo-Consistograph NG.

To determine the consistograme for each sample there were made the following tests:

- Constant hydration test (CH) - to determine the maximum pressure (Pr max), thus obtaining flour water absorption ability which can be used to obtain the right consistency of the dough.
- Adapted hydration test (AH) - for tracking and studying to obtain desired consistency dough during kneading behavior such as time to reach the maximum pressure (T Pr MAX), tolerance (TOL), falling to 250 seconds (D250) and fall in 450 seconds (D 450).

From the consistograme the following indicators were obtained:

- flour moisture (H2O)
- maximum pressure (Pr MAX)
- hydration potential of the flour (HYDRA)
- time to reach the maximum pressure (T Pr MAX)
- tolerance or dough stability (TOL)
- pressure drop compared to PrMax after 250 seconds or the degree of softening of the dough after 250 seconds (D 250)
- pressure drop compared to PrMax after 450 seconds or the degree of softening of the dough after 450 seconds (D 450)
- water absorption capacity WAC.[3]

Based on the time to reach the maximum pressure (T Pr MAX) and the tolerance or dough stability (TOL) the flour can be classified as follows:

- weak flour: T Pr MAX between 1 – 3 minutes; TOL between 1 – 4 minute;
- medium flour: T Pr MAX between 3 – 8 minute; TOL between 4 – 5 minute;
- strong flour: T Pr MAX between 8 – 15 minute; TOL between 10-15 minute

## RESULTS AND DISCUSSIONS

*Alvographic method*

The dough samples alevogrames are represented in Fig. 1, Fig. 2, Fig. 3 and Fig. 4. Each dough sample alveorgam show the five dough patties tested (marked with different colors) and the parameters registered at the testing moment. The results of the samples are represented by the average value obtained from the values of the dough patties tests for each dough sample.In Fig. 1and Fig.2 the dough samples MARTOR durum alveograme and MARTOR aestivum alveograme represents the dough sample prepared from flour obtained from Triticum durum wheat and from Triticum aestivum wheat that do not contain any enzyme preparation. These two samples are considered the standard blank sample for the samples prepared from flour obtained from Triticum durum wheat and Triticum aestivum wheat.

<u>Results</u>
$P_{martor\ D}$ = 89 $mmH_2O$
$L_{martor\ D}$ = 89 mm
$G_{martor\ D}$ = 21,0
$W_{martor\ D}$ = $249x10^{-4}J$
$P/L_{martor\ D}$ = 1,0
$Ie_{martor\ D}$ = 51,7 %

<u>Results</u>
$P_{martor\ A}$ = 95 $mmH_2O$
$L_{martor\ A}$ = 60 mm
$G_{martor\ A}$ = 17.2
$W_{martor\ A}$ = $204x10E^{-4}J$
$P/L_{martor\ A}$ = 1.58
$Ie_{martor\ A}$ = 49.4 %

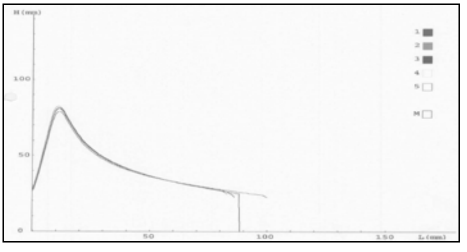

**Fig. 1** Sample MARTOR durum (no enzyme) alveograme

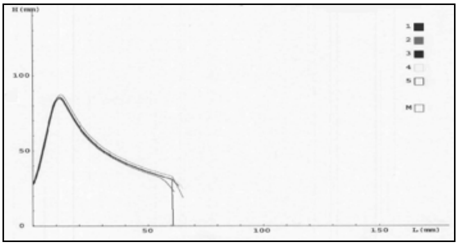

**Fig. 2** Sample MARTOR aestivum (no enzyme) alveograme

<u>Results</u>
$P_{F\ D}$ = 58 $mmH_2O$
$L_{F\ D}$ = 83 mm
$G_{F\ D}$ = 20.3
$W_{F\ D}$ = $159x10^{-4}J$
$P/L_{F\ D}$ = 0.70
$Ie_{F\ D}$ = 52.7 %

<u>Results</u>
$P_{F\ A}$ = 72 $mmH_2O$
$L_{F\ A}$ = 75 mm
$G_{F\ A}$ = 19.3
$W_{F\ A}$ = $183x10^{-4}J$
$P/L_{F\ A}$ = 0.96
$Ie_{F\ A}$ = 52.0 %

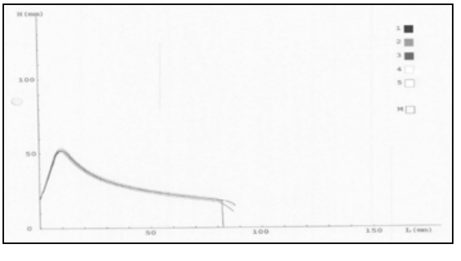

**Fig. 3** Sample F durum (contain 150g/100kg flour of lipoxygenase) alveograme

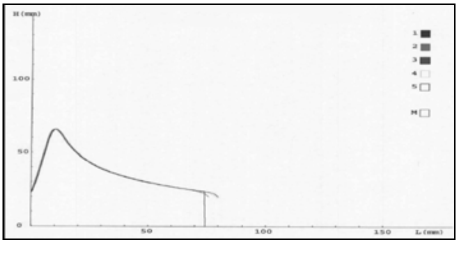

**Fig. 4** Sample F aestivum (contain 150g/100kg flour of lipoxygenase) alveograme

The alveograme's characteristics for flour used in pasta products have the fallowing values: P = [63 – 70mm], L = [100 – 130mm], G = [19 – 20], P/L = [0,65 – 0,70] and W =180 - 200x$10^{-4}$J.

The values for dough sample MARTOR durum (no enzyme) Fig. 1, regarding the resistance of the deforming dough ($P_{martor\ D}$) and the balance between dough strength and extensibility ($P/L_{martor\ D}$ ratio) are higher than the normal values. The values regarding the dough extensibility ($L_{martor\ D}$) are lower with 11mm than the normal values. The expansion index ($G_{martor\ D}$) and the total quantity of absorbed energy during the dough deformation ($W_{martor\ D}$) are very high, therefore the dough is very resistant to stretch and does not easily brake.The values for dough sample MARTOR aestivum (no enzyme) Fig. 2 are worse than the sample MARTOR durum (no enzyme). The resistance to deformation dough ($P_{martor\ A}$) is higher by 6mm $H_2O$ and the dough extensibility ($L_{martor\ A}$) is with 29mm lower than ($L_{martor\ D}$). The $P/L_{martor\ A}$ ratio is higher with 0,58 and the expansion index ($G_{martor\ A}$) is lower by 4,2 than sample MARTOR durum (no enzyme). The total quantity of absorbed energy during the dough deformation ($W_{martor\ A}$) is lower, therefore the dough is not resistant to stretch and can easily brake. These parameters suggest that bought samples are not suitable for pasta products. In Fig. 3 is represented the alveogram of dough sample F durum which contain 150g/100kg flour of lipoxygenase. Compared with the blank sample MARTOR durum there is a significant change regarding the dough strength ($P_{F\ D}$) that decreased with 31 mm$H_2O$. Looking at the extensibility characteristics and the absorbed energy during the dough deformation we can see, obviously, the dough quality improvements. The $P/L_{F\ D}$ value is lower because of the decreased dough strength and increase of the dough extensibility. These results suggest that the flour obtained from Triticum durum wheat and also the dough can be considered for manufacturing of pasta products. In Fig. 4 is the alveograme for the dough sample F aestivum which contain 150g/100kg flour of lipoxygenase. Addition of enzyme preparation which contains lipoxigenase in dough, reduces the dough strength ($P_{F\ A}$) with 23 mm$H_2O$. The absorbed energy during the dough deformation ($W_{F\ A}$) has been reduced under 200x $10^{-4J}$ as well as the $P/L_{F\ A}$ ratio which was reduce to 0.96 but not as the low as the sample F durum . There is a small increase of the extensibility characteristics and of the elasticity index ($Ie_{F\ A}$) compared to the normal values. Both dough samples with lipoxigenase content have a significant improvement in the characteristics and can be used for pasta products, but as it can be seen the sample F durum is more suitable as sample F aestivum because it shows better extensibility and elasticity characteristics which leads to a good handling in the manufacturing process.

The dough sample MARTOR aestivum (no enzyme) has the highest values for the resistance of the deforming dough ($P_{martor\ D}$) and the balance between dough strength and extensibility ($P/L_{martor\ D}$ ratio) and the lowest values for the elasticity index ($Ie_{martor\ D}$) and dough extensibility ($L_{martor\ D}$) compared to the other samples. This indicators were improved when adding the lipoxygenase as it can be seen in sample F aestivum which shows that the total quantity of absorbed energy during the dough deformation ($W_{F\ A}$), the dough resistance to deformation ($P_{F\ A}$) and the $P/L_{F\ A}$ ratio decreased significantly.

Although the sample F aestivum shows improvement we can see that the best characteristics are in Sample F durum (contain 150g/100kg flour of lipoxygenase) due to a significant decrease for the dough strength ($P_{F\ D}$) and the absorbed energy during the dough deformation ($W_{F\ D}$) which suggest that addition of lipoxygenase helps to enhance boiling and chewing properties, creates a firmer structure, reduces loss through boiling and lightens the colour.

In Tabel 1. there are presented the characteristics of dough samples obtained by alveogr-aphic method.

**Table 1** Alveograph results of the dough samples: MARTOR durum (no enzyme); MARTOR aestivum (no enzyme); F durum (contain 150g/100kg flour of lipoxygenase); F aestivum (contain 150g/100kg flour of lipoxygenase)

| Sample | MARTOR durum (no enzyme) | MARTOR aestivum (no enzyme) | Fdurum (contain 150g/100kg flour of lipoxygenase) | Faestivum (contain 150g/100kg flour of lipoxygenase) |
|---|---|---|---|---|
| P(mm$H_2O$) | 89 | 95 | 58 | 72 |
| L(mm) | 89 | 60 | 83 | 75 |
| G | 21 | 17.2 | 20,3 | 19.3 |
| W($10^{-4}$J) | 249 | 204 | 159 | 183 |
| P/L | 1,0 | 1.58 | 0,7 | 0.96 |
| Ie(%) | 51,7 | 49.4 | 52,7 | 52.0 |

*Consistographic method*

The dough samples consistogrames are represented in Fig. 5, Fig. 6, Fig. 7 and Fig. 8. The consistographic method works on recording of applied pressure of dough on a sensor. During recording constant hydration test, the maximum pressure is measured (Pr Max). This differs proportionally to the potential for moisture absorption by the flour leading to determine the rate of hydration which is adapted hydration and also is showed in the consistograme as HYDRA. This rate of hydration depends on the consistency tracked. The pressure sensor registers the dough's pressure during kneading. This pressure determines both dough's consistency and water absorption capacity of the flour.

The rheological characteristics of the dough that did not contain enzymes are shown in Fig. 5 and Fig. 6 which represent the consistogrames for samples MARTOR durum and MARTOR aestivum.

Regarding sample MARTOR durum Fig. 5, the time at which the maximum pressure is reached is 180 seconds, and the tolerance or stability of the dough is 304 seconds. These two parameters indicate that the flour presents the characteristics of medium flour. The softening at 250 and 450 seconds is low (88 and 491 mb) and water absorption capacity is 53.8% b 15%.

The sample MARTOR aestivum Fig.6, the time at which the maximum pressure is reached is 82 seconds, and the tolerance or stability of the dough is 214 seconds. These two parameters indicate that the flour presents the characteristics of weak flour. The softening at 250 and 450 seconds is high (429 and 800 mb) and water absorption capacity is 53.3% b 15%.

The consistograme sample F durum (contain 150g/100kg flour of lipoxygenase) Fig. 7 present and increase of the time at which it reaches the maximum pressure (480 seconds) and also in the tolerance and stability of the dough (612 seconds). This indicate that that the flour the characteristics of a strong flour. Moreover the softening at 250 and 450 seconds is 151 and 68 mb and water absorption capacity is 55.9% b 15%.

The consistograme sample F aestivum (contain 150g/100kg flour of lipoxygenase) Fig. 8 shows the following improvements: the time at which it reaches the maximum pressure is 126 seconds and the tolerance and stability of the dough is 277 seconds which indicate that that the flour presents the an improvement in the characteristics can be considered a medium flour, even if the softening at 250 and 450 seconds is quite high (225 or 629 mb) and water absorption capacity is 55.2% b 15%.

The data presented in the above table (Table 2) are the result of the consistographic method. By comparing the two samples MARTOR durum and MARTOR aestivum we can see a significant difference in the softening of the sample at 250 and 450 which is higher in sample MARTOR aestivum as sample MARTOR durum. Also the time at which the maximum pressure is reached and dough tolerance for sample MARTOR aestivum are much lower than al the other samples. What we can also notice is that the sample F durum has the best characteristics due to high time at which the maximum pressure is reached and dough tolerance compared the other samples. Sample F aestivum has improvements in the dough tolerance and the time at which the maximum pressure is reached compared to the blank samples but does not reach the same quality as the sample F durum.

Results

$H_2O_{M\ durum}$ = 13.90%
$TOL_{M\ durum}$ = 304 s
$HYDHA_{M\ durum}$ = 52,1% b 15%
$D250_{M\ durum}$ = 88 mb
$PRMAX_{M\ durum}$ = 1943 mb
$D450_{M\ durum}$ = 491 mb
$TPRMAX_{M\ durum}$ = 180 s
$WAC_{M\ durum}$ = 53,8 % b 15%

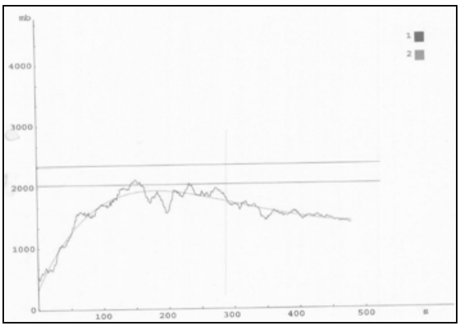


**Fig. 5** Sample MARTOR durum (no enzyme) consistograme

Results

$H_2O_{M\ aestivum}$= 13.90%
$TOL_{M\ aestivum}$ = 214 s
$HYDHA_{M\ aestivum}$ = 51,2% b 15%
$D250_{M\ aestivum}$ = 429 mb
$PRMAX_{M\ aestivum}$ = 2143 mb
$D450_{M\ aestivum}$ = 800 mb
$TPRMAX_{M\ aestivum}$ = 82 s
$WAC_{M\ aestivum}$ = 53,3 % b 15%

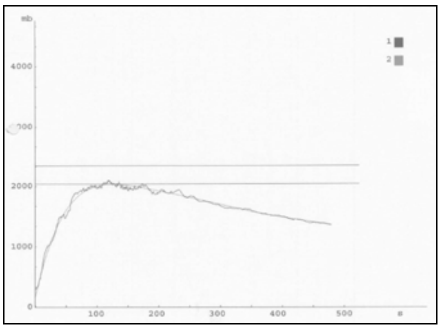


**Fig. 6** Sample MARTOR aestivum (no enzyme) consistograme

Results

$H_2O_{F\ durum}$ = 13,90%
TOL $_{F\ durum}$ = 612 s
HYDHA $_{F\ durum}$ = 54.0% b 15%
D250 $_{F\ durum}$ = 151 mb
PRMAX $_{F\ durum}$ = 2052mb
D450 $_{F\ durum}$ = 68 mb
TPRMAX $_{F\ durum}$ = 480 s
WAC $_{F\ durum}$ = 55,9 % b 15%

Results

$H_2O_{F\ aestivum}$ = 13,90%
TOL $_{F\ aestivum}$ = 277 s
HYDHA $_{F\ aestivum}$ = 53,3% b 15%
D250 $_{F\ aestivum}$ = 225 mb
PRMAX $_{F\ aestivum}$ = 2043mb
D450 $_{F\ aestivum}$ = 629 mb
TPRMAX $_{F\ aestivum}$ = 126 s
WAC $_{F\ aestivum}$ = 55,2 % b 15%

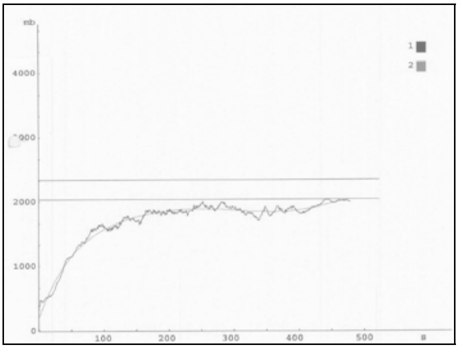


Fig. 7. Sample F durum (contain 150g/100kg flour of lipoxygenase) consistograme

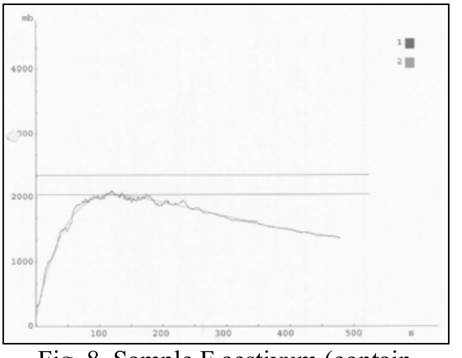


Fig. 8. Sample F aestivum (contain 150g/100kg flour of lipoxygenase) consistograme

**Table 2** Consistograph results of the dough samples: MARTOR durum (no enzyme); MARTOR aestivum (no enzyme); F durum (contain 150g/100kg flour of lipoxygenase); F aestivum (contain 150g/100kg flour of lipoxygenase)

| Sample | MARTOR durum (no enzyme) | MARTOR aestivum (no enzyme) | Fdurum (contain 150g/100kg flour of lipoxygenase) | Faestivum (contain 150g/100kg flour of lipoxygenase) |
|---|---|---|---|---|
| $H_2O$(%) | 13,90 | 13,90 | 13,90 | 13,90 |
| HYDHA(%) | 52,1% b 15% | 51,2% b 15% | 54,0% b 15% | 53,3% b 15% |
| PRMAX(mb) | 1943 | 2143 | 2052 | 2043 |
| TPRMAX(s) | 180 | 82 | 480 | 126 |
| TOL(s) | 304 | 214 | 612 | 277 |
| D250(mb) | 88 | 429 | 151 | 225 |
| D450(mb) | 491 | 800 | 68 | 629 |
| WAC(%) | 53,8 % b 15 | 53,3 % b 15 | 55,9 % b 15 | 55,2 % b 15 |

In conclusion sample F durum is enhanced by the addition of lipoxygenase enzyme preparation based on which the dough increases tolerance to prolonged boiling, increases the firmness of cooked pasta, reduce oil uptake of fried instant pasta.

## CONCLUSIONS

The additive actions of complex enzymes as ameliorator on flour have positive effects on the rheological characteristics of dough. The technological characteristics of the flour and the nutritive value of the bread are characterized by the following variables: initial volume, fermentation time, flexibility, the dough condition to fermentation, water retention, maximum resistance, extensibility, final rise to baking, final volume of the bread, nutritive value, and energy value In order to improve these variables, different additives and substances are used in the bread manufacture, some of these being native components of the flour.

The alveograph test provides results that are common specifications used by flour millers and processors to ensure a more consistent process and product. The alveograph is well suited for measuring the dough characteristics and what we can notice is that the best characteristics are in Sample F durum (contain 150g/100kg flour of lipoxygenase) due to a significant decrease for the dough strength ($P_{F\ D}$) and the absorbed energy during the dough deformation ($W_{F\ D}$) which suggest that addition of lipoxygenase helps to enhance boiling and chewing properties, creates a firmer structure, reduces loss through boiling and lightens the colour.

The consistographic test shows the dough's features, the water absorption capacity of the flour and observes the changes in the process of kneading dough. The results of the tested samples showed that the samples MARTOR durum and MARTOR aestivum which do not contain lipoxygenase enzyme preparation do not have the optimal characteristics for the manufactuing of pasta, and that sample F durum which contains lipoxygenase shows the best parameters compared to the blank samples and to sample F aestivum. The time required to complete hydration sample F durum ($TPRMAX_{F\ durum}$) show an increase compared to sample F aestivum. Also the dough's tolerance of sample F durum shows an increase compared to sample F aestivum and also to the blank samples. The reason is the addition of lipoxygenase which improves firmness of cooked pasta and reduce oil uptake of fried instant pasta. The softening of the dough after 250 seconds and 450 seconds after ($D250_{F\ durum}$ and $D450_{F\ durum}$) in sample F durum has decreased compared to sample F aestivum and to samples MARTOR durum and aestivum which leads to an increase in consistency and a decrease in extensibility of the dough.

Enzyme preparation based on lipoxygenase used to obtain products with improved color and gloss are also used to reduce the drying time of noodles, improved surface appearance and mechanical stability of noodles and pasta, and reduce raw material costs. It positively influences the quality of final products by increasing tolerance to prolonged cooking, cooked pasta firmness and helps reduce oil uptake of fried instant pasta. They do not modify the technological process of bread making and their utilization is not expensive. Selecting a correct enzyme preparation will be made in conformity with the rheological characteristics of dough and the proportions from the dough will be added so that they would be maximal. The enzyme preparations are used to obtain bakery products with “clean label”, more natural, this products being the product that enjoys the greatest interest from consumers.

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42. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

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# THE ENZYME ACTIVITY OF HEMICELULLASE USED ON DOUGH OBTAINED FROM WHEAT FLOUR

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**SUMMARY**

*This study presents the action of an exogenous enzyme: hemicelullase in different dosages, in the bread dough. The determination of the rheological characteristics of the dough is obtained by alveographic and consistographic method. The alveographic method shows the resistance to deformation and the elasticity of the samples, but also the total quantity of absorbed energy during the dough deformation and the consistographic method determines the consistency of dough and water absorption capacity of flour. For the standard sample which does not contain any enzyme, the results from both methods show that the dough is sensitive to stretch and can easily brake due to high resistance to deformation and low extensibility properties, moreover the time at which the maximum pressure is reached and the stability of the dough are very low which is associated with a weak flour. In case of insufficient dose of hemicelullase such as sample F1 (including hemicelullase 3g/100kg wheat flour) shows also similar charateristics as the standard sample with very small improvements. In case of overdose of hemicelullase such as the sample F3 (including hemicelullase 20g/100kg wheat flour) the dough presents an increase in stickiness even if the time required for complete hydration and dough tolerance show an increase. The other characteristics such as the degree of softening of the dough after 250 seconds and after 450 seconds are very low suggesting that this flour can be included in the week category. A correct dosage of hemicelullase as in sample F2 (including hemicelullase 10g/100kg wheat flour) presents a decrease of the dough consistency which suggests a high extensibility and decreases resistance to deformation of the dough. The consistographic method also confirms that the sample F2 (including hemicelullase 10g/100kg wheat flour) presents an improvement in dough mixing and stability, but also in retention capacity of moisture and gases.*

***Key words***: *bread, hemicelullase, alveograph method, consistograph method*

## INTRODUCTION

Enzymes applications have grown to be a common practice in the baking industry with advantage of being considered as natural additives. The enzymes are being used in the baking industry to improve dough-handling properties. The synthetically additives can be replaced with natural additives, as enzymes.

After Banu C., hemicelullase can be grouped into: endo - hemicellulases, which acts inside the hemicelullose chain and have limited activity on oligomers with short chain; exo - hemicellulases acting progressively reducing either the reducing or non-reducing end of the hemicellulose and hemicellulases which cleaves native hemicellulose in plants (acetyl esterases and esterases). [1]

Addition of hemicelullase in dough leads to an increase in volume, products with high fiber content, improvement of flower quality and final product stability by positive effects against aging, extension of freshness and increasing the life time of the products. Also hemicelullase has positive effects on the texture of the product by a softer core, more refined and with a uniform structure of the pores, improvement in the stability of frozen dough, a better crispiness, lower hygroscopicity. [1] Regarding the color hemicelullase helps in browning effects, improves the color of the crust. Overall the quality of the product improves by the compensation when the recipes are changing, also by replacing bromate, sodium metabisulphite, the emulsifier, vital gluten, bread with low fat and the nutritional properties improve by increase in total and soluble dietary fiber.

The purpose of the research is finding the proper dosage of hemicelullase enzyme used on dough in order to compensate and improve the rheological characteristics of a flour that has a low content in endogenous enzymes.

## METHODS

*Samples preparation*

For the alveographic method the materials used for the preparation of the dough samples are wheat flour 650, salt, water, yeast and hemicelullase.

A sample of 250g of flour is mixed with a solution of salt, yeast and hemicelullase in a laboratory mixer 15 min to form dough. In the first phase the flour absorbs water creating the dough with developing the hydratation heat. Then the dough is becoming elastic. [2] The amount of water was adjusted according to the water absorption capacity of flour.The first dough sample MARTOR contained 95% flour, 1.7% salt, 1.7% yeast and does not any hemicelullase.The second dough sample F1 contained 95% flour, 1.7% salt, 1.7% yeast and hemicelullase. 3g/100kg wheat flour The third dough sample F2 contained 95% flour, 1.7% salt, 1.7% yeast and hemicelullase 10g/100kg wheat flour.The fourth dough sample F3 contained 95% flour, 1.7% salt, 1.7% yeast and hemicelullase 20g/100kg wheat flour.

Each dough sample is divided in five circular consecutive dough patties witch are rested 20 min in the alveograph in a temperature-regulated compartment at 25 °C. Each dough patty is tested individually and the result is the average of the five dough patties.

In order to determine the consistogrames following tests were performed: the constant hydration test (CH) and adapted hydration test (AH).

Constant hydration is essential in order to make adapted hydration.

In order to prepare the device for the tests it is needed to include the double-mixing auger into the mixing space.

Sample preparation is done by weighing 250 g flour with a precision of 0.5 g sample. Then it is determined the moisture with the analytical balance. After this it is prepared a 2.5% NaCl solution which is placed in the burette of the consistograph. The temperature of the solution is between 18 to 22 ° C. The volume of this solution is equal to the initial specified moisture. Then the mixing phase is started and after 1 min the device is stopped and cleaned on the side walls of the kneading space, taking care not to touch the sensor and not longer than 2 minutes for cleaning. Then it starts again and after 250 seconds of mixing the consistograph and indicates the quantity of sample that will take part in the next test and the salt solution required to determine the adapted hydration.

The beginning of the adapted hydration test is conducted by weighing the suitable quantities of flour and the required amount of water indicated, then the operation is started again by doing the mixing according to the first test. After 480 seconds the consistograph stops and the consistographic results for the sample is recorded by Alvoelink.

The hemicelullase used is a commercial product: HCE 7002– enzyme preparation which contains hemicelullase; dosage: 5-15g/100kg of wheat flour

Methods of analysis

The determination of the rheological characteristics of the dough was obtained by alveographic method and consistographic.

The alveographic method relies on measuring the resistance to biaxial stretch under air pressure of a dough sample prepared in standard conditions.

The dough patty is placed on the alveograph, witch blows air into it. The dough patty expands into a bubble that eventually breaks. The pressure inside the bubble is recorded as a curve on graph paper. The alveograph determines the gluten strength of dough by measuring the force required to blow and break a bubble of dough. The results include P Value, L Value, and W Value. Stronger dough requires more force to blow and break the bubble (higher P value). A bigger bubble means the dough can stretch to a very thin membrane before breaking. A bigger bubble indicates the dough has higher extensibility; that is, its ability to stretch before breaking (L value). A bigger bubble requires more force and will have a greater area under the curve (W value).

From the alveogram the following indicators were obtained:

- P Value is the force required to blow the bubble of dough. It is indicated by the maximum height of the curve and is expressed in millimeters (mm). It is also known as the viscosity or the value of maximum pressure that is in relationship to the resistance of the deforming dough (mm $H_2O$)
- L Value is the extensibility of the dough before the bubble breaks. It is indicated by the length of the curve that begins from the origin until the perpendicular point that

corresponds to decreasing pressure due to rupture of air bubble and is expressed in millimeters (mm).

- G Value is the expansion index G being the average of the expansion index on the graphic of cellules and corresponds to breaking the abscise L, G =2.226L, where L – air volume ($cm^3$) used to stretch the dough under bubble form.
- P/L Ratio is the balance between dough strength and extensibility. It is the rapport of configuration of the curve.
- W Value is the area under the curve. It is a combination of dough strength (P value) and extensibility (L value) and is expressed in joules. It represents the action of deformation of the dough, based on a gram of dough, evaluated at 10 E – 4 joule, calculated as follows: W= 1.32 x (V/L) x S, where V- air volume in $mm^3$; L- the average abscise at breaking point in mm; S- surface of the curve, $cm^2$.
- Ie – elasticity index, represents the raport between the measured pressures, expressed in mm $H_2O$ to form bubbles after the insufflations of 200 $cm^3$ of air in dough form, that correspond to a length L of 40 mm or an index of expansion G from 14,1 and the maximum of the curve P: Ie%= P200/Pmax. [3]

The consistographic method is used to determine the consistency of dough and water absorption capacity of flour and observing changes in the process of kneading dough.

The equipment used to determine consistogrames is Alveo-Consistograph NG.

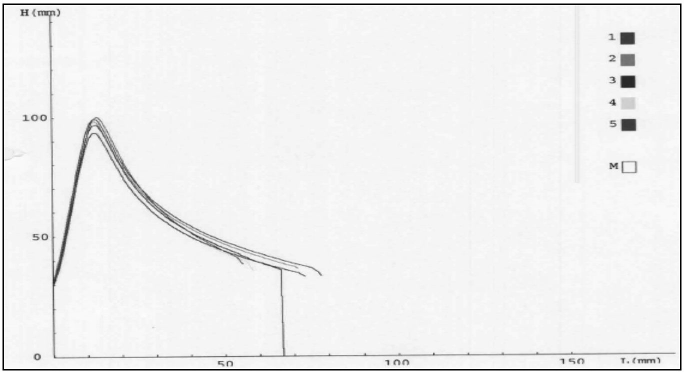
From the consistograme the following indicators were obtained:

- flour moisture (H2O)
- maximum pressure (Pr MAX)
- hydration potential of the flour (HYDRA)
- time to reach the maximum pressure (Pr T MAX)
- tolerance or dough stability (TOL)
- pressure drop compared to PrMax after 250 seconds or the degree of softening of the dough after 250 seconds (D 250)
- pressure drop compared to PrMax after 450 seconds or the degree of softening of the dough after 450 seconds (D 450)
- water absorption capacity WAC.[3]

## RESULTS AND DISCUSSIONS

*The alveographic method*

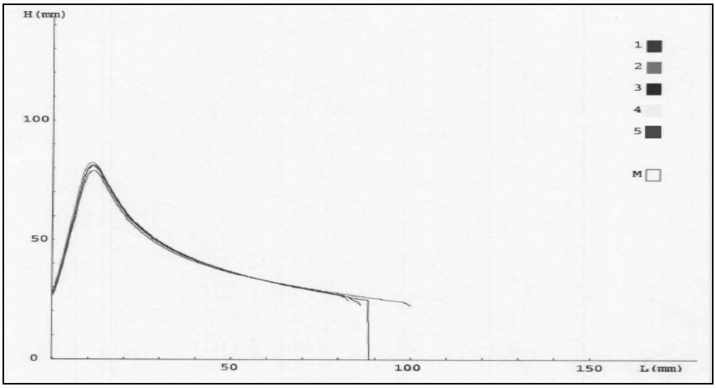
The dough samples alevograms are represented in Fig. 1, Fig. 2, Fig. 3 and Fig. 4. Each dough sample alveorgam show the five dough patties tested (marked with different colors) and the parameters registered at the testing moment. The results of the samples are represented by the average value obtained from the values of the dough patties tests for each dough sample.




Results

$P_M$ = 107 mm$H_2O$
$L_M$ = 66 mm
$G_M$ = 18.1
$W_M$ = 256x$10^{-4}$J
$P/L_M$ = 1.62
$Ie_M$ = 53.8 %

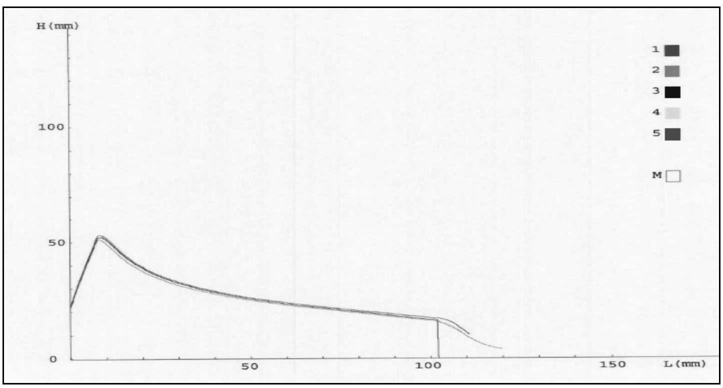
**Fig 1** MARTOR sample (not including hemicelullase) alveogram




Results

$P_{F1}$ = 89 mm$H_2O$
$L_{F1}$ = 89 mm
$G_{F1}$ = 21.0
$W_{F1}$ = 249x$10^{-4}$J
$P/L_{F1}$ = 1.0
$Ie_{F1}$ = 51.7 %

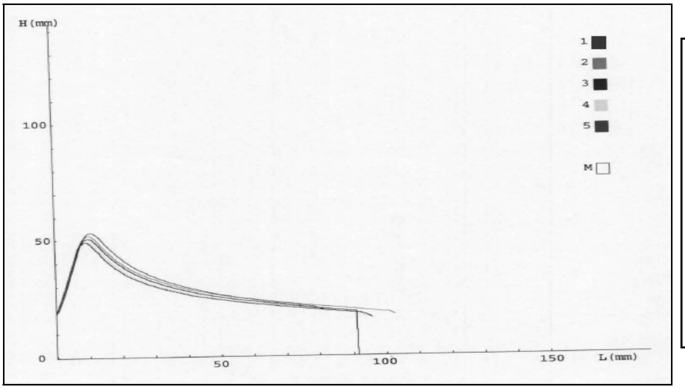
**Fig 2** F 1 sample (including hemicelullase 3g/100kg wheat flour) alveogram




Results

$P_{F2}$ = 58 mm$H_2O$
$L_{F2}$ = 102 mm
$G_{F2}$ = 22.5
$W_{F2}$ = 187x$10^{-4}$J
$P/L_{F2}$= 0.57
$Ie_{F2}$= 54.4 %

**Fig. 3** F 2 sample (including hemicelullase 10g/100kg wheat flour) alveogram




Results

$P_{F3} = 56\ mmH_2O$
$L_{F3} = 92$ mm
$G_{F3} = 21.4$
$W_{F3} = 172x10^{-4}J$
$P/L_{F3} = 0.61$
$Ie_{F3} = 55.3$ %

**Fig. 4** F 3 sample (including hemicelullase 20g/100kg wheat flour) alveogram

In Fig. 1 the dough sample MARTOR alveogram represents the dough sample that does not contain any hemicelullase. This sample is considered the standard blank sample. The alveogram's standard characteristics for flour used for bread have the fallowing values: P = [60 – 70mm], L = [130 – 150mm], G = [20 – 30], P/L = [0,5 – 0,6] and W > $180x10^{-4}$J. The values for dough sample MARTOR, regarding the resistance of the deforming dough (P) and the balance between dough strength and extensibility (P/L ratio) are higher than the normal values. The values regarding the dough extensibility (L) and expansion index (G) are very low, therefore the dough is sensitive to stretch and can easily brake. It cannot be used for bread making.

In Fig. 2 is represented the alveogram of dough sample F 1 (including hemicelullase 3g/100kg wheat flour) that has in composition hemicelullase 3g/100kg wheat flour. Compared with the blank sample MARTOR there are small differences regarding the dough strength (P) that decreases with 18 $mmH_2O$, but looking at the extensibility characteristics and the absorbed energy during the dough deformation we can see, obviously, the dough quality improvements. Only the P/L ratio and the Ie value have decrease because of the dough strength and the dough extensibility. Using 3g/100kg hemicelullase improves the stability of dough and its tolerance for fermentation and decreases of dough viscosity.

In Fig. 3 the alveogram of dough sample F 2 (including hemicelullase 10g/100kg wheat flour) represents the dough sample that contains 10g/100kg hemicelullase. There is a noticeable increase in the main indicators that suggests the improvement of the dough. The dought resistants to deformation (P) has decreased, also the dough extensibility characteristics (L and G) are higher than the value of dough sample MARTOR. Moreover, the elasticity index (Ie) has increased with 0.6%, although the total quantity of absorbed energy during the dough deformation (W) is with $69x10^{-4}$J lower than the value of dough sample MARTOR. This result expresses advantages of using hemicelullase in the preparation of the dough for bakery. The reduction of dough's consistency through the addition of hemicelullase leads to the increasing of extensive character and decreasing of the resistance of dough

In Fig. 4 is the alveogram for the dough sample F3 (including hemicelullase 20g/100kg wheat flour) that contains 20g/100kg hemicelullase. Addition of this dosage of hemicelullase, decreased the dough strength (P) with 51 mm$H_2O$. The absorbed energy during the dough deformation (W) and the P/L ratio are reduced. There is an increase of the extensibility characteristics and of the elasticity index (Ie). Addition of hemicelullase in bakery products improves the dough handling and stability and increases the dough volume, but in case of overdose the dough presents an increase in stickiness.

**Table 1** Alveograph results of the dough samples: MARTOR (not including hemicelullase), F 1 (including hemicelullase 3g/100kg wheat flour), F 2 (including hemicelullase 10g/100kg wheat flour), F 3 (including hemicelullase 20g/100kg wheat flour)

| Sample | MARTOR (not including hemicelullase) | F 1 (including hemicelullase 3g/100kg wheat flour) | F 2 (including hemicelullase 10g/100kg wheat flour) | F 3 (including hemicelullase 20g/100kg wheat flour) |
|---|---|---|---|---|
| P(mm$H_2O$) | 107 | 89 | 58 | 56 |
| L(mm) | 66 | 89 | 102 | 92 |
| G | 18.1 | 21.0 | 22.5 | 21.4 |
| W($10^{-4}$J) | 256x$10^{-4}$J | 249x$10^{-4}$J | 187x$10^{-4}$J | 172x$10^{-4}$J |
| P/L | 1.62 | 1.0 | 0.57 | 0.61 |
| Ie(%) | 53.8 | 51.7 | 54.4 | 55.3 |

In Tabel 1. there are presented the characteristics of dough samples obtained by alveogr-aphic method.

The dough sample F 2 (including hemicelullase 10g/100kg wheat flour) has the most adequate values for the following indicators, the dough extensibility characteristics (L and G), the total quantity of absorbed energy during the dough deformation (W) compared to the dough samples F 1 (including hemicelullase 3g/100kg wheat flour)) and F 3 (including hemicelullase 20g/100kg wheat flour)).

The dough sample F 1 (including hemicelullase 3g/100kg wheat flour) presents improve-ments of the dough extensibility characteristics compared to the MARTOR sample. The dosage of 3g/100kg hemicelullase helps in dough viscosity and improves the processing quality but it does not achive the standard parametrs for bread.

The dough sample F 3 (including hemicelullase 20g/100kg wheat flour) has the dough characteristics worsen compared to the dough sample F 1 (including hemicelullase 3g/100kg wheat flour) and dough sample F 2 (including hemicelullase 10g/100kg wheat flour). This dosage shows that the dough resistance to deformation characteristics (P) and the total quantity of absorbed energy during the dough deformation (W) have decrease significantly.

*The consistographic method*

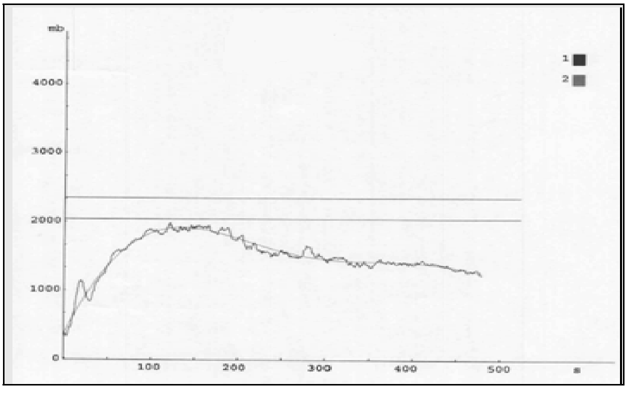
The dough samples consistograms are represented in Fig. 5, Fig. 6, Fig. 7, Fig. 8. Each dough sample consitograme show the parameters registered at the testing moment.

The following classification of flour based on the time to reach maximum pressure (T Pr MAX) and dough tolerance (TOL)

- Weak flour: T Pr MAX between 1-3 minutes TOL between 1 - 4 minutes
- Medium flour: T Pr MAX between 3-8 minutes TOL between 4 - 5 minutes
- Strong flour: T Pr MAX between 8-15 minutes and 10-15 minutes TOL.

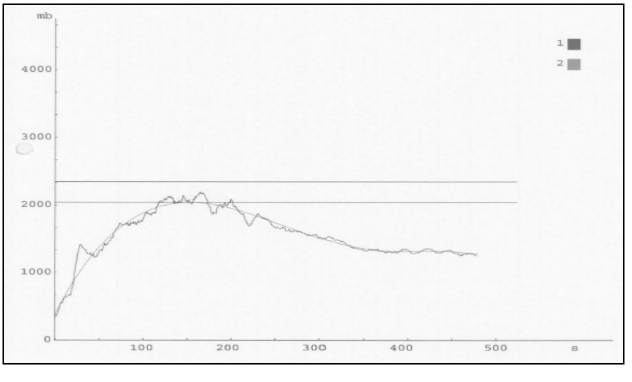
In fig. 5 is presented the consistograme for sample **MARTOR** (not including hemicellullase)

In Fig 5. it is presented the consistograme of the sample MARTOR (not including hemicelullase). The time at which the maximum pressure is reached in 135 seconds, and the tolerance and stability of the dough is 198 seconds. These two parameters indicate that the characteristics of the flour are associated with a week flour. The degree of softening at 250 and 450 seconds is high (349 and 596 mb ) and the water absorption capacity is 53.6 % b 15 % .In



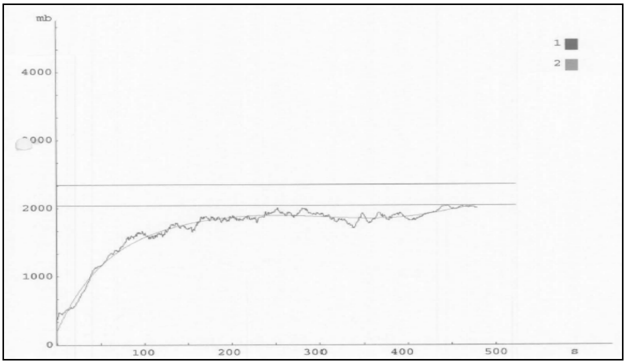

Results
$H_2O$ = 14.30%
$HYDHA_M$ = 51.8% b 15%
$PRMAX_M$ = 1927 mb
$TPRMAX_M$ = 135 s
$TOL_M$ = 198 s
$D250_M$ = 349 mb
$D450_M$ = 596 mb
$WAC_M$ = 53.6 % b 15
$HYDHAC_M$ = 51.1 % b 15

**Fig 5** MARTOR sample (not including hemicelullase) consistograme



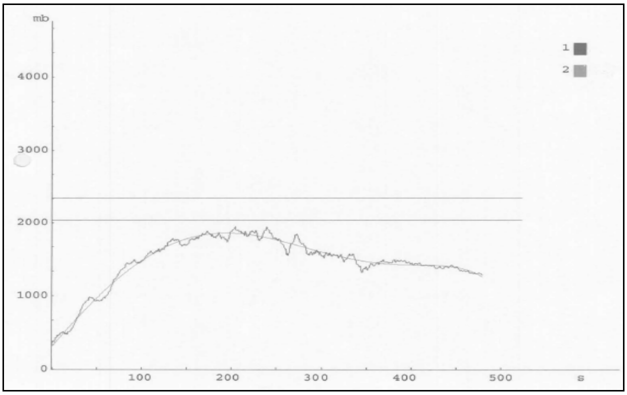

Results
$H_2O_{F1}$ = 14.30%
$HYDHA_{F1}$ = 50.5% b 15%
$PRMAX_{F1}$ = 2047 mb
$TPRMAX_{F1}$ = 154 s
$TOL_{F1}$ = 203 s
$D250_{F1}$ = 298 mb
$D450_{F1}$ = 729 mb
$WAC_{F1}$ = 48.3 % b 15
$HYDHAC_{F1}$ = 45.8 % b 15

**Fig 6** F 1 sample (including hemicelullase 3g/100kg wheat flour ) consistograme




Results
$H_2O_{F2}$ = 14.30%
HYDHA $_{F2}$ = 54 % b15%
PRMAX $_{F2}$ = 2052 mb
TPRMAX $_{F2}$= 480 s
TOL $_{F2}$ = 503 s
D250 $_{F2}$ = 151 mb
D450 $_{F2}$ = 68 mb
WAC $_{F2}$ = 55.9 % b 15
HYDHAC$_{F2}$ =53.4%b15

**Fig 7** F 2 sample (including hemicelullase 10g/100kg wheat flour ) consitograme




Results
$H_2O_{F3}$ = 14.30%
HYDHA $_{F3}$ = 52,7%b15%
PRMAX $_{F3}$ = 1860 mb
TPRMAX $_{F3}$= 195 s
TOL $_{F3}$ = 240 s
D250 $_{F3}$ = 92 mb
D450 $_{F3}$ = 466 mb
WAC $_{F3}$= 54.2 % b 15
HYDHAC$_{F3}$ =51.7%b15%

**Fig. 8** F 3 sample (including hemicelullase 20g/100kg wheat flour) consitograme

Fig. 6. we can see the consistograme of F 1 sample (enzymes preparation which contains hemicelullase 3g/100kg wheat flour). The time at which the maximum pressure is reached has increased with 19 seconds as well as the stability of the dough by 5 seconds. Even if this two parameters show improvement they indicate that the flour has weak characteristics. The degree of softening at 250 and 450 seconds are also very high (298 amd 729 mb) and the water absorption capacity is 48.3 % b 15 %. In fig. 7 we noticed that in comparison with the sample MARTOR (not including hemicelullase) and F 1 sample (enzymes preparation which contains hemicelullase 3g/100kg wheat flour) the flour characteristics show an significant improvement. One can observe an increase of the maximum pressures ($PRMAX_{F2}$ ) to 2052 mb, and the time required to complete hydration ($TPRMAX_{F2}$) is very high. Also the tolerance of dough shows an increase which demonstrate that the addition of enzyme preparation containing 10g/100kg hemicellulase improves dough mixing and stability, but also that there is an improvement of the retention capacity of moisture and gases . The softening of the dough after 250 seconds and 450 seconds have decreased due to the addition of enzyme preparation . This means that there is an improvement in the extensibility of the dough and also in it's consistency . According to this results the flour

can be considered as a strong flour. In Fig. 8 is shown the consistograme of F 3 sample (enzyme preparation which contains hemicelullase 20g/100kg wheat flour). One can see a significant decrease in maximum pressure of 67 mb compared with sample MARTOR. The time required complete hydration and dough tolerance SAMPLE 550 ( TOL4 ) shows an increase but the degree of softening of the dough after 250 seconds and after 450 seconds are very low.This flour can be included in the week category.

**Table 2** consistograph results of the dough samples: MARTOR (not including hemicelullase), F1 (including hemicelullase 3g/100kg wheat flour), F2 (including hemicelullase 10g/100kg wheat flour), F 3 (including hemicelullase 20g/100kg wheat flour)

| Sample | MARTOR (not including hemicelullase) | F 1 (including hemicelullase 3g/100kg wheat flour) | F 2 (including hemicelullase 10g/100kg wheat flour) | F 3 (including hemicelullase 20g/100kg wheat flour) |
|---|---|---|---|---|
| $H_2O$(%) | 14.30 | 14.30 | 14.30 | 14.30 |
| HYDHA(%) | 51.8 | 50.5 | 54 | 52,7 |
| PRMAX(mb) | 1927 | 2047 | 2052 | 1860 |
| TPRMAX(s) | 135 | 154 | 480 | 195 |
| TOL(s) | 198 | 203 | 503 | 240 |
| D250(mb) | 349 | 298 | 151 | 92 |
| D450(mb) | 596 | 729 | 68 | 466 |
| WAC(%) | 53.6 | 48.3 | 55.9 | 54.2 |
| HYDHAC(%) | 51.1 | 45.8 | 53.4 | 51.7 |

The data presented in the above table (Table 2) are the result of the consistographic method. By comparing the MARTOR samples with F1 sample we can notice a slight difference between dough rheological characteristics. Although the degree of softening at 250 and 450 of the MARTOR samples are similar to the F1 sample, the time for the maximum pressure to be reached ($TPRMAX_M$) and dough tolerance ($TOL_M$ ) are lower than the F1 sample which suggest an improvement for F1 sample.You can also see that the maximum pressures and the time needed for complete hydration for F2 sample are higher than the rest of the samples. The tolerance dough shows an increase which demonstrate that the addition of enzyme preparation containing 10g/100kg hemicellulase improves the gluten quality and dough mixing stability. The softening of the dough after 250 seconds and 450 seconds for F2 sample decreases due to the addition of enzyme preparation. This represents an increase consistency and improved extensibility. Comparing F2 sample to F3 sample it is noted that the addition of 10g/100kg wheat flour enzyme preparation consisting of hemicellulase has a positive infuence on the F2 sample because the tolerance dough ($TOL_{F2}$) is higher by 263 seconds compared to TOL $_{F3}$. These parameters indicate that the F2 sample has a better stability of dough mixing and gluten quality higher compared with the F3 sample. In conclusion the addition of hemicellulase enzyme preparation in dough improves the retention of moisture and gases, and increase the configuration, size and structure of the bread, and the ability to absorb and retain water is very important for the production of the soft core, with long storage, and natural flavor of gluten, which contributes to the overall flavor of the product, increasing its acceptability by consumers.

## CONCLUSIONS

The analysis made by alveographic and cosistographic methods showed that by adding hemicelullase in a ratio of 10g/100kg wheat flour (sample F2) is the adequate dosage that should be used on a flour that has high resistance of the deforming dough (P) and high value of the balance between dough strength and extensibility (P/L ratio). The improvement is in the extensibility of the dough and also in it's consistency. Moreover the dough mixing and stability are positive affected, but also there is an improvement of the retention capacity of moisture and gases. The results show that it is not relevant if it is used a lower dosage of hemicelullase (sample F1) because the missing endogenous enzyme of the flour are not compensated and even if we see an improvement in the dough extensibility characteristics and in dough viscosity, the dough does not achieve the standard parameters for bread. As a negative result is also shown that when using a higher dose of hemicelullase (sample F3) leads to a wet and sticky content of the dough because the dough resistance to deformation (P) and the total quantity of absorbed energy during the dough deformation (W) are decreased significantly, but also due to low values in the degree of softening of the dough after 250 seconds and after 450 seconds affecting the dough handling during the technological process and an abnormal volume and porosity.

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42. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

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Preliminary communication

# AIR TEMPERATURE AND RELATIVE HUMIDITY DISTRIBUTION IN DIFFERENT TYPE OF GREENHOUSE CONSTRUCTIONS

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## ABSTRACT

*Greenhouse plant production is one of the most intensive parts of the agricultural production. In order to reduce the costs and save the energy, various greenhouse constructions and different coverings are offered to the farmers. One of the biggest problems is in winter production when additional heating and light are needed as well as in summer when intensive cooling is needed. During these period construction and coverings fully show their qualities. The aim of this research was to investigate the temperature and air relative humidity distribution in the different greenhouse constructions in the different production systems in order to see if the choice of the greenhouse construction can improve the production conditions inside the greenhouse enabling the better energy efficiency and lower energy input for heating / cooling. Results show that temperature pattern and its values during the night and day depends on the greenhouse construction, plant specie that is grown and production season. Temperature differences of 6.91°C in the tunnel construction during winter were found to be very significant while in the gutter-connected greenhouse these differences were not significant. In the summer period temperature differences were not significant in neither of the greenhouses. In the winter production gutter-connected greenhouse had significantly, 5.09 °C, higher temperatures compared to the outside during the day and during the night. In the tunnel greenhouse these temperatures were significantly higher only during the day. Air relative humidity showed significantly higher values for the summer and winter period. In the gutter-connected greenhouse these differences were higher only in the summer period.*

***Key words**: tunnel, gutter-connected greenhouse, air temperature, air relative humidity, lettuce, tomato*

## INTRODUCTION

Greenhouse is a very complex and intensive agricultural production system. It is intensive in terms of production, energy consumption, labour and cost. From their beginning in the early fifties in 20th century greenhouse technology passed various phases of development regarding construction material, shape and covering materials (Dimitrijevic et al, 2011). Reason for this intensive development are various and are starting from plain men curiosity how to "play" with the nature and are finishing with the global energy, ecology and economy issues. Thanks to the technology development it is possible to completely control the production conditions in the greenhouses and in this way have the "summer" conditions in the winter time and, thus, having the year-around high profit plant production. The question is only for what energy and economy price.

Factors that determine the greenhouse production system are air temperature, relative humidity of air and soil, air quality and light conditions. Tracking these micro-climatic conditions is of a great importance for the successful greenhouse production (Ponjican et al, 2011). If these conditions are to be tracked continuously micro-climatic conditions in the region and plant psychology and physiology should be know, on the one side, and on the other side greenhouse system characteristic such as greenhouse dimensions, covering material characteristics, greenhouse orientation etc.

Various types of greenhouse constructions and covering materials are available at the market and are offered to the farmer. Purpose of tracking the greenhouse production continuously is to optimize the plant productions in the greenhouse. It is necessary to know the correlation between greenhouse construction, covering material and type of the plant production.

Temperature conditions in the greenhouses influence the overall plant growth, yield and fruit quality. If the air temperature and relative humidity in the greenhouse are lower than optimal plants will be shorter with smaller dark green leaves. In the case of lower temperature and higher relative air humidity flowering of the plants will be delayed and the yield will be lower. Higher night temperatures cause the higher consumption of organic matter by plants which grow with the long pale green gently leaves with the lower yield and deformed fruits. It is stated (Lazić Branka i dr, 2001, Hanan, 1998, Nelson, 2003) that night temperatures and the temperatures during the day should be 3–5° C lower compared outside temperatures during the sunny days. It is also stated that temperature variations during the day should not be more than 2 do 3° C. Literature sources (Lazić Branka i dr, 2001, Hanan, 1998, Nelson, 2003, Sengar and Kothari, 2008, Singh and Tiwari, 2000) confirm the statement that temperature in greenhouses varies along their length, width and height. The pattern of this variation is influenced by the greenhouse type of construction and its dimensions, covering material, orientation and applied heating and venting systems.

The aim of this paper was to show how the type of greenhouse construction, production season and plant species can influence the uniformity of the micro-climatic conditions in the greenhouses.

## METHODS

For the research a tunnel type (TUN) 5.5 x 24 m covered with 180 µm PE UV IR outside folia (Figure 1) and a gutter connected plastic covered greenhouse (GUT) 21 x 250 m and with 50 µm inner folia and 180 µm outside folia were used.

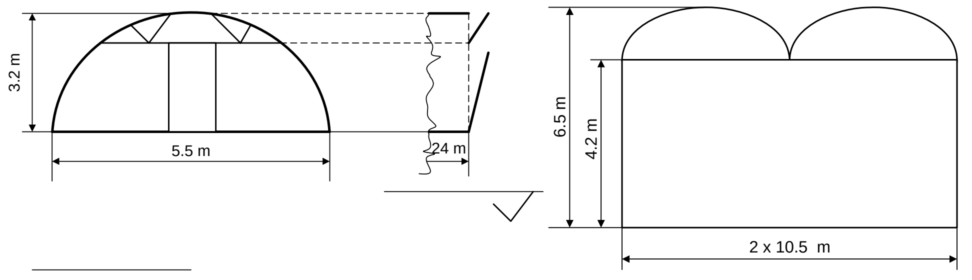



**Fig. 1** Tunnel and gutter connected greenhouses

Production surface of the tunnel greenhouse was 132 m$^2$, covering material / production area ratio was 19.91 and its specific volume 12.56 m$^3$/m. Gutter-connected greenhouse had the 5250 m$^2$ production surface, covering material / production surface ratio 1.62 and specific volume of 37.92 m$^3$/m. Experiment was carried at the private property in Pancevo (Serbia) on 20°38 E altitude and 44°52 N latitude and at a private property near Jagodina (Serbia) on 21°16E altitude and 44°1N latitude.

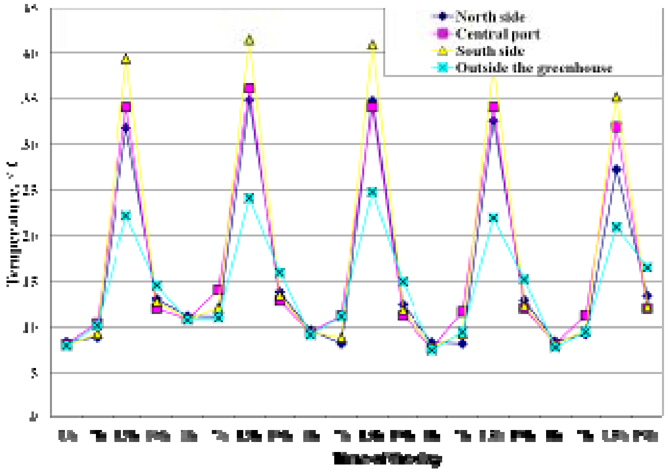
Temperature and air humidity were measured using the sets of WatchDog Data loggers 150 Temp/RH, t= 0.6 °C and RH= 3% and a WatchDog Data Logger Model 450 – Temp, Relative Humidity - Temp/RH, t= 0.6 °C and RH= 3%. In the tunnel greenhouse, lettuce production conditions were analysed for the October 2008 production season while tomato production conditions were analysed for the summer 2008 production season. In the gutter connected greenhouse lettuce production conditions were analysed for the winter 2008/09 production season while tomato production was analysed for the summer 2008 production season. Both of the greenhouses were without heating systems.

Statistical analysis of the results was based on variance analysis, F tests and LSD tests which were used for determine if the temperature and relative humidity are uniform along the greenhouses and if the type of construction and plant specie influence the temperature and relative humidity uniformity. Data used for the analysis represent the five days average values.

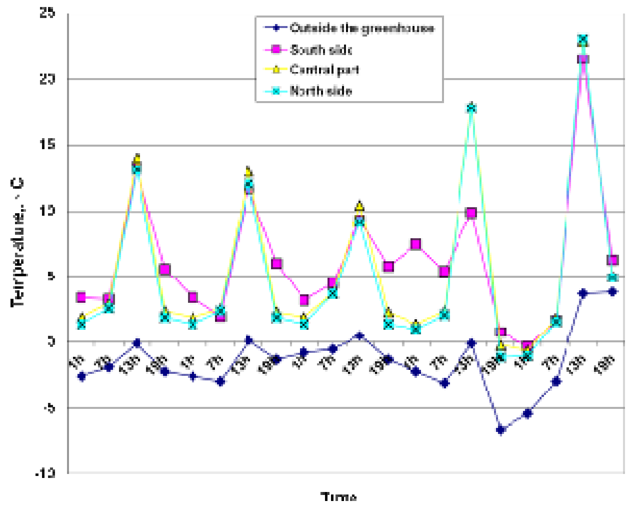
## RESULTS AND DISCUSSION

*Temperature distribution*

According to some authors (Enoch, 1978, Hanan, 1998, Nelson, 2003) tunnel greenhouses are considered to be the simplest form of the greenhouses in which temperature and the other production parameters vary during the day significantly depending on the outside climatic parameters. It is said in the literature that temperature is higher in the parts of the greenhouse where more solar energy is transmitted (Stanhil et al, 1973, Hanan, 1998, Hall and Hanan, 1976). It is also stated that the type of plant production influences temperature and relative humidity distribution in the greenhouses. For example, higher temperatures were observed in the greenhouses where roses were grown compared to the greenhouses with the carnations. Greenhouse corridors and paths also influence the temperature distributions around them (Fuchs, 1990).




Tunnel:




Gutter-connected greenhouse:

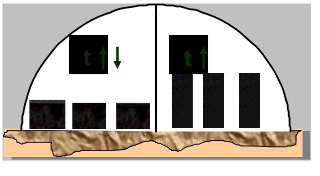
**Fig. 2** Greenhouses outside / inside temperatures during the day in the lettuce production

Temperature measurements in the tunnel greenhouse show that temperature varies along the greenhouse (Fig. 2). During the night it was highest on the north side and lowest on the south side of the greenhouse (Tab. 1). In the morning hours the highest temperature was observed in the central part, while in the afternoon hours the highest temperature was measured in the south part of the greenhouse while the lowest was measured in the north part. Statistical analysis of the data showed that temperature differences along the greenhouse during the night are not significant. The LSD test (0.05 and 0.01 significant level) of the morning temperatures showed that there is a very significant difference in the temperatures along the greenhouse (Fig. 3). These values were 2.05° C and 2.74° C for the given levels of significance. Temperature difference of 2.63° C between the south and the central part of greenhouses showed to be significant. Variation coefficient was10.82% and standard deviation 1.11° C. Measurements in the 13h also showed variations in the temperature along the tunnel greenhouse. Temperature was highest in the south part and lowest in the north part (Tab. 1). Variance analysis confirmed that these differences are significant and based on the LSD test it was concluded that difference of 5.13° C between south and central part was significant and that difference of 6.91° C between south and north side was very significant (Fig. 3). Variation coefficient was 8.32% while standard deviation was 2.93° C.

**Tab. 1** Temperature variation inside and outside the greenhouses in the lettuce production

| | Time of the day | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1h | | 7h | | 13h | | 19h | |
| | TUN | GUT | TUN | GUT | TUN | GUT | TUN | GUT |
| INSIDE | | | | | | | | |
| North side | 9.21 | 0.85 | 9.15 | 2.46 | 32.32 | 15.05 | 13.18 | 1.79 |
| Centre part | 8.88 | 1.31 | 11.78 | 2.69 | 34.10 | 15.67 | 12.10 | 2.35 |
| South side | 8.87 | 3.41 | 9.85 | 3.36 | 39.23 | 13.12 | 12.55 | 4.88 |
| *Average* | *8.99* | *1.86* | *10.26* | *2.84* | *35.22* | *14.61* | *12.61* | *3.01* |
| OUTSIDE | 8.66 | -2.63 | 10.28 | -2.25 | 22.84 | 14.64 | 15.46 | -1.52 |
| Inside/outside difference | 0.33 | 4.49 | -0.02 | 5.09 | 12.38 | -0.03 | -2.85 | 4.53 |

1h $\Delta t=0.35^0$ C
**7h $\Delta t=2.63^0$ C** *
**13h $\Delta t=6.91^0$ C** **
**19h $\Delta t=1.08^0$ C** *
Maximum daily $\Delta t= 30.36^0$ C



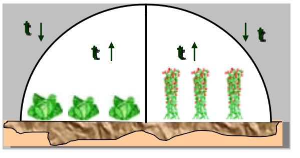
1h $\Delta t=0.83^0$ C
7h $\Delta t=1.26^0$ C
13h $\Delta t=2.3^0$ C
19h $\Delta t=2.62^0$ C
Maximum daily $\Delta t= 22.76^0$ C

**Fig. 3** Temperature variation significance in the tunnel lettuce and tomato production

Measurements in 19h (Tab.1) show that the north part had the highest temperature and the central part had the lowest temperature. Variance analysis showed that these are significant differences and the LSD test showed that the difference of 1.08° C was significant between north and central part. Coefficient of variation was 3.49% and standard deviation 0.44° C. It can be concluded that in the case of lettuce production in the tunnel greenhouse one could expect significant temperature variation along its length during the day.

Statistical analysis for testing the mean values showed that there are differences between inside and outside temperature in the tunnel structure and that these differences are very significant in the afternoon hours (Fig. 4). This means that during the night and early morning hours one should not expect significantly higher temperatures inside the greenhouse compared to the outside temperatures.

1h $\Delta t=0.83^0$ C
7h $\Delta t=0.02^0$ C
**13h $\Delta t=12.38^0$ C** **
**19h $\Delta t=2.85^0$ C** **



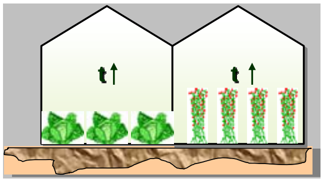
1h $\Delta t=1.25^0$ C
**7h $\Delta t=7.64^0$ C** **
**13h $\Delta t=8.31^0$ C** **
19h $\Delta t=2.16^0$ C

**Fig. 4** Outside / inside tunnel temperature differences in lettuce and tomato production

In the winter vegetable production the most critical are the temperatures during the night. Temperature measurements in the gutter-connected greenhouse in lettuce production show variations during the day (Fig. 2) and along the greenhouse. The lowest temperature was observed during the night in the north part of the greenhouse (Tab. 1). Statistical analysis showed that temperature does not vary significantly along the greenhouse in the night. Variation coefficient was 59.68% while standard deviation was 1.11° C. The same situation was observed for all other measuring periods (Fig. 5). This means that in the gutter-connected greenhouse temperature does not vary significantly along its length which means that in the case of winter lettuce production more uniform temperature conditions can be expected in the gutter-connected greenhouses compared to the tunnel structures. Concerning the fact that both type of greenhouses had the same covering material, with the same period of exploitation the reasons for these differences in the temperature uniformity distribution can be searched in the type of construction, its volume and orientation. Tunnel greenhouse is a single span type of greenhouse with the specific volume of 12.56 m3/m and covering material / production surface ratio of 1.91 while gutter-connected greenhouse is a type of multi-span greenhouse with the specific volume of 37.91 m3/m and covering material / production surface ratio of 1.62. It is stated (Nelson, 2003, Hanan, 1998) that the smaller is the ratio covering material / production surface the smaller is the surface of the greenhouse that is exposed to the weather and thus are the heating requirements lower because the temperature conditions in the greenhouses are more uniform. The other parameter that can be responsible for the temperature oscillation is the greenhouse orientation. Single span greenhouses in this region should be orientated north-south but in this case the orientation was east-west.

Measurements of the outside temperature (Tab. 1) showed that the temperature in the greenhouse was significantly higher compared to the outside during the day as well as during the night (Fig. 6). During the night temperature was up to 5.47° C higher compared to the temperature outside the greenhouse. During the days these differences are even higher (up to 18.83° C at 13h). When inside and outside temperature patterns are analyzed it can be concluded that the gutter-connected greenhouse is well thermally balanced. Inside temperature is stabile and does not vary much during the day and along the greenhouse length enabling to all the plants in the greenhouse to have the same production conditions.

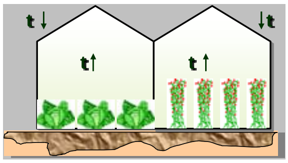
1h Δt=2.56$^0$ C
7h Δt=0.9$^0$ C
13h Δt=2.55$^0$ C
19h Δt=3.09$^0$ C
Maximum daily Δt= 4.82$^0$ C



1h Δt=0.32$^0$ C
7h Δt=0.19$^0$ C
13h Δt=0.19$^0$ C
19h Δt=1.33$^0$ C
Maximum daily Δt= 25.96$^0$ C

**Fig. 5** Temperature variation significance in the gutter-connected lettuce and tomato production

**1h Δt=4.22$^0$ C ****
**7h Δt=5.09$^0$ C ****
**13h Δt=13.79$^0$ C ****
**19h Δt=4.53$^0$ C ***



1h Δt=1.89$^0$ C
**7h Δt=4.97$^0$ C ****
**13h Δt=12.69$^0$ C ****
19h Δt=0.31$^0$ C

**Fig. 6** Outside / inside gutter-connected temperature differences in lettuce and tomato production

In the summer greenhouse vegetable production it is important to have good ventilation systems that will lower the temperature in the greenhouses and that will eliminate parts of the greenhouses with high temperature.

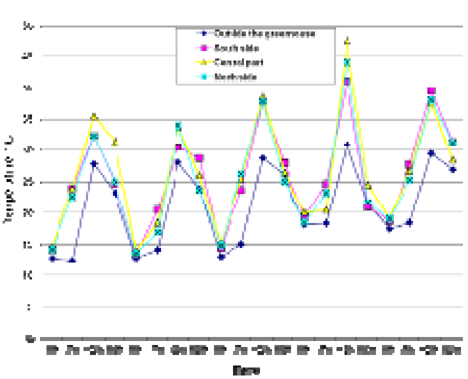
Temperature measurements in the tunnel and gutter-connected greenhouse show that the temperature varies during the day (Fig. 3 and Fig. 5), being the lowest in the night and the highest in the noon, as well along the greenhouses (Tab. 2, Fig. 7) being in most of the cases the highest in the central part of the greenhouses.

**Tab. 2** Temperature variation inside and outside the greenhouses in the tomato production

| | Time of the day | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1h | | 7h | | 13h | | 19h | |
| | TUN | GUT | TUN | GUT | TUN | GUT | TUN | GUT |
| INSIDE | | | | | | | | |
| North side | 15.80 | 17.67 | 22.87 | 22.42 | 37.26 | 42.55 | 25.35 | 24.86 |
| Centre part | 16.63 | 17.99 | 23.05 | 22.54 | 38.56 | 43.63 | 27.97 | 23.50 |
| South side | 16.10 | 17.84 | 24.13 | 22.35 | 36.26 | 42.44 | 26.20 | 23.51 |
| *Average* | *16.07* | *17.83* | *23.32* | *22.44* | *37.36* | *42.87* | *26.51* | *23.96* |
| OUTSIDE | 14.93 | 17.83 | 15.71 | 17.46 | 29.05 | 30.18 | 24.35 | 23.95 |
| Inside/outside difference | 1.14 | 0 | 7.61 | 4.98 | 8.31 | 12.69 | 2.16 | 0.01 |

The exception was the tunnel structure in the morning hours where south side was with the higher temperature and the gutter-connected greenhouse in the afternoon hours where north part of greenhouse had the higher temperature.

As for the differences in the greenhouses inside and outside temperatures the results have the similar tendencies for the tunnel and gutter-connected greenhouse. In both cases temperature differences appear to be significant in the early morning hours and in the noon (Fig. 4 and Fig. 6). In case of tunnel greenhouse the temperature difference in the 7 h was up to 11.07° C and statistical analysis showed that these differences were very significant. The similar results were obtained for the measurement in 13h. The differences were up to 13.18° C and, after statistical analysis, showed to be very significant. In the gutter-connected greenhouse similar results were obtained. Temperature differences during the night and in the evening were not statistically significant. Measurements in 7 h showed that temperature in the greenhouse was up to 11.35° C higher compared to the outside temperatures. Statistical analysis showed that the differences of 3.37° C can be considered as very significant. Measurements in 13 h show that temperature inside the greenhouse was up to 22.16° C higher compared to the outside temperature. Statistical analysis showed that temperature difference of 5.02° C can be considered as very significant.



Tunnel

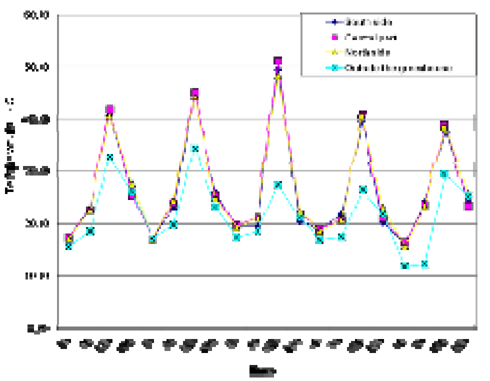

Gutter-connected greenhouse

**Fig. 7** Greenhouses outside / inside temperatures during the day in the tomato production

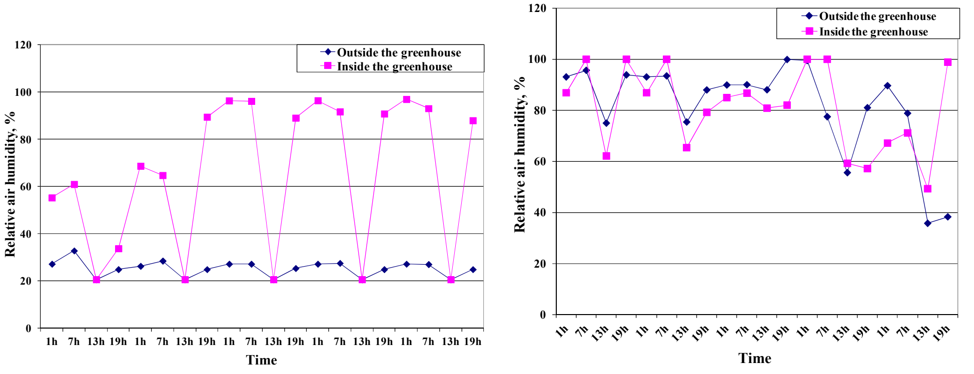
In this way it can be concluded that in the summer tomato production in the tunnel and gutter-connected greenhouse temperature conditions in the greenhouses do not vary much along the greenhouse length. Significant differences were only observed in the inside and outside temperatures in both greenhouses in the early morning hours and at noon. Concerning the temperature values, these oscillations can be considered as acceptable.

*Relative humidity distribution*

Relative humidity is a very important factor of plant growth and development because it influences plant transpiration, photosynthesis and disease risks. Different plants have a different demand concerning the air relative humidity. Optimal relative humidity for cucumber is very high (90 - 95%) while for the tomato it is 50 - 65%. Literature (Lazić

Branka et al, 2001, Hanan, 1998, Nelson, 2003, Sengar and Kothari, 2008, Singh and Tiwari, 2000) states that air humidity varies during the day and along the greenhouse length and height. It is stated that the pattern of variation depends on greenhouse type of construction its dimensions, covering material and the plant specie that is produced in the greenhouse.

In the tunnel lettuce production, relative humidity measurements showed that there are differences between outside and inside values as well as differences in the greenhouse during the day (Fig. 8). It can be seen that relative air humidity inside the greenhouse is higher through the day if compared to the outside.




Tunnel

Gutter-connected greenhouse

**Fig. 8** Greenhouses outside / inside air relative humidity during the day in the lettuce production

Statistical analysis showed that differences between inside and outside relative air humidity were very significant in the early morning hours, in the evening and in the night (Fig. 9). In the early morning the differences were up to 68.97% and 52.69% difference was considered to be very significant. In the evening the difference of 53.2% was considered as very significant. In the night the average difference was 55.71% and was considered to be very significant.

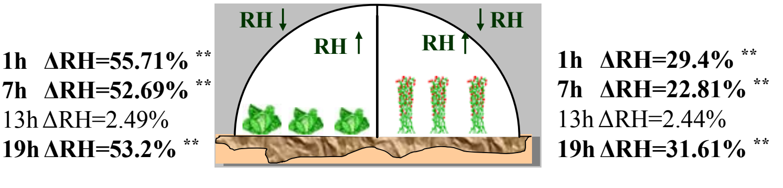



**Fig. 9** *Outside / inside tunnel air relative humidity differences in lettuce and tomato production*

This result was expected concerning the plant respiration that, as a consequence, has production of heat, water and $CO_2$. Since no ventilation was applied, because of the temperature uniformity, the relative humidity in the tunnel was growing higher up till early morning hours.

Measurements of the relative air humidity in the gutter-connected greenhouse show that great care must be taken into account when choosing the type of greenhouse construction. Like in the case of tunnel construction, air relative humidity in the greenhouse show variations compared to the outside relative air humidity (Fig. 8). Statistical analysis of the obtained data shows that these differences are not significant (Fig. 10). During the night hours air relative humidity was even lower inside the greenhouse. In average it was 6.52% lower. In the early morning hours air relative humidity was higher inside the greenhouse. In average the difference was 3.68% higher it was considered not to be significant. Measurements show that in 13h relative air humidity was higher outside the greenhouse. Again, in the afternoon, air in the greenhouse had higher relative humidity.

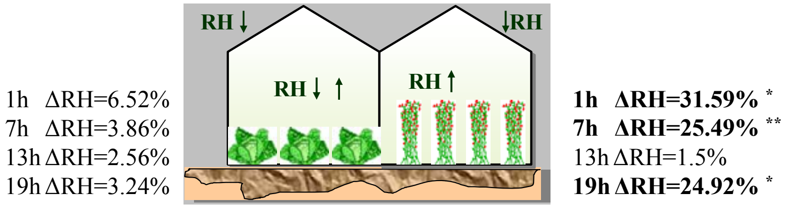
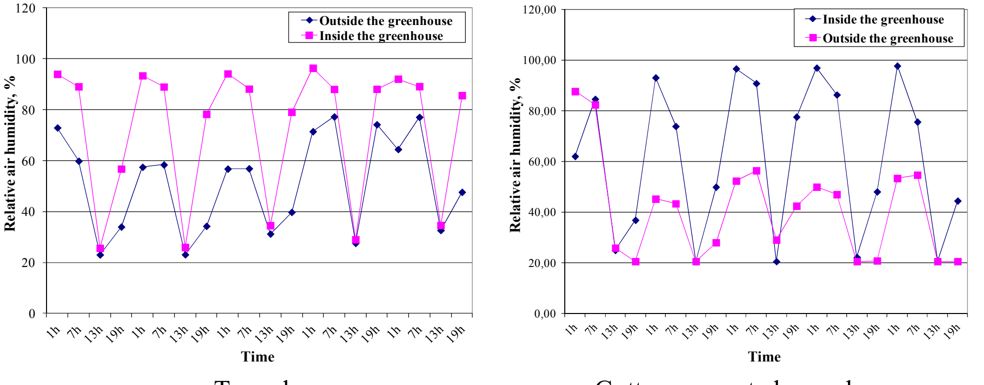



**Fig. 10** Outside / inside gutter-connected greenhouse air relative humidity differences in lettuce and tomato production




Tunnel

Gutter-connected greenhouse

**Fig. 11** Greenhouses outside / inside air relative humidity during the day in the tomato production

Gutter-connected has showed to be beneficial in the tomato production since tomato plants are not adjusted to the higher values of air relative humidity. In the tunnel greenhouse air relative humidity was higher through the day and night compared with the outside air relative humidity (Fig. 11). Statistical analysis of the obtained data (Fig. 9) shows that these differences were all very significant except in the middle day period.

During the night the differences in the air relative humidity were up to 37.4%. In the early morning hours these differences were up to 31.3%. In the middle day the differences were the lowest and were up to 3.29%. In the afternoon hours air relative humidity inside the tunnel rose and the differences were up to 43.99%.

In the gutter-connected greenhouse there was the same tendency but the differences between inside and the outside air relative humidity were smaller. Again the differences were significant in the afternoon hours and during the night (Fig. 10). In the early morning hours the differences were the highest (up to 39.33%) and were, statistically, considered to be very significant.

## CONSLUSIONS

Obtained results show that micro-climatic conditions in the greenhouse vary during the day and along the greenhouse length. The variation pattern depends on the greenhouse type of construction, its orientation, plat production season and type of plant production. Generally it can be concluded that regarding the both lettuce and tomato production tunnel greenhouse construction can not be recommended as an optimal choice. It specific volume was 12.56 $m^3/m$ and covering material / production surface ratio 1.91. In the winter it does not provide significantly higher temperatures inside the greenhouse. Also the temperature conditions inside the greenhouse are not uniform and stabile. In the summer production higher air relative humidity brings the risk of introduction of plant diseases. On the other side gutter-connected greenhouse, having the specific volume of 37.92 $m^3/m$ and covering material / production surface 1.62, in the winter production conditions provides more uniform temperature inside the greenhouse and provides significantly higher temperatures during the day. In the summer production variation of the temperatures were observed only in the midday section. Relative humidity inside the greenhouse was higher but the differences were much lower compared to the differences obtained in the tunnel structure.

## ACKNOWLEDGEMENTS

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42. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

UDK 582.542:620.952
Pregledni rad
Review paper

# UTJECAJ UZGOJA I ENERGETSKOG ISKORIŠTENJA LIGNOCELULOZNIH USJEVA NA MOGUĆNOST SMANJENJA EMISIJA $CO_2$ – PRIMJER: KULTURA *MISCANTHUS X GIGANTEUS*

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## SAŽETAK

*Globalno gledajući, rastuća potreba za proizvodnjom hrane, ali i energije, neizbježno dovodi do povećanja emisije $CO_2$ u okoliš. U Republici Hrvatskoj, prema National Inventory Report 2013, sektor poljoprivrede u 2011. godini doprinio je ukupnoj emisiji stakleničkih plinova s 11,7% čime se navedeni sektor nalazi na drugom mjestu prema doprinosu ukupnoj emisiji, odmah iza sektora energetike (73,3%). Kao jedno od mogućih rješenja za stabilizacijom dijela globalne emisije $CO_2$ nameće se proizvodnja i korištenje obnovljive „zelene energije“. Predviđanja ukazuju da će se obnovljivi izvori energije, uz sunce i vjetar, temeljiti na proizvodnji biomase iz visokovrijednih usjeva za proizvodnju energije, čije su površine u konstantnom porastu u cijelome Svijetu. Jedna od kultura koja se koristi za proizvodnju energetski visoko-vrijedne biomase je i višegodišnja trava* Miscanthus x giganteus*. Ekološki gledano, jedan od glavnih razloga formiranja usjeva pod kulturom* Miscanthus x giganteus *je njegov potencijal za reduciranjem emisije stakleničkih plinova. Postoje dva mehanizma kojima uzgoj lignocelulozne trave* Miscanthus x giganteus*, kao izvor obnovljive energije, može utjecati na smanjenje emisije stakleničkih plinova a to su: smanjenje $CO_2$ emitiranog u okoliš tijekom uzgoja, te procesom sekvestracije ugljika (u tlo i biljku).*

***Ključne riječi:*** Miscanthus x giganteus*, emisija $CO_2$, sekvestracija, „zelena energija“*

## UVOD

Klimatske promjene jedan su od najvećih izazova s kojima se danas suočavamo. Utjecaj čovjeka na klimu naglo je povećan u drugoj polovici 18. stoljeća s početkom industrijske revolucije. Izgaranjem fosilnih goriva, industrijskim procesima, odlaganjem otpada, promjenom načina korištenja zemljišta (urbanizacijom, sječom šuma i sl.), intenzivnom poljoprivrednom proizvodnjom i stočarstvom došlo je do promjene kemijskog sastava atmosfere, odnosno, do povećanja koncentracije stakleničkih plinova u atmosferi u odnosu na predindustrijsko doba. Od početka industrijalizacije do danas, značajno se povećala koncentracija ugljikovog dioksida u atmosferi, s 280 ppm u predindustrijsko doba na 392 ppm u 2011. godini (National Oceanic and Atmospheric Administration's - NOAA, Earth System Research Laboratory, 2012). Klimatske promjene osjećaju se u svim dijelovima Svijeta pa tako i u Republici Hrvatskoj. Trend porasta temperature zraka u 20. stoljeću zabilježen je i na postajama u Republici Hrvatskoj (Gajić-Čapka i sur. 2010). Stoljetni nizovi mjerenja temperature zraka upućuju na porast između 0.02 °C i 0.07 °C na 10 godina. Kao i na globalnoj razini, trend porasta temperature zraka u Republici Hrvatskoj osobito je izražen u posljednjih 50, odnosno 25 godina. Predviđa se da će do 2025. godine prosječne temperature u Republici Hrvatskoj porasti za 1 °C (zimi, ljeti i u jesen), dok će prosječne proljetne temperature ostati iste (Dobra klima za promjene 2008). Pritisci kojima poljoprivreda utječe na okoliš očituju se u onečišćenju tla, voda i atmosfere te ujedno doprinose globalnom zagrijavanju uslijed emisija stakleničkih plinova. Globalno gledajući, rastuća potreba za proizvodnjom hrane, ali i energije, neizbježno dovodi do povećanja emisije $CO_2$ u okoliš (Agencija za zaštitu okoliša - AZO 2012). Prema Izvješću o inventaru stakleničkih plinova na području Republike Hrvatske za razdoblje 1990. – 2010. Agencije za zaštitu okoliša (NIR 2012), izvori emisija plinova staklenika, prikazanih kao ekvivalent $CO_2$ iz poljoprivredne proizvodnje u Republici Hrvatskoj u 2010. godini zauzimaju visoko drugo mjesto, odmah iza procesa vezanih uz izgaranje fosilnih goriva za proizvodnju električne i/ili toplinske energije (tablica 1.).

**Tablica 1** Emisije stakleničkih plinova (Gg $CO_2$-eq) po sektorima (1990. – 2011.) u RH (NIR, 2013)

| Izvor | 1990 | 1995 | 2000 | 2005 | 2008 | 2009 | 2010 | 2011 |
|---|---|---|---|---|---|---|---|---|
| Energija | 22,796 | 17,263 | 19,482 | 22,672 | 22,903 | 21,651 | 21,009 | 20,715 |
| Industrija | 3,789 | 2,016 | 2,861 | 3,295 | 3,592 | 2,984 | 3,211 | 3,000 |
| Poljoprivreda | 4,381 | 3,055 | 3,130 | 3,478 | 3,431 | 3,314 | 3,193 | 3,319 |
| Otpad | 564 | 619 | 707 | 814 | 1,001 | 1,057 | 1,050 | 1,078 |
| Otapala | 117 | 108 | 109 | 195 | 239 | 153 | 152 | 144 |
| Ukupno | 31,647 | 23,061 | 26,290 | 30,454 | 31,167 | 29,159 | 28,615 | 28,256 |

Pitanje klimatskih promjena na globalnom planu pokušava se riješiti Okvirnom konvencijom Ujedinjenih naroda o promjeni klime (UNFCCC). Na Trećoj Konferenciji stranaka UNFCCC-a u Kyotu je 1997. godine prihvaćen Kyotski protokol kojim su se industrijalizirane države svijeta obvezale na smanjenje emisija stakleničkih plinova. Republika Hrvatska je potpisala Kyotski protokol 1999. godine te ga ratificirala 2007. godine. S ciljem ublažavanja klimatskih promjena kroz smanjenje emisija stakleničkih plinova, a temeljem postavljenih smjernica proizašlih iz Kyotskog protokola, Europska komisija je propisala Energetsku strategiju za Europu do 2020. godine (2009/28/EC). U njoj su postavljena tri glavna cilja a to su: održivost (za područje zaštite okoliša), konkurentnost (prikaz troškova) te sigurnost opskrbe (razvoj tehnika i tehnologija); poznatije kao 3 x 20. Navedeno zapravo znači smanjenje emisije stakleničkih plinova za 20%, smanjenje ukupne potrošnje energije za 20% te povećanje svih obnovljivih izvora za 20%, s time da se 10% biogoriva mora potrošiti u prometu. Obzirom da je Republika Hrvatska u 2013. g. postala punopravna članica EU, samim time preuzima obaveze navedene Direktive Europske komisije. Kako bi zadovoljila postavljene zahtjevne kriterije, a samim time i smanjila negativne pritiske na okoliš iz poljoprivrede, Republika Hrvatska će morati intenzivnije razmatrati mogućnosti uvođenja novijih tehnologija vezanih uz obnovljive izvore energije.

Predviđanja ukazuju da će se proizvodnja obnovljive energije, uz energiju sunca i vjetra, temeljiti na proizvodnji lignocelulozne biomase iz energetskih usjeva čije su površine u cijelome Svijetu u konstantnom porastu. Kako postoji jaka veza između korištenja fosilnih izvora energije i problema globalnog zagrijavanja okoliša, lignocelulozni energetski usjevi su jedan od mogućih rješenja smanjenja potrošnje neobnovljivih izvora energije i sve su veći dio strategije čiji je cilj smanjenje emisija stakleničkih plinova (Beeharry 2001).

Cjelokupna $CO_2$ emisija i korištenje primarne energije može se prikazati temeljem tzv. LCA (*Life cycle assessment*) ISO 14040 norme. LCA norma uključuje sve procese koji utječu na emisiju i potrošnju energije u cjelovitom procesu, što u konačnici rezultira kumulativnoj procjeni utjecaja na okoliš.

## PRIMARNA STRATEGIJA SMANJENJA EMISIJA $CO_2$

Mnoga znanstvena istraživanja ukazuju na neophodnu potrebu za stabilizacijom atmosferskog $CO_2$ kao i drugih stakleničkih plinova s ciljem ublažavanja rizika globalnog zatopljenja uzrokovanog efektom staklenika. Stoga, uz smanjenje stope korištenja fosilnih sirovina za proizvodnju energije, postoje dvije primarne strategije smanjenja emisija $CO_2$ a to su razvoj niskih ili bez ugljičnih goriva (tzv. $CO_2$ neutralnih goriva) i sekvestracija $CO_2$ iz točkastih izvora ili atmosfere (Schrag 2007; Han i sur. 2012).

Postoje dvije tehnološke mogućnosti sekvestracije atmosferskog $CO_2$ u jedan od globalnih rezervoara/bazena, a to su abiotska i biotska sekvestracija. Abiotska sekvestracija se temelji na fizikalnim i kemijskim reakcijama te inženjerskim tehnikama bez intervencije živih organizama (npr. biljke, mikrobi). Brz napredak postignut je u razvojnim tehnologijama hvatanja, transporta i utiskivanja $CO_2$ (Kerr 2001). Nadalje, abiotska sekvestracija obuhvaća utiskivanje u oceane i geološke strukture te ispiranje i mineralnu karbonizaciju. Za razliku od abiotske, biotska sekvestracija se temelji na uklanjanju atmosferskog $CO_2$ kroz proces fotosinteze. Pod pojmom biotske sekvestracije, osim sekvestracije fotosintezom, ubrajamo i sekvestraciju u oceane, kopno te u sekundarne karbonate (Lal 2007). Postoje brojne sekundarne prednosti biotske sekvestracije ugljika: poboljšana kvaliteta tla i voda, smanjen gubitak hranjiva iz ekosustava, smanjena erozija tla, poboljšanje staništa biljnog i životinjskog svijeta te obnavljanje degradiranih tala. Stoga, proces biotske sekvestracije ugljika jača i poboljšava ekosustav, uz posljedično poboljšanje poljoprivredne proizvodnje. Međutim, ukupni kapacitet ponora za biotsku sekvestraciju ugljika, osobito onu u kopnenim ekosustavima je nizak (50 - 100 Pg ugljika tijekom razdoblja 25 do 50 godina. Proces sekvestracije ugljika važna je „strategija“ koja se prvenstveno očituje kroz smanjenje emisija uzrokovanih razvojem $CO_2$ - neutralnih energenata. Nadalje, uslijed mogućnosti učinkovite proizvodnje „zelene energije“ te pronalaženja alternative za dio fosilnih goriva, biogoriva su važan sastavni dio sustava obnovljivih izvora energije. (Lal 2007).

## VISOKOVRIJEDNE ENERGETSKE KULTURE KAO FAKTORI SMANJENJA OTISKA UGLJIKA

Dugoročno postavljeni ciljevi u proizvodnji obnovljivih izvora energije iz poljoprivrede, karakteriziraju ostatke usjeva ratarske proizvodnje (slama žitarica i uljarica, kukuruzovina) kao vrijedan izvor lignocelulozne biomase za proizvodnju biogoriva druge generacije (Somerville 2006; Graham i sur. 2007). Obzirom da navedeni ostatci predstavljaju dragocjenu sirovinu u vidu zelene gnojidbe bitnu za očuvanje kvalitete tla, njihovo nesmotreno uklanjanje može ozbiljno ugroziti kvalitetu tla (Wilhelm i sur. 2004). Štetni utjecaji uklanjanja ostataka na kvalitetu tla moraju biti objektivno i kritički preispitani prije njihovog iskorištenja u energetske svrhe. Prema naputcima Europske komisije maksimalno 30% od potencijalno dostupne biomase se može koristiti u energetske svrhe. Stoga, glavnina lignocelulozne biomase mora biti proizvedena na zasebno oformljenim energetskim plantažama (Lal 2007, Tomić i sur. 2011).

Izbor energetskih kultura za proizvodnju lignoceluloznih biogoriva temelji se na uštedi relativno visoke neto fosilne energije tijekom uzgoja te ujedno kroz mogućnost smanjenja emisija stakleničkih plinova po jedinici biomase i poljoprivrednog zemljišta (Boehmel i sur. 2008). Ukoliko navedenim tezama pridodamo izrazito visok stupanj otpornosti na bolesti i štetočinje te mogućnost racionalnog korištenje hranjivih tvari iz tla (CRES 2006), višegodišnja energetska trava *Miscanthus x giganteus* se nameće kao adekvatna kultura koja odgovara na sve postavljene uvjete. Visokovrijedni energetski usjevi, pa tako i *Miscanthus x giganteus,* su oni koji se mogu požeti relativno suhi (vlaga < 16%) kao i oni koji imaju mogućnosti višegodišnjeg rasta (15 - 20 godina i više), s krajnjim ciljem izbjegavanja dodatnih emisija ali i troškova kroz procese sušenja, odnosno obrade tla i sadnje na godišnjoj razini. Zbog izražene sposobnosti translokacije minerala i hranjiva iz nadzemnih organa u rizome na kraju vegetacije, te ponovne re - translokacije iz rizoma u nadzemne organe na početku vegetacije, *Miscanthus x giganteus* se odlikuje izuzetnom efikasnošću kod iskorištenja hranjiva, poglavito dušika, te ujedno utječe i na smanjenju količinu ispiranja nitrata uslijed primjene nižih gnojidbenih tretmana (Clair i sur.; 2008; Tilman i sur. 2006.; Davis i sur. 2010). Uz navedeno, na ekološki aspekt navedene kulture dodatno utječe i činjenica da se aplikacija herbicida, kao i većina ostalih agrotehničkih zahvata provodi samo u prvoj i eventualno drugoj godini od zasnivanja usjeva (Caslin i sur. 2010), čime se izravno utječe na smanjenje emisija stakleničkih plinova u odnosu na konvencionalne poljoprivredne kulture. Nadalje, *Miscanthus x giganteus* karakterizira i činjenica da se radi o prirodnom sterilnom hibridu čime se kategorički odbija mogućnost nekontroliranog širenja kulture van predviđenih površina unatoč tome što je strana uvezena vrsta (Istočna Azija). (Jones i Walsh, 2001; Jørgensen, 2011). Nadalje, ekološki je prihvatljiv i u vidu smanjenja ispiranja nitrata, poboljšanja kakvoće zraka, povećanja biološke raznolikosti te poboljšanja plodnosti tla (Lal 2004; Tilman i sur. 2006, Caslin i sur. 2010). Stoga, može se sa sigurnošću reći da proizvodnja poljoprivredne „zelene energije“

ima potencijal pozitivnog doprinosa pitanjima vezanim uz zaštitu okoliša kako iz poljoprivrednog sektora tako i na globalnoj razini (Lal 2007.).

Za razliku od korisnih utjecaja, negativni su kompeticija za zemljište i vodu koji su potrebni za uspostavu usjeva *Miscanthus x giganteus* kao i pojačana opasnost od požara u vremenskom periodu od potpunog osušivanja trave do žetve (Jørgensen 2011). Međutim, istraživanje koje su proveli Leto i Bilandžija (2013) ukazuje na mogućnost uzgoja kulture *Miscanthus x giganteus* na neiskorištenim poljoprivrednim tlima lošije kvalitete u Republici Hrvatskoj, čime proizvodnja energije ne konkurira tlima pogodnim za proizvodnju hrane.

Obzirom na energetsku iskoristivost, *Miscanthus x giganteus* se trenutno najviše koristi za su izgaranje s fosilnim energentima i izravnim izgaranjem za proizvodnju električne i/ili toplinske energije (Smeets i sur. 2009) i to najčešće u obliku sječke, peleta/briketa i bala. Biomasa trave *Miscanthus x giganteus* se smatra $CO_2$ neutralnom jer ugljik koji se emitira uslijed procesa izgaranja ne utječe na povećanje atmosferskog ugljikovog dioksida i to prvenstveno uslijed apsorpcije $CO_2$ plina tijekom rasta nasada. Količina emisije stakleničkih plinova najviše ovisi o korištenim metodama tijekom proizvodnje biomase, vrsti korištenog pogonskog goriva tijekom procesa proizvodnje te tehnologijama koje se koriste za daljnju doradu biomase. Energetskim iskorištenjem kulture *Miscanthus x giganteus* omogućuje se značajno očuvanje fosilnih izvora energije, primjerice, 20 t biomase *Miscanthus x giganteus* predstavlja ekvivalent 12 t kamenog ugljena (Lewandowski i sur., 1995.), dok je 30 t navedene biomase ekvivalent 12 000 litara loživog ulja (El Bassam, 1996.).

## *MISCANTHUS X GIGANTEUS* I SMANJENJE EMISIJA $CO_2$ PLINA

Ekološki gledano, jedan od glavnih razloga formiranja usjeva pod kulturom *Miscanthus x giganteus* je njegov potencijal za reduciranjem emisije stakleničkih plinova. Postoje dva mehanizma kojima uzgoj lignocelulozne trave *Miscanthus x giganteus*, kao izvor obnovljive energije, može utjecati na smanjenje emisije stakleničkih plinova, a to su smanjenje $CO_2$ plina emitiranog u okoliš tijekom samog uzgoja (obrada tla se provodi samo u prvoj godini zasnivanja nasada) te procesom sekvestracije ugljika (u tlo i biljku). Navedenim mehanizmima i morfološkim karakteristikama same kulture omogućuje se izgaranje $CO_2$ neutralne sirovine.

*Smanjenje $CO_2$ emisije emitirane u okoliš tijekom uzgoja i izgaranja*

Biomasa visokovrijedne energetske kulture *Miscanthus x giganteus* predstavlja takozvano $CO_2$ neutralno gorivo jer je kao što je i prethodno navedeno, ugljik koji se oslobađa tijekom procesa izgaranja je apsorbiran u biljku tijekom njegovog uzgoja procesom fotosinteze. Obzirom na morfologiju i agrotehničke zahtjeve tijekom uzgoja trave *Miscanthus x giganteus*, emisije stakleničkih plinova su neusporedivo niže u odnosu na konvencionalne ratarske usjeve (Caslin i sur., 2010.).

Kako je već spomenuto, za kalkulaciju stvarnih emisija $CO_2$ plina (temeljem *Life cycle assessment* norme) u izračun se ubrajaju svi radni zahvati uslijed kojih dolazi do otpuštanja emisija. Emisije stakleničkih plinova tijekom uzgoja, skladištenja, manipulacije i prijevoza (100 km) baliranog i usitnjenog *Miscanthus x giganteus-a* se procjenjuju u količinama 67 - 111 kg $CO_2$-eq suhe tvari/t, odnosno 3,7 - 6,1 kg $CO_2$-eq za proizvodnju 1 GJ energije prema Lewandowski i sur. (1995.) te Smeets i sur. (2009). Pri tome valja naglasiti da su emisije usitnjene biomase (rinfuzno stanje - sječka) veće u odnosu na baliranu biomasu uslijed povećane upotrebe fosilnih goriva tijekom korištenja samohodnih krmnih kombajna za žetvu i usitnjavanja biomase. Međutim, obzirom da emisije tijekom energetskog iskorištenja tekućih fosilnih goriva (benzin, dizel, loživo ulje) iznose približno 83 kg $CO_2$-eq/GJ, prirodnog plina 60 kg $CO_2$-eq/GJ te ugljena 101 kg $CO_2$-eq/GJ, može se zaključiti da su navedene emisije daleko više od onih emitiranih tijekom iskorištenja trave *Miscanthus x giganteus*. Nadalje, Clifton - Brown i sur. (2007) su utvrdili da izgaranjem požete biomase, usporedno sa ugljenom, *Miscanthus x giganteus* smanjuje emisije za 4,0 – 5,3 t $CO_2$-eq/ha godišnje. Styles i Jones (2008) navode mogućnost smanjenja emisija $CO_2$ plina za 75 - 93% zamjenom plina, loživog ulja i električne energije sa biomasom trave *Miscanthus x giganteus*, dok Lewandowski i sur. (1995) ističu da se izgaranjem trave *Miscanthus x giganteus*, umjesto mrkoga ugljena, mogu postići uštede od 90% u emisiji $CO_2$.

Moguća smanjenja emisija $CO_2$ mogu se ostvariti i zamjenom konvencionalnih poljoprivrednih i brzorastućih šumskih kultura sa nasadima lignoceluloznih trava. Brandão i sur. (2011) navode potencijalne uštede od 11,096 kg $CO_2$–eq/ha godišnje, odnosno 171 kg $CO_2$–eq/GJ u odnosu na nasade uljane repice i brzorastuće vrbe. Potencijalnim uštedama emisije $CO_2$ zamjenom usjeva pod pšenicom s travom *Miscanthus x giganteus*, bavili su se i Clair i sur. (2008) koji su utvrdili uštede u prvoj, trećoj i petoj godini od zasnivanja usjeva *Miscanthus x giganteus.* Nadalje, uštede kod pšenice uzgojene konvencionalnom obradom su bile 566 kg $CO_2$–eq/ha godišnje u prvoj godini, 1922 kg $CO_2$–eq/ha godišnje u trećoj godini te 3284 kg $CO_2$–eq/ha godišnje u petoj godini, dok su one kod reducirane obrade iznosile 441 kg $CO_2$–eq/ha godišnje u prvoj godini, 1545 kg $CO_2$–eq/ha godišnje u trećoj godini te 2656 kg $CO_2$–eq/ha godišnje u petoj godini.

Smeets i sur (2009) su istraživali emisije stakleničkih plinova i korištenje primarne energije tijekom procesa proizvodnje peleta, kao jednog od najčešće korištenog oblika energetskog iskorištenja trave *Miscanthus x giganteus*. Emisije su proračunate na 89 g $CO_2$-eq suhe tvari/toni od kojih 69 g $CO_2$-eq suhe tvari/toni proizlaze iz uporabe fosilne energije i 19 g $CO_2$-eq suhe tvari/toni iz uporabe električne energije. Korištenjem primarne energije utrošeno je 1,6 GJ suhe tvari/toni što je jednako 9% sadržaja energije biomase.

*Smanjenje koncentracije $CO_2$ plina procesom sekvestracije ugljika*

Smanjenje emisija $CO_2$ plina vezanih uz proces sekvestracije ugljika prvenstveno se odnosi na količinu ugljika kojeg *Miscanthus x giganteus* može uskladištiti tijekom uzgoja te pritom, apsorpcijom, spriječiti njegovo ispuštanje u atmosferu. Ugljik se može skladištiti u rizomima i korijenju, kao i u strništu (Caslin i sur. 2010). Anderson-Teixeira i sur. (2009) su utvrdili da uzgoj višegodišnjih energetskih trava utječe na povećanje akumulacije organskog ugljika u tlu. Navedenu tezu potvrđuju višegodišnja istraživanja koja utvrđuju da *Miscanthus x giganteus* može uskladištiti 5,2 – 8,8 t C/ha godišnje u svojim rizomima i korijenju tijekom perioda od 12 – 15 godina (Jones i Walsh 2001; Clifton-Brown i sur. 2007). Istražujući isto, El Bassam (2010) navodi nešto višu akumulaciju od 9,1 t C/ha. Količina uskladištenog ugljika može biti dodatno povećana ukoliko su usjevi korišteni za proces bioremedijacije (Jones i Walsh 2001). Nadalje, Zeri i sur. (2011) su istraživali sekvestraciju ugljika u tri višegodišnja travnata usjeva (među ostalim *Miscanthus x giganteus*) i kulturama u plodoredu (soja, kukuruz). Temeljem dobivenih rezultata, kukuruz je imao najvišu maksimalnu stopu usvajanja ugljika dok su višegodišnje trave imale značajno produženu sezonu rasta, tako da se njihovo ukupno usvajanje ugljika moglo usporediti sa onim kukuruza u drugoj sezoni uzgoja. U trećoj godini rasta, očekivano, višegodišnje energetske kulture uvelike premašuju usvajanje ugljika kako u kukuruzu tako i u soji.

Obzirom na sekvestraciju ugljika u tlo, važno je napomenuti da se žetva trave *Miscanthus x giganteus* može provesti od listopada pa sve do ožujka ili travnja naredne godine. Međutim, žetva se najčešće odgađa od jeseni do početka proljeća kako bi se postigla biomasa s manjim udjelom vode što izravno utječe na energetska svojstva biomase, ali pritom dolazi do značajnog snižavanja ukupnog prinosa. Od jeseni kada usjev „odumre“, do žetve u rano proljeće, čak 25-50% suhe tvari predstavlja gubitak biomase u vidu prostirke (lišće i ne-drvenasti dijelovi kulture) koja ostaje na tlu (Clifton-Brown i Lewandowski 2002). Navedena biomasa sekvestracijom se akumulira u tlo te pridonosi stvaranju organskog ugljika, odnosno povećanju postotnog udjela količine humusa u tlu (Hansen i sur. 2004). Obzirom na istraživanja koja su proveli Gorgan i Matthews (2001), Clifton-Brown i sur. (2007), Dawson i Smith (2007) te El Bassam (2010) može se reći da se sekvestracijom ugljika u tlo putem razgradnje otpale prostirke uklanja 0,61 – 3,10 t C/ha godišnje iz atmosfere. Istraživanja povezana s prenamjenom zemljišta pod konvencionalnim usjevima u zemljišta za proizvodnju biomase navode povećanje sekvestracije ugljika u tlo između 2,8 – 4,1 t $CO_2$/ha godišnje za *Miscanthus x giganteus* (Smeets i sur. 2009).

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Temeljem pregleda relevantnih literaturnih navoda može se zaključiti da postoje dva primarna mehanizma kojima uzgoj lignocelulozne trave *Miscanthus x giganteus*, kao sirovina za proizvodnju obnovljive energije, može utjecati na smanjenje emisije $CO_2$. Prvi mehanizam mogućeg smanjenja emisije $CO_2$ emitirane u okoliš odnosi se na sami uzgoj. U odnosu na konvencionalne poljoprivredne kulture obrada tla se provodi samo u prvoj godini zasnivanja nasada, mala je mogućnost pojave bolesti i štetočinja (ne primjenjuju se pesticidi), herbicidi se apliciraju samo u prvoj te eventualnoj drugoj godini uzgoja te ujedno tijekom uzgoja navedena kultura ne zahtijeva veće gojidbene tretmane. Nadalje, procesi sekvestracije ugljika (u tlo i biljku) su također identificirani kao bitan faktor koji utječe za smanjenje emisija $CO_2$. Prirodni mehanizmi i morfološke karakteristike same kulture omogućuju izgaranje tzv. $CO_2$ neutralnog energenta što u konačnici rezultira smanjenjem emisija $CO_2$ za 75 - 93% tijekom energetskog iskorištenja biomase trave *Miscanthus x giganteus* u odnosu na fosilne izvore energije.

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# IMPACT OF LIGNOCELLULOSIC CROPS CULTIVATION AND ENERGY UTILIZATION ON POSSIBILITY OF CO2 EMISSIONS REDUCTION -CASE STUDY: CULTURE *MISCANTHUS X GIGANTEUS*

NIKOLA BILANDŽIJA, ŽELJKA ZGORELEC, DARIJA BILANDŽIJA, MILAN MESIĆ

## ABSTRACT

*Globally, the increasing demand for food as well as for the energy production, inevitably leads to an increase of atmospheric $CO_2$ emissions. According to National Inventory Report 2013, agricultural sector contributed with 11.7% to total Croatian greenhouse gas (GHG) emissions by which this sector was on the second place by contribution to total GHG emissions in 2011, after energy sector (73,3 %). One of the possible solutions for stabilization of global $CO_2$ emissions is production and utilization of renewable energy. Predictions indicates that the sources of renewable energy will be based on the production of high-quality biomass energy crops, whose production area is in constant increase all over the world, along with sun and wind. One of the crops that can be used for the production of high-quality energy biomass is perennial grass* Miscanthus x giganteus*. Ecologically, one of the main reasons for production of* Miscanthus x giganteus *crops is its potential for reduction of greenhouse gas emissions. Cropping of lignocellulosic grass* Miscanthus x giganteus *(as a source of renewable energy) can have impact on reduction of greenhouse gas emissions by two mechanisms: by reduction of emitted $CO_2$ into the environment during the process of growing and by carbon sequestration (into the soil and plant).*

***Key words**:* Miscanthus x giganteus*, $CO_2$ emissions, carbon sequestration, "green energy"*

42. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

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Stručni rad
Expert paper

# INFLUENCE OF AGRICULTURAL AND FORESTRY BIOMASS PHYSICAL CHARACTERISTICS ON COMPACTING/PELLETING

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## SUMMARY

*Romania owns large quantities of agricultural and forest wastes, which are let on agricultural fields or around villages being subjected to the action of water, wind etc. These residues (biomass), when they are inappropriately stored may pollute the environment, especially the soil and ground-water layer. The paper is studying the biomass compaction process, in order to capitalize it as pellets/agro-pellets, being strongly influenced by biomass physical characteristics: dimensions, granulometric shape, humidity, density, etc). Depending on these features, different types of pellets (different recipes), obtained out of different mixtures of biomass can be achieved; thus, high quality pellets will be obtained and their valorization will significantly reduce the noxious emissions in atmosphere.*

***Key words:*** *biomass, compaction, pellets, physical characteristics, recipes.*

## INTRODUCTION

In December 2008, the European Council adopted an integrated energy and climatic changes policy, which includes challenging targets for 2020, aiming to ensure a sustainable energetic future in Europe, by reducing carbon and diminishing the power consumption through [1]:

- Reducing greenhouse gases by 20% (comparing to 1990);
- Reducing energy consumption by 20% through increasing the energetic efficiency;
- Covering 20% of energy consumption from renewable sources.

Through D 2009/27/EC regarding „Promotion of electric energy produced from renewable sources to the unique energy market", the member states have embraced a policy enhancing the electric energy production from renewable sources and supporting the economic agents which capitalize this type of sources.

Main action directions of D 2009/27/EC consist in:

- Increasing the valorization degree of energy renewable sources within the electric energy production;
- Setting a target quote of electric energy consumption produced from energy renewable sources;
- Adopting procedures appropriate to finance the investments in energy renewable sources field;
- Amplifying the administrative procedures regarding the implementation of projects which capitalize energy renewable sources;
- Renewable energy technologies are very advantageous because they use inexhaustible less pollutant resources, which have an insignificant influence on climate changes. Furthermore, their utilization reduces the dependence on convention resources, which will be exhausted in times to come. [3].

Biomass is the first form of energy used by human being, since he discovered the fire. Energy included in biomass is released by different methods, which finally represent the chemical burning process [4].

Biomass is usually obtained from several plants such as: hemp, corn, poplar tree, willow, osier, reed, mischantus, etc. Although the solid fuels come from biomass, they are not considered as biomass because of their carbon content, which has not entered the natural cycle for a very long time.[7].

Biomass contributes by 14% to world consumption of primary energy and for three quarters of people living in developing countries, it represents the most important source of energy .At European Union level it is foreseen to create over 300,000 new working places in rural environment, based on biomass exploitation. At the present moment, in EU, 4 % out of energy required is assured by biomass, [6].

Main agricultural byproducts, which can be turned to thermal energy as agro-pellets are:

- Straw and chaff coming from straw cereals (wheat, rye, barley, two-row barley, rice and oat);
- Maize stems and corncobs;
- Stems of sunflower and rape;
- Stalks of soy beans, peas and beans;
- Wine stalks;
- Fruit trees branches.

The purpose and objectives of the research was carried out to achieve with a new pelletizing equipment designed recipes agro-pellets and pellets appropriate. To achieve this study were monitored along the following physical property of agricultural and forestry biomass used for experimentation:

- Dimensions and granulometric shape of mixture used in compaction process;
- Moisture content
- Net calorific value.

## MATERIALS AND METHODS

For obtaining pellets and agro-pellets, a pelleting press designed and achieved by INMA Bucharest has been used (fig. 1).

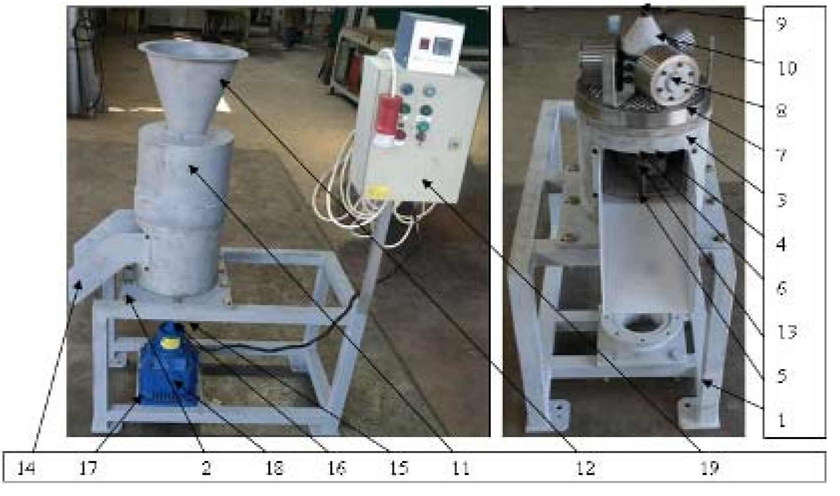



Fig. 1 Pelleting equipment – EP-0; 1 – frame; 2 – supporting plate; 3 – case; 4 - shaft; 5 – evacuating rotor; 6 – cutting rotor; 7 - mould; 8 – pressing assembly; 9 – special screw; 10 – leading cone; 11 – electric installation; 12 – protection case; 13 – lubrication system; 14 – evacuating chute; 15 – dog clutch; 16 – motoreduction axle; 17 – motoreduction support; 18 – motoreduction device; 19 – electric installation

By means of pelleting equipment with rotating mould, pellets / agro-pellets from agricultural and forest solid biomass are obtained, their length being adjustable between 10 ÷ 30 mm with adjustable knives.

Pelleting equipment (fig. 1) is made of the following main parts: metallic weld case pos. 3 in interior of which is mounted, by quaquaversing-axial bearings, a vertical shaft acting on the pressing assembly pos. 8, assembly endowed with three lay-on rollers placed at equal distances on diameter. Pressing assembly is made of a cylindrical body, in which are set three axles on which are mounted by means of two quaquaversing-axial bearings , the three lay-on rollers whose cylindrical exterior surface is notched. When the vertical shaft pos. 4, rotates, the pressing assembly and rollers rotate too. On the case, is rigidly mounted the compression mould with pressing channels of 6 mm or 8 mm pos 7. Channels are specially shaped for facilitating the material compression and obtaining high quality pellets.

Constructive and functional characteristics

- Productivity [kg/h]: max.100
- Installed power [kW]: 5.5
- Number of lay-on rollers [pcs]: 3
- Rotative speed of principal shaft [rot/min]; 56
- Exterior diameter of mould [mm]: 320
- Diameter of pellets achieved [mm]; 6 sau 8
- Pellets length [mm]; 10 ÷ 30
- Pellets cutting method: with adjustable knife
- Pellets evacuating method: with impeller
- Overall dimensions, Lxlxh [mm]: 1020 x 570 x 1563.

For obtaining pellets and agripellets, the following raw materials have been used: forest wastes, fir tree shavings, wheat straw, miscanthus, maize stems (ears).

Raw materials humidity has been determined by means of a thermo balance IR KERN RH-120-3 (fig. 2), reference and the methodology by which it was determined is the standard EN 14774-1:2009 Solid Biofuels-Methods for the determination of moisture content.

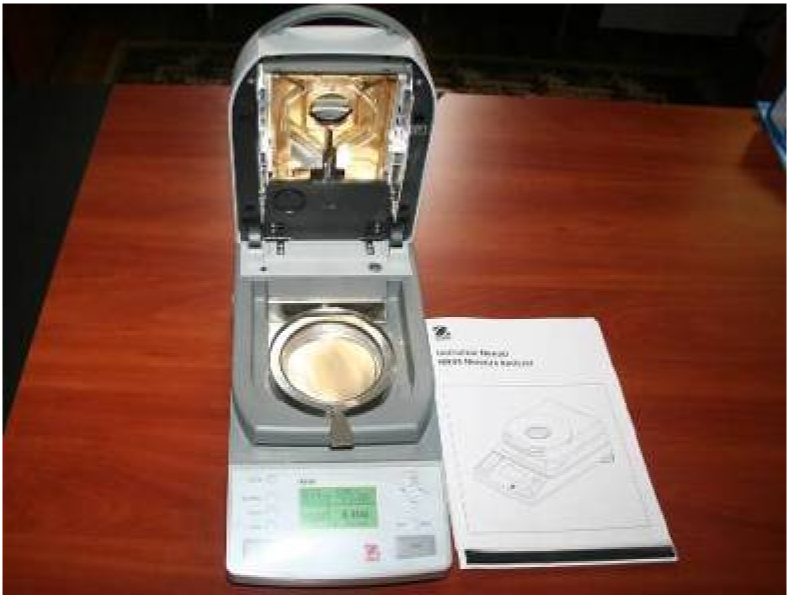


**Fig. 2** Thermobalance with IR KERN RH-120-3

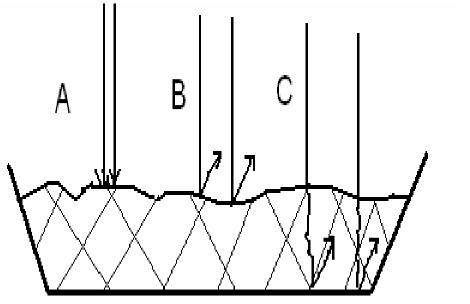



**Fig. 3** Energy transfer: A – incident radiation; B – radiation reflected by sample surface; C – radiation reflected by tray bottom

For determining the humidity, the apparatus uses the method of drying the agricultural and food products by electromagnetic waves with wave length in infrared, produced by a special lamp. During the drying, the water is removed as vapors and the sample is permanently weighed with an analytical balance present in the apparatus. This drying infrared method is a thermogravimetric method designed to determine the humidity. Content of humidity is determined through water loss, under the infrared waves action, which are partially turned to heat. Radiations penetrate the material and heat it from bottom to top. (fig. 3). Thermobalance emits electromagnetic radiations within infrared medium and short waves range. (length of 2 – 3.5 μm). Transfer of energy by infrared radiations allows raising the temperature of irradiated bodies. The part of electromagnetic absorbed radiations correspond to radiation which is niether reflected, nor transmitted.

For determining the calorific power a calorimeter system of C 200 type was used. System is produced and supplied by IKA-Werke GmbH & Co. KG. KGJanke & Kunkel, Germany. The reference standard was determined by the net calorific value is ISO 1928:2009 Solid mineral fuels - Determination of gross calorific value by the bomb calorimetric method and calculation of net calorific value.

Method of work: The material sample is introduced into the nacelle and it is weighed and its calorific power is determined. A cotton thread is attached in the center of the wire and the other end of the thread is introduced in the sample, for spreading the combustion in it. The nacelle placed in its support is introduced in calorimeter bomb and is sealed. Then, the bomb is filled with oxygen at 20-30 bar pressure by means of oxygen producing plant connected to an oxygen cylinder. The ignition adapter is attached to the bomb and then it is introduced in calorimeter inner vessel. Approximately 2 l of demineralized water are poured in calorimeter tank, monitoring the level indicator.

For preparing the measurement, in the measuring menu are introduced the sample weight, the type of operation to be performed (calibration or measurement), type of a calorimetric bomb and correction values of heat generated by cotton thread burning (implicit value is 50 J) .

The calorimeter cover is shut and apparatus starts measuring. First, the inner vessel is filled with water, and then the combustion takes place, the final stage being the equalization of inner and outer vessels temperature, by heat transfer from the inner vessel to outer vessel, and display of measured calorific temperatures.

Calculation of calorific power was performed according to the following hypotheses:

- Temperature of fuel and combustion products is of 25 °C;
- Water contained by fuel and water formed by hydrogene combustion are in liquid sate when the process is finished.;
- Atmosphere natrium has not been oxidized;
- Combustion gas products are: $O_2$, $N_2$, $CO_2$ and $SO_2$;
- Ashes are formed.

Granulometry deals with the study of particle size distribution belonging to a heterogeneous mono or polydispers mixture, as well as determining the particles percentage distribution according to their size, in the mixture mass.

Mixture granulometry is a fundamental characteristic of a powder product or a suspens-ion. It ddirectly influences the deployment of major categories of unit operations (grinding, separation, mixing, substance transfer, etc).

Need to establish dimensions and particles shape as well as determining the particles dimensions repartition percentage are imposed by the fact that they influence the specific impulse transfer and/or mass operations running. Within the operations in mechanical or hydrodynamic field, the flow behavior, characteristic defining the relative displacement of the disperse systems particles, depends on a series of properties, which are related to the particle geometry and their surface mechanical properties [5].

The the granulometric fractions determination for 5 types of raw materials for making agro-pelletes recipes was performed using a RETSCH AS 200 Basic screening system (fig. 4). The reference standard was then determined is represented by EN 15150:2011 - Solid Biofuels-Methods for the determination of particle density.

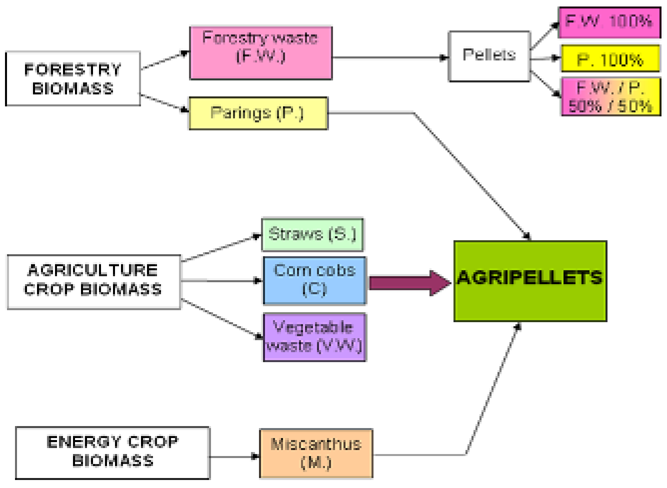
**Fig 4** Materials sieving

## RESULTS AND DISCUSSION

After analysis of pellets and agro-pellets obtained with the help of the pelleting equipment, using the laboratory equipment described above were obtained the following results shown in Table 1.

Table 1 F.W. – forestry waste; P.- parings; M - miscanthus; S - straws; C – corn cobs

| Den No. | Recipe (mixture) [%] TRF | T | M | P | C | Moisture content [%] | Density [kg/m$^3$] | Net calorific value [MJ /kg] |
|---|---|---|---|---|---|---|---|---|
| 1 | 100 | - | - | - | - | 12.46 | 508.36 | 17.85 |
| 2 | 100 | - | - | - | - | 22.6 | 351.29 | 17.54 |
| 3 | - | 100 | - | - | - | 10.94 | 554.26 | 18.06 |
| 4 | - | 100 | - | - | - | 15.4 | 411.13 | 17.99 |
| 5 | 33.33 | 33.33 | - | - | 33.33 | 13.26 | 476.23 | 18.40 |
| 6 | 33.33 | 33.33 | - | 33.33 | - | 12.45 | 491.91 | 18.36 |
| 7 | 33.33 | 33.33 | 33.33 | - | - | 12.86 | 483.34 | 17.96 |
| 8 | 65 | - | 35 | - | - | 13.64 | 461.63 | 17.62 |
| 9 | 65 | - | 35 | - | - | 15.15 | 409.19 | 17.53 |
| 10 | 65 | - | - | 35 | - | 12.67 | 443.88 | 17.44 |
| 11 | 65 | - | - | 35 | - | 14.05 | 404.09 | 17.39 |
| 12 | - | 65 | 35 | - | - | 12.79 | 434.96 | 17.38 |
| 13 | - | 65 | 35 | - | - | 15.33 | 364.00 | 17.36 |
| 14 | - | 65 | - | 35 | - | 12.93 | 451.27 | 17.20 |
| 15 | - | 65 | - | 35 | - | 13.36 | 408.36 | 17.16 |
| 16 | 60 | - | 40 | - | - | 12.64 | 379.64 | 17.37 |
| 17 | 60 | - | 40 | - | - | 15.04 | 386.15 | 17.32 |
| 18 | 60 | - | - | 40 | - | 12.38 | 380.44 | 17.27 |
| 19 | 60 | - | - | 40 | - | 14.89 | 389.36 | 17.24 |
| 20 | - | 60 | 40 | - | - | 12.17 | 375.54 | 17.34 |
| 21 | - | 60 | 40 | - | - | 15.13 | 394.16 | 17.29 |
| 22 | - | 60 | - | 40 | - | 12.54 | 372.77 | 17.23 |
| 23 | - | 60 | - | 40 | - | 15.36 | 391.58 | 17.15 |
| 24 | 55 | - | 45 | - | - | 12.46 | 389.15 | 17.33 |
| 25 | 55 | - | 45 | - | - | 15.84 | 450.22 | 17.28 |
| 26 | 55 | - | - | 45 | - | 12.73 | 394.56 | 17.22 |
| 27 | 55 | - | - | 45 | - | 15.14 | 404.28 | 17.20 |
| 28 | - | 55 | 45 | - | - | 12.44 | 373.66 | 17.31 |
| 29 | - | 55 | 45 | - | - | 14.96 | 390.45 | 17.27 |
| 30 | - | 55 | - | 45 | - | 12.35 | 371.96 | 17.20 |
| 31 | - | 55 | - | 45 | - | 15.09 | 405.38 | 17.11 |
| 32 | 50 | - | 50 | - | - | 15.38 | 384.78 | 17.24 |
| 33 | 50 | - | - | 50 | - | 15.74 | 387.15 | 17.19 |
| 34 | - | 50 | 50 | - | - | 15.96 | 388.46 | 17.29 |
| 35 | - | 50 | - | 50 | - | 16.08 | 390.15 | 17.24 |




Flow of the biomass for obtaining agro-pellets

After processing the data from the table were obtained following graphs:

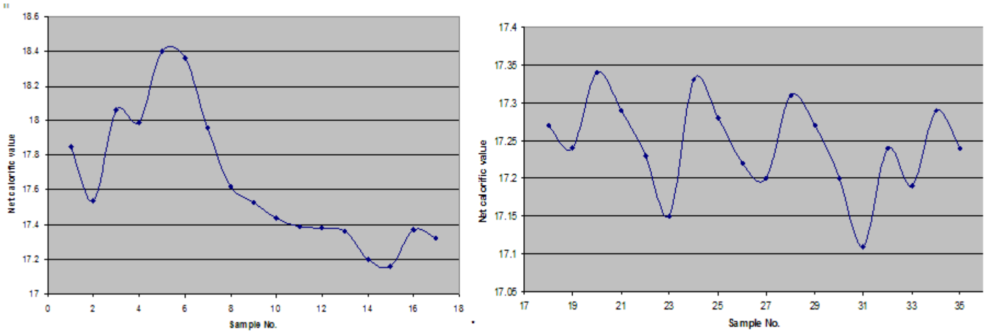



**Fig. 5** Graphical representation of net calorific value (MJ/kg) for 35 agro-pellets recipes

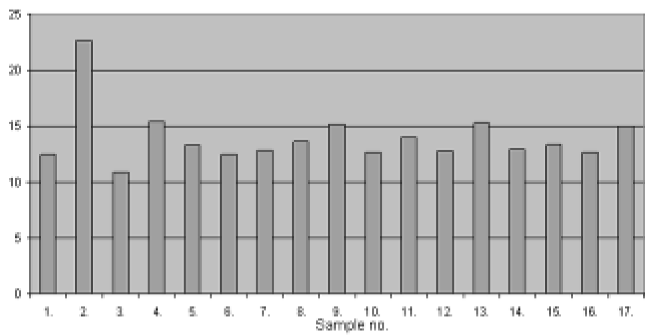



**Fig. 6** Graphical representation of moisture content (%) for 17 agro-pellets recipes (1-17)

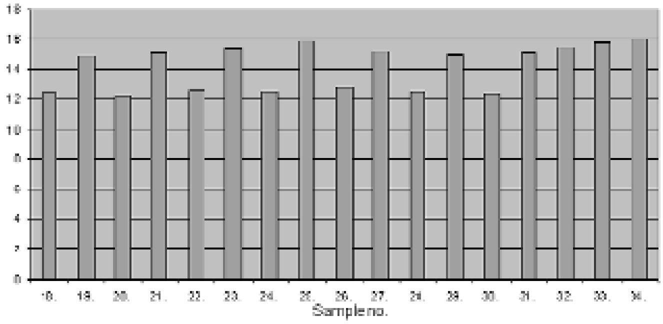



**Fig. 7** Graphical representation of moisture content (%) for 18 agro-pellets recipes (18-35)

## CONCLUSIONS

From the laboratory tests results, it is noted that:

For *agricultural* and forestry *biomass samples:* 1÷17:

- samples moisture content has an average value of 13.97 %, the highest humidity having the recipe (sample) number 2 and the lowest humidity - number 3 sample;
- sample net calorific value has an average value of 17.64 MJ/kg and varies inverse proportionally with the total humidity content of the analyzed sample; as the total moisture content is lower, the net calorific value is greater;

For *agricultural and forestry biomass samples*: 18÷35:

- samples moisture content has an average value of 13.36 %, the highest humidity has recipe (sample) number 35 and the lowest humidity has number 30 sample;
- sample net calorific value has an average value of 16.29 MJ/kg and varies inverse proportionally with the total moisture content of the analyzed sample; as the total humidity is lower, the net calorific value is greater;

Thus it appears that agro-pellets recipes containing humidity in field interval 11.5-13.8 % and a minimum 1/3 TRF or Wood Chips percentage, determine a finished product in compliance with EU fuel standards, without needing a binding agent.

Agro-pellets were also obtained from recipes containing less or more content than the specified range, but durability and combustion power are lower.

Size of raw materials used to make the 35 recipes of pellets / agro-pellets was between 1-8 mm.

In terms of net calorific value it has been found that the values obtained for analyzed pellets variants are comparable to those given in the literature data obtained for analyzed pellets variants are comparable to those given in the literature data.

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42. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

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Stručni rad
Expert paper

# CONTROLLED STEMS CUTTING MODULE FOR SRC NURSERIES

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## ABSTRACT

*The paper presents the results of developed cutting controlled module designated for integration in complex equipment for produce SRC stems in nurseries. At beginning, there are presented the method used for value analysis and base functions of future device. More base solutions were considered by using more criteria for future life cycle (technical, technological, manufacturing, exploitation, maintenance, recuperation etc.) and costs. It was developed an original method for analyzing the behavior or energetic willow stems (rods) while cutting accurately. The purpose of present paper is to provide one application for practical use, if it researches the behavior of willow rods for preparing in nurseries than use planting machines (e.g. EGEDAL "Energy Planter"). Nowadays and, also in the future, it will develop the use of the rods of plants, not only in cultivation system, also in industrialization of energetic willow. This system supposes more advantages technical, social, economical and for environment objectives. The results of different experiments were used for designing new cutting equipment for different rods as willow and poplar.*

**Key words:** *cutting, willow, nurseries*

## INTRODUCTION

Nowadays at EU level, a lot of strategies and official documents analyzes and give recommendations for important targets and possibilities in the renewable energy production, for next horizon 2020 and 2050, [6].

The general energy crisis, and environmental demands, determine imperative the necessity for renewable energy from alternative resources according with increasing of energy requirements and depleting of fossil fuels reserves, also taking into consideration the polluting effects on the ecosystem and global heating [1], [2], [3], [4].

An important sector becomes the biomass, especially SRC cultivation, and developing of corresponding agricultural machinery almost for harvest and conditioning SRC stems (rods), ready-to-use for planting machines.

For example realizing of harvesting and sorting machines for rods in nurseries, it is an important aim, to develop, construct and test an automatic harvesting and sorting system for SRC material, a system able to combine the harvesting (cutting), sorting and packaging of the SRC stems [5], prepared for use in step-planting machines [7].

The paper presents the steps and results in developing an original cutting controlled module designated for integration in complex equipment for produce SRC rods in nurseries.

The objective of the researches was to develop, build and test a system for cutting SRC rods automatic controlled. This module was designated for integration in complex equipment for produce SRC rods in nurseries.

Such system must satisfy the practical demands: to cover the influence of different parameters on the cutting force (up to 7 kN); to permit modifying of cutting cycle time according with practical value (less than 1 s); to insure the quality and productivity of cutting process, according with general customer's requirements.

## METHOD

The developing process respects classical steps corresponding to value analysis method, presented in figure 1, where: Vu – global use value and Cp – production costs. The authors worked in FP7 project „ROD PICKER - Automatic harvesting system for SRC nurseries", at Mechanical Technology Laboratory, Mechanical Engineering Faculty, "Politehnica" University of Timisoara.

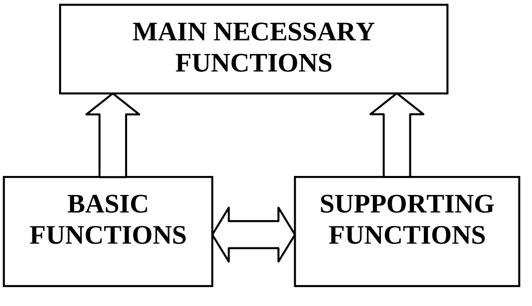


**Figure 2** Main necessary function structure

For determine social needs and analysis of present situation a dedicated questionnaire was distributed in 2012 year to 30 SRC nurseries in Germany, Denmark, Sweden, Romania and Hungary.

The answers were used for determine the almost technical characteristics of new developed equipment.

Based on these steps were identified the main necessary functions, and were split in two categories: basic functions and supporting functions, which interactions (figure 2).

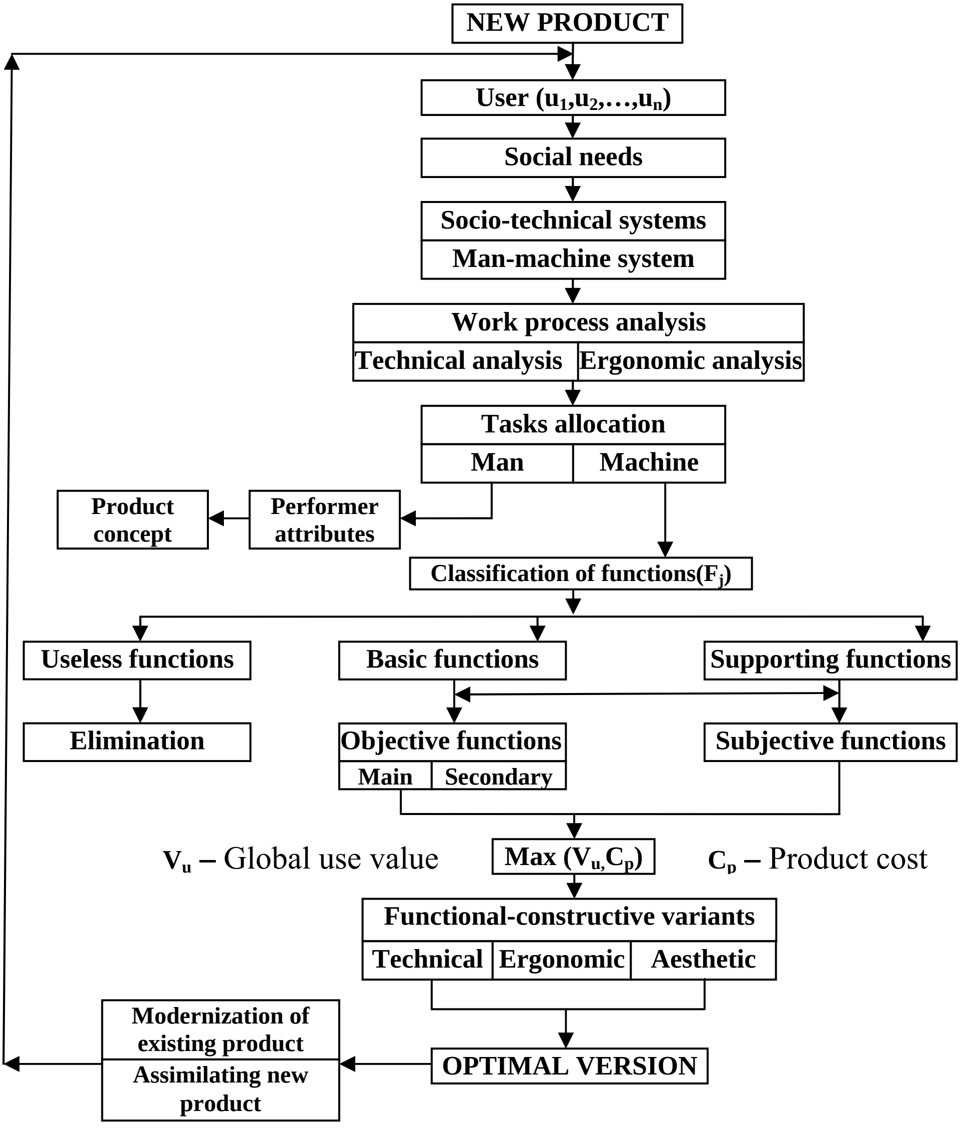


**Figure 1** Steps of value analysis method for cutting unit

The hierarchy of functions was made by psychological experiment, because there wasn't any background in this field, the product being absolutely new and estimation of manufacturing costs was impossible.

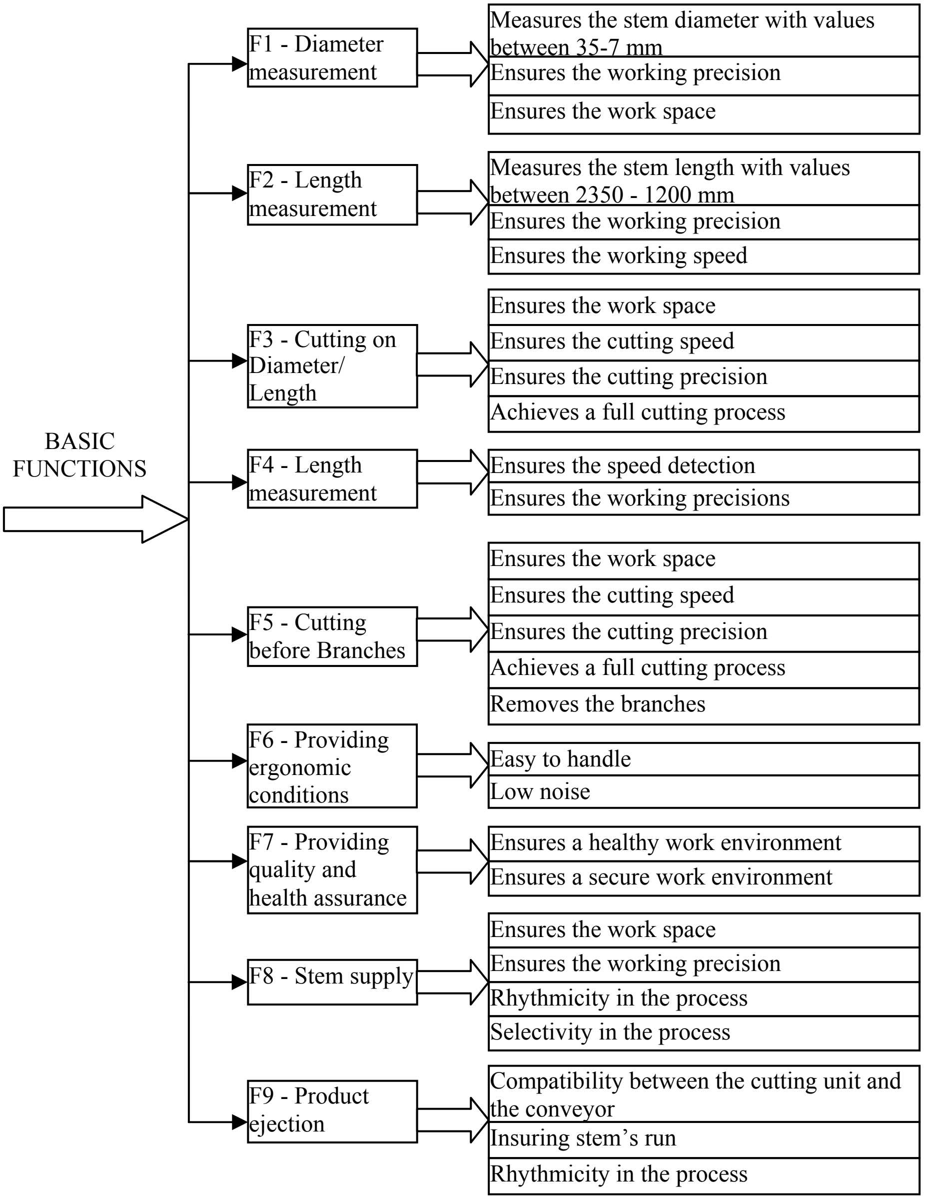


**Figure 3** Presentation and description of Base Functions

Based on identified functions, critical analysis, and partial known solutions were designed the experimental model for tests in laboratory and at end-user.

The last step will happen after tests and brainstorming with end-users during the next demonstrations and supposes the upgrading of the model.

## RESULTS AND DISCUSSION

In figure 3 are presented and described the basic functions identified and in figure 4 the supporting functions identified.

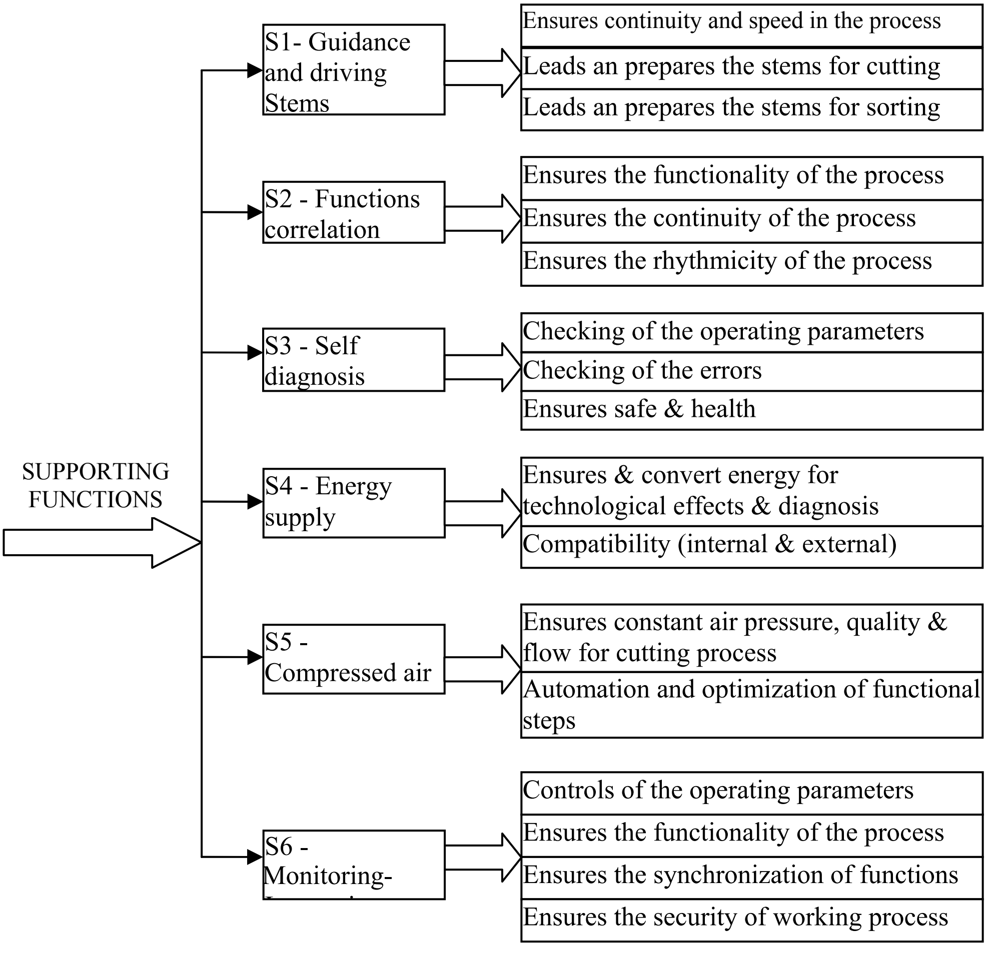


**Figure 4** Presentation and description of Supporting Functions

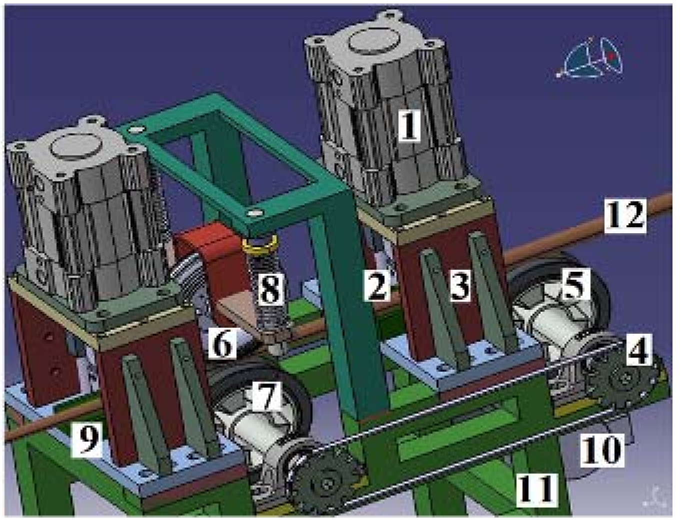


**Figure 5** Concept of cutting unit

Based on value analysis approach was elaborated the general ensemble design of cutting unit (figure 5), and after the virtual model developing, was created and tested the prototype of cutting module (unit), presented as result in picture 6.

**Picture 6** Cutting unit by testing

The resulted cutting unit includes two air cylinders (pos. 1 in fig. 5), for powering the knifes, with full command system (electro-waves, distributer, air splitter, support etc.), knifes and its support and guiding columns (pos. 2 in fig. 5), cutting skeleton (pos. 3 in fig. 5) and opposite knife (pos. 9 in fig. 5). From step by step engine (pos.10) and gear belt transmission (pos. 4, fig. 5) and powering wheel insures the precision displacement of stem. Wheel (pos. 5) evacuates the stem. Ensemble copy wheel (pos. 6) and pressing system (pos. 8) measures the length of stem.

The cutting cycle time is less than 1 sec. and performs cutting forces up to 8 kN.

## CONCLUSIONS

The development of new agricultural machinery for energy crops is a new and important branch of agricultural engineering, and also is a challenge in the next years in Europe. The processes automation and production hazard involves the use of new designing methods as value analysis, life cycle costs, fuzzy logic etc.

The value analysis permits to identify the main functions and to associate the corresponding parts of machine in conditions of optimum costs, fiability and reliability.

Also, it involves special algorithm and software, a lot of qualified workers and good relationships between designer, producer and end-user.

## ACKNOWLEDGEMENT

This work was partially supported by the project „ROD PICKER - Automatic harvesting system for SRC nurseries", financed by Research Executive Agency – Research for SMEs, Grant Agreement N°: 315416.

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42. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

UDC 582.623:631.342.2:635.037
Prethodno priopćenje
Preliminary communication

# THE BEHAVIOR OF WILLOW STEMS BY CUTTING IN NURSERIES

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## SUMMARY

*The objective of paper is to present one application for practical use, if it researches the behavior of willow stems for preparing its in nurseries than use planting machines, EGEDAL "Energy Planter". Nowadays and, also in the future, it will develop the use of the stems of plants, not only in cultivation system, also in industrialization of energetic willow. This system supposes more advantages both technical, social, economical and for environmental objectives. The proposed method includes a test package (hard and software), consisting of original and special device, integrated with equipment for test the strength of material. Proposed equipment permits to measure the influences of different factors, cutter's parameters, stem properties, geometry and speed of cutting tool, on the cutting force by continuous and constant loading. Also, the cutting surface conditions can be evaluated according with such factors. The results of different experiments were used for designing new cutting equipment for different rods as willow and poplar.*

***Key words:*** *willow, cutting, nurseries*

## INTRODUCTION

There are well known actually environmental demands, regarding the necessity for find new ways of producing energy from alternative resources and for replace classics fuels [4].

At EU level, a lot of strategies and official documents analyzes and give recommendations for important targets and possibilities in the renewable energy production. For example the „Energy Roadmap 2050 – Impact Assessment and Scenario Analysis" and „Renewable Energy Road Map Impact Assessment (Road Map IA)", [10], was estimated, largely based on GREEN-X modeling, [8], that around 195 Mtoe biomass will be consumed in primary energy to realize the objective of the 20% renewable energy target in 2020.

A detailed study shows that the estimated biomass resources potentials for 2020 differs between the studies. According to GREEN-X, the results show the lowest potential of 2.8 EJ $y^{-1}$ (67 Mtoe $y^{-1}$) by 2020, but, the same aim, by the EEA show 4.0 EJ $y^{-1}$ (96 Mtoe $y^{-1}$).

Interesting is that both studies (reports), GREEN-X and EEA, provide a breakdown of resources that are produced on the available land by 2020 to arrive at their total resource potential. Other studies indicates higher potentials from energy crops, although the estimates typically in the same order of magnitude.

For example, Matthias Dees [5], based on Kyriakos Maniatis & Paul Grabowski, Presetation, Bioeneregy, Contractors Meeting, 15-16 October 2008, Bruxels, proposes the comparisson between different scenarious and estimations of future potential of biomass, presented in table 1.

**Table 1** Overview on estimates of future potential of biomass for energy

| **Scenario** | **Potential of biomass for Year [Jx10$^{18}$]** | | |
|---|---|---|---|
| | **2025** | **2050** | **2100** |
| Shell (1996) | 85 | 200-220 | - |
| IPCC (1996) | 72 | 280 | 320 |
| Greenpeace (1993) | 114 | 181 | - |
| Johansson et al. (1993) | 145 | 181 | - |
| WEC (1993) | 59 | 94-157 | 132-215 |
| Dessus et al. (1992) | 135 | - | - |
| Lashof and Tirpak (1991) | 130 | 215 | - |
| Faaij (2006) | | 40-1100 | |

(Source: Matthias Dees, Bioenergy for Europe – Supply scenarios, presentation in „Policy Dialogue on Potential Sustainable Wood Supply in Europe", European Forest Week, FAO, Rome, Oct. 22, 2008, http://www.unece.org/fileadmin/ DAM/timber/ docs/tc-sessions/tc-66/pd-docs/presentations/pws-dees.pdf, October 11th, 2013)

According with different studies and sources, the study „Technical assistance for an evaluation of international schemes to promote biomass sustainability", from December 2009 [9], presents a comparison of values from different studies, splitting biomass in three categories (agricultural products (energy crops), agricultural residues (crop residues) and forestry residues), for three reference years (2010, 2015 and 2020), based of 2000 year (table 2).

The results show the priority for development of agricultural products (energy crops) and SRC (short rotation coppice) in the next years in Europe, also importance and good opportunities for obtaining biomass.

The increased interest for such activities already imposed new and special agricultural technologies, which integrates machinery, technologies and social rural activities [1], [2], [3], and different approach by general and special methods [6], [7].

Actually, the up to date cultivation technology for SRC supposes the use of rods (from 1,2m to 2,4 m long) for planting machines, which are developed to cut and plant willow cuttings, for increasing the work efficiency, quality and safety [11].

In such conditions became important to develop agricultural machinery for harvest and conditioning SRC stems (rods), ready-to-use for planting machines.

These conditions can be insured by the mean of harvesting and sorting machines for rods in nurseries, by developing it's according to quality and productivity demands, an important operation being the cut of stems.

**Table 2** Comparison of values from different studies, splited in three biomass categories for the reference year (2000), 2010, 2015 and 2020

| Category | Values for biomass for different years, [J x $10^{18}$] | | | | Source |
|---|---|---|---|---|---|
| | 2000 | 2010 | 2015 | 2020 | |
| Agricultural products (energy crops) | 34,2 | | | 57,1- 113,7 | RENEW |
| | | 47,1 | | 95,8 | EEA |
| | 16,2 – 27,5 | 25,1- 79,8 | | 60.9-182.2 | Thran *et al.* (2006) |
| | 43.2 | | | 124.2-148.1 | Ericsson and Nilsson (2006) |
| | 26.2 | 35.9 | 52.9 | 67.0 | GREEN-X |
| Agricultural residues (crop residues) | 43.7 | | | 35.3-37.5 | RENEW |
| | 18.6 | 18.6 | | 17.4 | Thran *et al.* (2006) |
| | 21.3 | | | 19.6 | Ericsson and Nilsson (2006) |
| | 18.4 | 21.7 | 25.5 | 30.0 | GREEN-X |
| Forestry residues | 17.2 | | | 19.6-20.1 | RENEW |
| | | 42.3 | | 39.2 | EEA (2005) |
| | 10.5 | 11.9 | | 13.1 | Thran *et al.* (2006) |
| | 40.1 | | | 3.8-55.4 | Ericsson and Nilsson (2006) |
| | 32.0 | 33.2 | 34.4 | 35.8 | GREEN-X |

(Source Technical assistance for an evaluation of international schemes to promote biomass sustainability, Final Report, December 2009, http://ec.europa.eu/energy/renewables/bioenergy/doc/2010_02_25_report_international_schemes.pdf, October 11th, 2013)

According to these, the paper proposes an original method for analyzing the behavior or energetic willow stems (rods) while cutting in nurseries.

The objective of the researches was to develop, build and test a system and a new method for determine the behavior or energetic willow and poplar stems (rods) while cutting in nurseries.

Also, another objective was to provide one application for practical use, if it researches the behavior of willow rods for preparing its in nurseries than use planting machines.

## METHOD

First condition was to develop the method by considering the practical demands: to determine the influence of different parameters on the cutting force; to modify the value of tested parameters according with practical value; to insure the reproducibility conditions and to insure the quality and productivity of cutting process.

In figure 1 are presented the steps of process for developing of the method, by using of systemic approach, and corresponding to different tiered testing approach. Also, these steps can be presented as results.

**METHOD FOR ANALYZING THE BEHAVIOR OF ENERGETIC WILLOW STEMS (RODS) WHILE CUTTING IN NURSERIES**

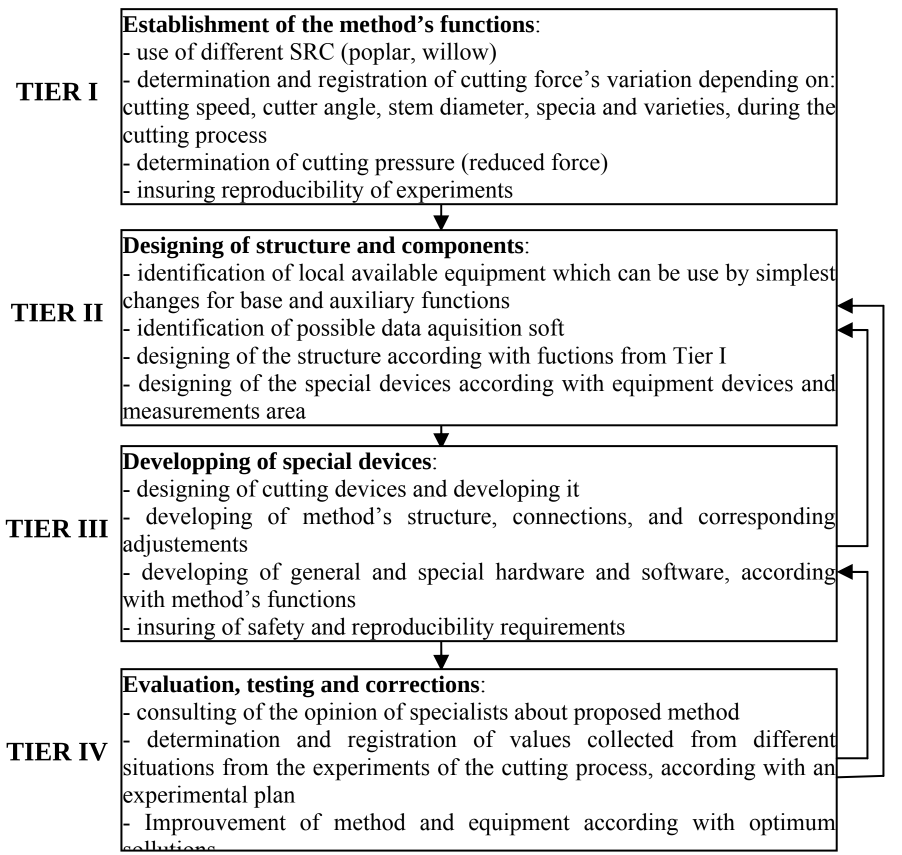


**Figure 1** Steps of the process for developing of the method

The testing equipment was integrated together with complex equipment from Strength of Materials Laboratory, Mechanical Engineering Faculty, “Politehnica” University of Timisoara, the final result being the stand presented in figure 2. The main base equipment consist in a Static Material Testing Machines from Zwick (Zwick/Roell Z005), integrated in as-named “ProLine materials testing machine”, with twin-column. The machine is specially designed for function-testing components and for routine materials testing, with high-accuracy Xforce load cells based on a rotation-symmetrical or axis-symmetrical design, making them highly resistant to transverse forces. The data acquisition rate for the test control measurement and control electronics is 320 kHz, and test speeds from 0.0005 to 1000 mm/min, with independent speed of test load. Also, position, force or strain control can be selected as required.

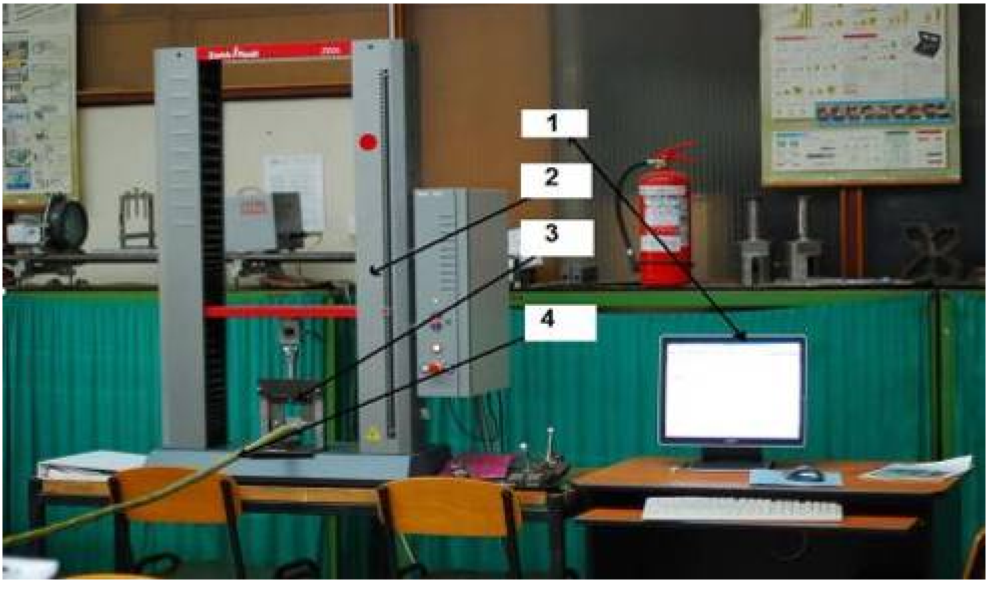


**Figure 2** Working stand used for determination; 1 – Unit for recording and processing of the experimental data, 2 – Zwick/Roell Z005 Static material Testing Machine, 3 – SRC’s cutting tool, 4 – Sample (energetic willow stem); The method’s testing integrated equipment requires a special cutting tool for SRC.

## RESULTS AND DISCUSSION

According with the steps from figure 1, were created, designed and developed an original special device for completes the base equipment for analyze of the cutting process, presented in figure 3

The SRC’s cutting tool must permit variation of cutting speed, cutting angle, stem’s diameter and SRC species and variety, and insure compatibility with Zwick/Roell Z005 Static material Testing Machine.

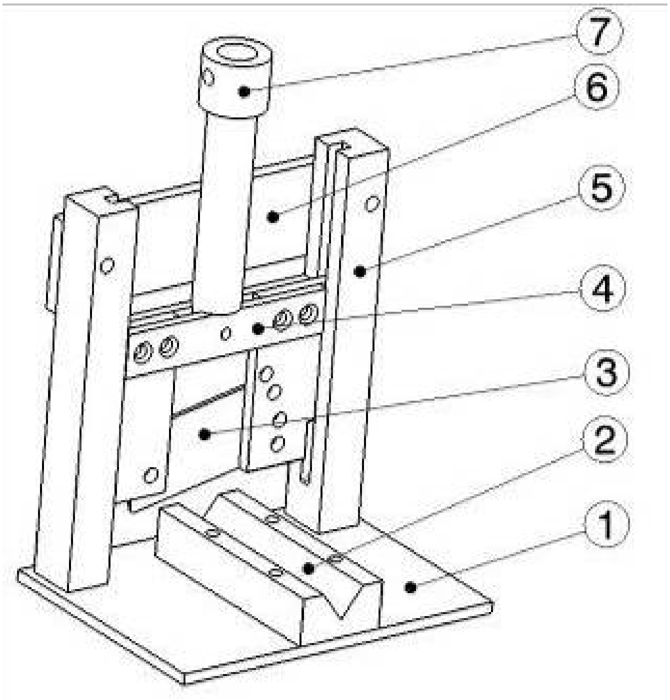


**Figure 3** Cutting device (1 – motherboard, 2 – “V” support, 3 – cutting blade, 4 – beam, 5 – guiding columns, 6 – fixing bar, 7 – coupling bar)

For demonstration in table 3 are presented the results obtained for study of dependence between cutting force and cutting speed for 0,019 m stem’s diameter and cutter’s angle $10^0$, for energetic willow INGE variety. In table 3, $D_m$ represents the media of maximum and minimum diameter (D1, respective D2), measured on orthogonal direction.

The results where statistically processed, taking into account the obtaining of the variability curve and the statistic relevance. This test was possible by the help of the statistically software package from Microsoft EXCEL 2007.

Based on the results from the table 3 it has been accomplished the representation of the dependence between cutting force and cutting speed, as it is shown in chart, figure 4. On the same chart there are presented the regression equation and $R^2$ – squared value.

For increasing the relevance and compare the results for different diameters, can be introduced the concept of reduced force, $F_R$, as well:

$$F_R = \frac{F}{D_m}$$

where F(cutting force) and $D_m$ (medium diameter) have the values from table 3.

**Table 3** Results obtained for study of dependence between cutting force and cutting speed for 0,019 m stem's diameter and cutter's angle $10^0$

| Sample Nr. | D1 [mm] | D2 [mm] | $D_m$ [mm] | Vi (Loading Speed) [(m/s)x$10^{-3}$] | F (Cutting force) [N] | Obs. |
|---|---|---|---|---|---|---|
| 1 | 18,46 | 19,8 | 19 | 0,5 | 968 | |
| 2 | 18,66 | 19,01 | 19 | 0,83 | 891,9 | |
| 3 | 18,53 | 19,07 | 19 | 1 | 745 | |
| 4 | 18,63 | 19,02 | 19 | 1.41 | 806,72 | |
| 5 | 18,43 | 19,04 | 19 | 1.67 | 849,3 | |

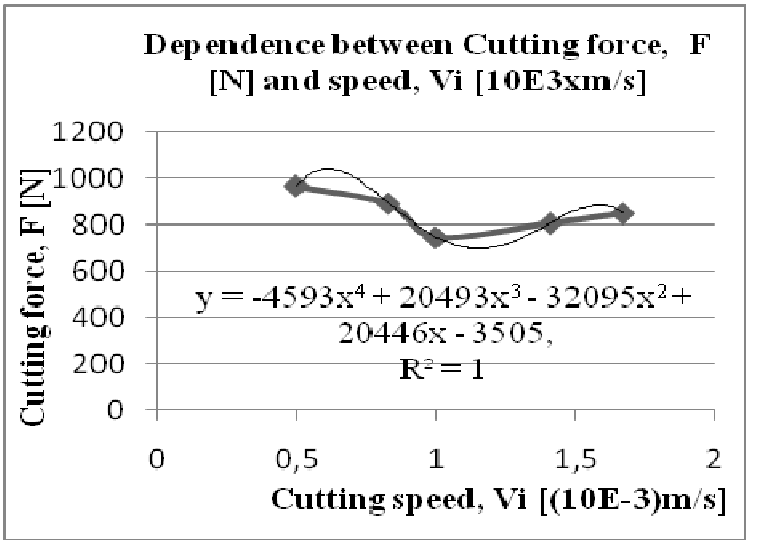


**Figure 4** Dependence between cutting force and cutting speed

After regression analysis results the optimum model for relationship between cutting speed and cutting force, as function polynomial of degree 4:

$y = -4593x^4+20493x^3 - 32095x^2 + 20446x - 3505$. Statistical analysis shows good value for coefficient of determination,

$R^2 = 1$, so it can be considered an optimum value of cutting speed between [1 ; 1,5] $10^{-3}$ m/s.

This is the optimum value for diameter of stem at 0,019 m and cutting angle $10^0$. For global analyze it will be necessary to use a multi-factorial and multi-criteria analysis, together with examination of cutting surface quality.

## CONCLUSIONS

In nurseries an important activity is the process of cutting of SRC stems, approached in many conditions: quality, productivity, efficiency, low costs etc.

This paper presents a method for analysis of cutting process, in such conditions. The results could be used for designining cutting machines. Proposed method studies the cutting process by complex approach, in different dimensions as: raw materials, equipment and technological parameters.

The obtained results, confirm an optimum value for cutting speed corresponding to a minimum value of cutting force. The position of minimum point depends on cutting angle and stem diameter.

For global analyze it will be necessary to use a multi-factorial and multi-criteria analysis, together with examination of cutting surface quality.

## ACKNOWLEDGEMENT

This work was partially supported by the project „ROD PICKER - Automatic harvesting system for SRC nurseries", financed by Research Executive Agency – Research for SMEs, Grant Agreement N°: 315416.

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42. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

UDC 661.9:662.767.2
Pregledni rad
Review paper

# POTENTIALS, OPPORTUNITIES AND BARRIERS FOR BIOGAS PRODUCTION AND UTILIZATION IN AUTONOMOUS PROVINCE OF VOJVODINA

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## SUMMARY

*Biogas is form of renewable energy source (RES), which is usually produced from manure and/or energy crops, but from other organic waste as well. Beside electricity generation, biogas could be utilized for heating/cooling energy generation and as substitution for fossil fuels in the sector of transport. Serbia has pledged to follow goals in line with Directive 2009/28/EC for the production and utilization of RES, and biogas among them. The objective of this investigation was to determine potentials for biogas production in the Autonomous Province of Vojvodina, agricultural region in the northern part of Serbia. Further objective was to assess the state of the art of biogas technology in the province and opportunities and barriers in order to fulfill stated goals for biogas in Serbian RES National Action Plan. For determination of potential biogas production in Vojvodina, the following substrates were considered: manure, energy crops, slaughterhouse waste, sewage sludge, municipal biodegradable waste and organic waste from food industry. The potentials for biogas production are expressed by the annual amount of available substrates in t, the potential annual biogas production in* $Stm^3/a$ *and through the installed electric power of cogeneration units in* $MW_e$*. The results showed that the largest potential for biogas production is from animal manure and energy crops, with 40* $MW_e$ *and more than half of total potential. Municipal biodegradable waste and organic waste from food industry are next significant substrates for biogas production in Vojvodina with 7 and 5* $MW_e$*, respectively. Regarding achievement of goals in Serbian RES National Action Plan, only biogas from manure has been taken into account, and Vojvodina could contribute with 20* $MW_e$*, which is two thirds of the planned biogas production in Serbia. Biogas potential for heating and cooling is 14 ktoe and sufficient to fulfill the stated goal, but feasibility of heat utilization depends on availability and conditions of potential heat consumers. Potential of* *biogas for biofuels production in the form of biomethane, using other substrates than manure, is 61 ktoe. Comparing with stated goal for total biofuels production of 267 ktoe, the value is significant, since biomethane from waste will be counted as a new generation biofuel, wherewith the potential would be multiplied. Yet, five biogas plants were constructed in Vojvodina, whereof two are agricultural, one for anaerobic treatment of sewage sludge and two for anaerobic treatment of sludge from purification of food industry waste waters. Since only few biogas plants are constructed in Vojvodina, there is opportunity for further development of biogas technology and construction of plants, in order to attain determined potential. Main barriers for this are incentive measures that are not appropriately adapted for all types of biogas plants, due to low feed-in tariffs and no additional support for heat use, but due to other perspective uses of substrates as well.*

***Key words:*** *biogas, potentials, opportunities, barriers, Vojvodina*

## INTRODUCTION

By Directive 2009/28/EC (Anonymous, 2009a), European Union has defined goals concerning production and utilization of renewable energy sources (RES). The main goal is that in the EU, by the 2020, share of RES in consumption of primary energy should be at least 20 %, and that at least 20 % of electric energy should be produced from RES. Therefore, this Directive is also known as RES 2020. Additional goal is replacement of 10 % of fossil fuels with biofuels in the sector of transport. All member countries, but also candidate countries, are obliged to achieve these goals.

By signing a Memorandum of integration into the EU energy market (Anonymous, 2007), Serbia has pledged to follow policy of EU in this field. One of the first concrete support measures to this program was adoption of Regulation on Conditions and Procedure for Acquiring the Status of Privileged Electricity Producer (Anonymous, 2009b) and Regulation on Incentive Measures for Privileged Electricity Producers (Anonymous, 2009c), which were obligation in the line with the actual Energy Law (Anonymous, 2012). Therewith, basic prerequisites for economically viable generation of electricity from renewable sources were achieved, since subsidized prices can be obtained for distribution of electricity to the public grid, *i.e.* feed-in tariffs. These regulations were innovated in 2013 (Anonymous, 2013a & 2013b), wherewith the values of the feed-in tariffs were slightly changed. According to the RES 2020, countries are obliged to adopt National Action Plans in the field of RES. In Serbia, in 2010, for the first time the Biomass Action Plan (Anonymous, 2010a) was adopted, which was followed by adoption of the RES National Action Plan (Anonymous, 2013c).

One form of RES that has been involved in Serbian RES National Action Plan is biogas that is produced from manure. Other substrates that can be used for biogas production are energy crops and organic waste. The specific significance of biogas production is reduction of methane emissions, a green house gas (GHG) with 23 time greater intensity than carbon dioxide and appropriate treatment and disposal of organic waste. Additional positive effects achieved by anaerobic fermentation of manure are odor reduction and prevention of emissions to the soil and ground water (Michel *et al*, 2010). So, the most important objective of a biogas plant construction is protection of environment. At most biogas plants in operation, biogas is commonly utilized for the electricity generation, where other uses of biogas are less perspective.

Vojvodina is Autonomous Province in the northern part of Serbia. It is an agricultural region, with $1.78 \cdot 10^6$ ha of arable land and therewith huge biomass potentials for co-generation (Martinov *et al*, 2008). This is basic for assumption that potentials for biogas production in Vojvodina in the agricultural sector are also significant and even larger when considering other potential substrates for biogas production as well. In the early eighties of the twentieth century, in Vojvodina and central Serbia, seven biogas plants were built at livestock farms to generate thermal energy. Some of these plants have never been started-up due to the failures during their construction. Others have stopped operating due to inadequate maintenance. Until the end of 2010, not a single contemporary biogas plant for electricity generation was constructed in Vojvodina.

According to Europe's Energy Portal, electricity price in Serbia is several times lower in comparison to those in EU member countries. Furthermore, incentive measures for support of electricity generation from RES, in the form of feed-in tariffs, are among the lowest in Europe as well. Values of feed-in tariffs, defined for electricity generation from biogas, are presented in Table 1, which are dependent on used substrates for biogas production and installed power of a biogas plant.

**Table 1** Excerpt from the Regulation on incentive measures for privileged electricity producer that defines feed-in tariffs for biogas plants (Anonymous, 2013b)

| **No.** | **Type of power plant** | **Installed power P, $MW_e$** | **Feed-in tariff, c€/$kWh_e$** |
|---|---|---|---|
| 3. | Biogas power plant | | |
| 3.1 | | up to 0.2 | 15.66 |
| 3.2 | | 0.2 – 1 | 16.498 – 4.188•P |
| 3.3 | | over 1 | 12.31 |
| 3.4 | Plant fuelled by biogas from animal origin waste | | 12.31 |
| 4. | Landfill and sewage gas power plant | | 6.91 |

Examples of studies on potentials for biogas production in Slovenia and Romania are given in Pšaker & Lobe (2010) and Anonymous (2008). The objective of this investigation was to determine potentials for biogas production in the Autonomous Province of Vojvodina and to assess the potential contribution of biogas production in Vojvodina for the goals on the national level. Further objective was to assess the state of the art of biogas technology in the province, but opportunities and barriers for its further development as well.

## MATERIALS AND METHODS

*Considered substrates*

For determination of potential biogas production in Vojvodina, the substrates presented in Table 2 were considered. Manure subsumes cattle, pig and poultry excrements from animals at larger farms, which are potential locations to construct biogas plants of acceptable size, *i.e.* more than 150 $kW_e$. The quantities of manure were assessed according to Anonymous (2011a). Maize silage is most commonly used energy crop for biogas production, due to high energy potential per hectare and usual practice for production, harvest and storage, and therefore considered in this investigation. According to EU Regulation (Anonymous, 2009d), slaughterhouse wastes are classified into three categories (KI, KII, KIII), for which specific requirements for its disposal are defined. In Serbia, actual is the Regulation on disposal of slaughterhouse waste (Anonymous, 2011b), which is a translated version of adequate EU Regulation. Only organic waste from the slaughter industry that is classified as KII and KIII, *i.e.* waste generated from the treatment of pig and poultry meat, is allowed to be used for biogas production and therefore considered as potential substrate. Sewage sludge originates from treatment of municipal waste water, which contains household waste water, partly purified industrial waste water and rainwater. It contains organic matter and therefore may be used as substrate for biogas production. According to Waste Management Law (Anonymous, 2010b), fractions of biodegradable waste that were considered as suitable for anaerobic digestion are other biodegradable waste (food/kitchen waste) and garden waste. Potential substrates that originate from food industry are organic waste from sugar mills (roots and sugar beets leafs, pulp and melasin) and beer industry (sludge from treatment of waste water, draff and yeast). Other substrates from food industry were not taken into account for potential biogas production in Vojvodina, since their quantities are not sufficient for construction of biogas plants that have significant power.

**Table 2** Considered substrates for determining of biogas potential in Vojvodina

| Substrate | Origin |
|---|---|
| Manure | Agriculture– animal husbandry |
| Energy crops | Agriculture– crop production |
| Slaughterhouse waste | Food industry– animal parts |
| Sewage sludge | Municipal waste water |
| Municipal biodegradable waste | Municipal solid waste |
| Organic waste from food industry | Food industry– sugar mills and beer production |

*Determination of biogas potentials*

The potentials for biogas production are expressed by the annual amount of available substrates in t, but it does not say enough about the energy potential, since biogas yields are different. Furthermore, the potential annual biogas production of defined heating value, are expressed in standard cubic meters ($Stm^3/a$) as well. This potential is applicable in the case of biomethane production, or use of biogas as a fuel for boilers. To consider utilization of biogas in cogeneration, the potential is expressed through the installed electric power of cogeneration units in $MW_e$.

The potentials are determined using following assumptions and data. Potential biogas yields from considered substrates ($Stm^3/t$) and methane content in produced biogas (% $CH_4$) are taken from Anonymous (2006) and Martinov & Đatkov (2012). In order to determine installed electric power of cogeneration units, it was assumed that the biogas plants operate continuously by nominal installed power, excluding the time required for maintenance and repair, *i.e.* 8,000 h/a and that the electric efficiency of cogeneration units is 38 % (Martinov *et al*, 2011).

## RESULTS AND DISCUSSION

*Potentials for biogas production*

In Table 3 are presented potentials for biogas production in Autonomous Province of Vojvodina until 2020 and in Table 4 potentials after 2020. Potentials are given until 2020, since goals according to RES National Action Plan must be achieved until this year and after 2020 in order to appraise the potentials in the future. Potentials are presented separately for each considered substrate and in total.

The largest potential for biogas production is in agriculture, with more than half of total potentials. It was assumed that energy crops would contribute potential biogas production not more than manure, although the potential biogas production from energy crops in Vojvodina could be much higher. The necessary acreage for maize silage production in order to achieve biogas potential from energy crops presented in Table 3 is 9,100 ha. This is negligible, comparing with $1.78 \cdot 10^6$ ha of total arable land in Vojvodina, wherewith it does not threaten food supply security.

**Table 3** Biogas potentials in Autonomous Province of Vojvodina until 2020

| Substrate | Substrate quantity, $10^3$ t/a | Biogas production, $10^6$ $Stm^3/a$ | Nominal electric power, $MW_e$ |
|---|---|---|---|
| Manure | 2,816 | 70.4 | 20.0 |
| Energy crops | 455 | 70.4 | 20.0 |
| Slaughterhouse waste | 35 | 5.3 | 1.5 |
| Sewage sludge | 12 | 1.1 | 0.3 |
| Municipal biodegradable waste | 205 | 24.6 | 7.0 |
| Organic waste from food industry | 37 | 17.6 | 5.0 |
| TOTAL | 3,560 | 189.4 | 53.8 |

The assessed biogas potential from slaughterhouse waste until 2020 is based on current meat production in Vojvodina and certain increase after 2020 due to enlargement of livestock production for export. Biogas production from sewage sludge is achieved only from available sludge on single existing facility for purification of municipal waste waters located in Subotica, with capacity of biogas plant 300 $kW_e$ (Table 3). Other settlements in Vojvodina will construct such facilities after 2020 and assessed potential would rate 3 $MW_e$ (Table 4). Increase of biogas potential from municipal biodegradable waste after 2020 is based on expected increase of waste quantities per capita, as well as share increase of municipal biodegradable waste that should be treated differently than landfilling. Organic waste from sugar mills and beer industry, that is currently not marketed as fodder or utilized as by-product to attain better economic effects than for biogas production, would be enough to install biogas plants with total power of 5 $MW_e$. It is expected that after 2020 other food processing companies would be developed as well, which will generate the substrates for biogas production and potential would be 10 $MW_e$.

**Table 4** Biogas potentials in Autonomous Province of Vojvodina after 2020

| **Substrate** | **Substrate quantity, $10^3$ t/a** | **Biogas production, $10^6$ $Stm^3/a$** | **Nominal electric power, $MW_e$** |
|---|---|---|---|
| Manure | 4,224 | 105.6 | 30.0 |
| Energy crops | 680 | 105.6 | 30.0 |
| Slaughterhouse waste | 47 | 7.0 | 2.0 |
| Sewage sludge | 120 | 10.6 | 3.0 |
| Municipal biodegradable waste | 270 | 35.2 | 10.0 |
| Organic waste from food industry | 73 | 35.2 | 10.0 |
| TOTAL | 5,414 | 299.2 | 85.0 |

*Achievement of goals*

RES National Action Plan in Serbia defines three different pathways of RES production and utilization– electricity generation, heating and cooling, as well as production of biofuels and their use in transport, which follows RES 2020 policy. Stated goals for biogas production and utilization in Serbia are presented in Table 5, which are thereafter compared with assessed potentials in Vojvodina. These potentials are considered assuming that entire amount of produced biogas would be utilized either for electricity generation, with additional generation of heating/cooling energy, or for production of biomethane as biofuel.

**Table 5** Goals in line with RES National Action Plan in comparison with potentials for biogas production

| **RES National Action Plan** | **Goal, total** | **Goal, biogas** | **Potential, biogas** |
|---|---|---|---|
| Electricity generation, $MW_e$ | 1,092 | 30 | 20 (53.8) |
| Heating and cooling, ktoe | 149 | 10 | 14 (37) |
| Biofuels in transport, ktoe | 267 | – | 36 (97) |

Regarding electricity generation from biogas, Vojvodina has potential to generate two thirds of the planned biogas amount in Serbia. However, RES National Action Plan considers only manure as substrate, but when taking other substrates into account, Vojvodina would have almost twice larger biogas potential than the stated goal (presented in parenthesis).

If entire heat energy from cogeneration would be utilized, the biogas potential for heating and cooling is sufficient to fulfill the stated goal, albeit this depends on availability of potential heat consumers in vicinity of biogas plants. Utilization of cooling energy requires additional investments in absorption chillers and installation, which puts the economic feasibility of the investment under question.

Since potential for biogas production from manure in Vojvodina sufficiently contribute to the fulfillment of the stated goal in RES National Action Plan regarding electricity generation, other substrates could be provided for biomethane production and its use as biofuel in the sector of transport. In Table 5, the stated goal for total biofuels production is 267 ktoe, accounting biodiesel, bioethanol and plant oil as well. Therefore, the potential of 61 ktoe, excluding biomethane from manure, is significant considering that biomethane from waste will be counted as a new generation biofuel. It is planned that these biofules will have increased impact, wherewith the potential of 61 ktoe would be multiplied.

*Constructed biogas plants in Vojvodina*

In Table 6, five biogas plants that operate in Vojvodina are presented, and their basic characteristics are given. At four plants, produced biogas is utilized for electricity generation with additional utilization of heat, i.e. for combined heat and power (CHP). However, in all cases generated heat is not delivered to external consumer, but utilized only for own needs. This is stated as general problem at most operating biogas plants and some perspective possibilities are proposed in Rutz et al. (2012).

**Table 6** Constructed biogas plants in Autonomous Province of Vojvodina

| Site | Plant type – gas utilization | Substrate | Power, $kW_e$ |
|---|---|---|---|
| Vrbas | Agricultural – CHP | Manure, energy crops | 1,000 |
| Čurug | Agricultural – CHP | Manure, energy crops | 635 |
| Subotica | Waste treatment – CHP | Sewage sludge | 626 |
| Senta | Waste treatment – CHP | Sludge from food processing waste water | 1,500 |
| Čelarevo | Waste treatment – heating | Sludge from food processing waste water | 290 |

CHP– combined heat and power

Two plants, located in Vrbas and Čurug, are agricultural, which as substrates mostly use manure from dairy farms and maize silage. Generated electricity is entirely delivered to the public electricity grid, in order to obtain feed-in tariffs and therewith facilitate economically feasible operation. Efficient utilization of surplus heat is planned for the future.

Other three facilities are intended for waste treatment, *i.e.* for anaerobic digestion and therewith appropriate disposal of sludge. At all three facilities, high share of generated heat is utilized for heating of digesters. Purpose of the biogas plant in Subotica is anaerobic treatment of sewage sludge, whereby it is only a part of facility for purification of municipal waste waters from Subotica town. Generated electricity is completely utilized for water purification processes, since feed-in tariff for this type of biogas plant is only 6.91 c€/kWh$_e$. This is the lowest feed-in tariff for generated electricity from biogas, as presented in Table 1. Therefore, covering the own energy needs was the most perspective pathway of biogas utilization. At biogas plant in Senta, sludge from purification of waste waters from yeast production is anaerobically treated. Produced biogas is utilized to generate electricity that is delivered to the grid. Biogas plant in Čelarevo was constructed in 2010, but planned in the period when Regulation for Incentive Measures for Privileged Electricity Producers was not adopted yet. Therefore, the produced biogas is utilized to substitute natural gas in boilers and to cover heat processing needs in beer production.

*Opportunities and barriers*

Since only few biogas plants are constructed in Vojvodina so far (Table 6), the significant potential exists to attain determined technical potential for biogas production and utilization that is presented in Table 3.

It is to be expected that the most biogas plants constructed in future will be agricultural, due to significant potential and available technology for anaerobic digestion of manure and energy crops as substrates. In the study on potentials and possibilities of biogas production in agricultural sector (Martinov et al, 2011), the economic feasibility of operation of biogas plants with different capacities was checked. The results showed that only larger plants, *e.g.* more than 500 kW$_e$, and in scenario with high share of external heat utilization, achieve positive economic figures. Therefore, the actual incentive measures, in the form of feed-in tariffs, are not appropriate for biogas plants with smaller capacities. The high share of heat utilization is scarcity in the practice and requires additional investments. The incentive measures do not additionally support utilization of surplus heat, which is identified as one of the most significant barriers for further development of biogas technology in Vojvodina. Existance of such supporting measures would contribute significantly the economic feasibility of future agricultural, but other types of biogas plants in Vojvodina as well.

Biogas plants for anaerobic treatment of sewage sludge are intended to contribute environmental protection, but rarely for decentralized energy generation. In Serbia and Vojvodina, this is particularly due to low feed-in tariffs for electricity generated from biogas obtained using sewage sludge as substrate (Table 1). Additionally, investments for such facilities are higher than for agricultural biogas plants, since substrate has high water content wherewith digesters and other reservoirs for substrate and digested residue storage should be largely dimensioned. Therefore, the feasible operation of these facilities is enabled only if investment is subsidized from external funds. In that case, positive economic figures are achieved by utilization of generated energy to cover energy needs in the process of water purification. This is the case of single biogas plant for anaerobic treatment of sewage sludge located in Subotica. Thus, determined potentials for biogas production in this sector are almost negligible for the near future (Table 3). Potentials are more significant in the future (Table 4), assuming that appropriate funds will be available and have to be used for projects that as purpose have environmental protection.

Other types of biogas plants that are intended for anaerobic treatment of waste, such as slaughterhouse waste, municipal biodegradable waste and organic waste from food industry have better opportunities to achieve positive financial effects, comparing with sewage sludge, and therefore better opportunities to achieve determined potential presented in Table 3. These types of biogas plants would be supported with the same incentive measures like agricultural plants, with an exception of biogas plants for slaughterhouse waste treatment, for which the feed-in tariff is independent on plant's size and rates 12.31 c€/kWh$_e$. However, investment in a biogas plant that treats slaughterhouse waste is significantly higher than for an agricultural biogas plant. Therefore, it would be desirable that feed-in tariff for these plants is higher, although the economic feasible operation could be achieved through additional income/saving from slaughterhouse waste disposal. So far, only two facilities in Vojvodina were constructed in Senta and Čelarevo, which use sludge from purification of food processing waste water. The reason is that these two food industry companies have obligation to purify waste waters and obtained sludge cannot be utilized for another purpose. Biogas plants that would use other organic waste, *e.g.* from sugar industry, will be constructed only if higher feed-in tariffs would be prescribed, since this organic material is mostly considered not as a waste, but rather as a by-product that could be used as fodder or feedstock in other food industry, which enables additional income. Municipal biodegradable waste will be perspective as substrate for biogas production in Vojvodina only if primary selection of waste will be conducted. In Serbia, according to Regulation on waste disposal at landfills (Anonymous, 2010c), acceptable level of biodegradable waste for landfilling by 2020 will be at most 50 %. It is to be expected that anaerobic treatment will represent just one implemented technology for disposal of this type of waste, beside incineration and composting.

## CONCLUSIONS

Autonomous Province of Vojvodina, as agricultural region in Serbia, has the largest potentials for biogas production exactly in the agricultural sector, considering manure from animal husbandry and energy crops as substrates. According to Serbian RES National Action Plan, where only biogas production from manure is stated as goal, the assessed potential from this substrate in Vojvodina is sufficient to fulfill the goals in heating and cooling energy generation and to significantly contribute planned electricity generation. Biomethane production and use in the sector of transport could be achieved using municipal and waste from food industry. Biogas technology started its implementation in Vojvodina, but only few biogas plants are constructed. One of the reasons is that RES legislation has been recently adopted. Furthermore, the actual incentive measures are insufficiently attractive for potential investors, particularly for biogas plants that would use waste as substrates for biogas production. Serbian Government should properly adapt the incentive measures for „green" electricity from biogas, in order to enable further development of biogas technology and construction of future biogas plants in Serbia, and in Vojvodina as well.

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# MITIGATION OF PEAK LOADS WITH SOLAR ENERGY IN AN ENTERPRISE

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## ABSTRACT

*The electricity consumption in enterprises has a significant share in the overall energy consumption. One of the main changes for the electricity consumers in Estonia has been the hourly-based billing that for larger electricity consumers (usually industries) was implemented from April 2010. What is more, these consumers usually have to make contracts with power companies with specific conditions.*

*One of the conditions usually applied is, that the larger electricity consumers have a consumption-based threshold: when the energy consumption in a single hour exceeds a certain limit, a higher price has to be paid for the electricity consumed over the before mentioned limit. This above-normal demand from the electrical grid during a short period of time can also be described as a peak load. In the current paper renewable electricity that would be generated on-site using PV-panels is considered for the mitigation of these peak loads in enterprises.*

*An enterprise that is located in a rural area in Central-Estonia and is connected to the main Estonian Electricity Network Operator was chosen as an example case for the analysis. The simulated renewable energy system is connected to the grid and therefore has no need for storage equipment.*

***Key words:*** *distributed energy generation, solar energy, peak shaving, renewable energy penetration, system optimization.*

## INTRODUCTION

The focus of this paper is an analysis of an enterprise's electricity consumption in Nordic conditions on the example of an Estonian company and evaluating the possibility of shaving electricity consumption peaks with solar electricity produced on-site.

The last trend in Estonia is to establish material and room capacious production in the countryside. This is caused by cheaper land, labour and relatively low transportation costs. From April 2010 enterprises with electricity consumption more than 2 GWh/year are obliged to buy electricity from the open market. All Estonian electricity consumers buy electricity under the conditions of open electricity market from the 1$^{st}$ of January of 2013 (Elering, 2013a). This means that the price of electricity has hourly variations. These variations depend on the available capacity for electricity production, hydroenergy levels in the Nordics and Latvia, European Union's rules on emissions trading etc (Elering, 2013b). These free market fluctuations are difficult to predict. For instance, fluctuations of hourly electrical prices in the year 2012 were in the range 7…183 €/MWh (Nord Pool Spot, 2013). Entrepreneurs who have relatively high electricity consumption can negotiate a fixed-price for their base-consumption. In the sample case a base consumption level of 232 kW is considered. This is derived from the yearly electricity consumption of large-scale consumers (2 GWh/year / 8760 h ≈ 232 kW). Consumption over this threshold is counted as peak load. If the consumption load exceeds this level, then a market-based price has to be paid instead of the fixed-price. If a local energy source would be used, then it would be possible to reduce the amount of electricity bought from the grid when exceeding the set base load threshold and avoid additional fees during hours with peak loads.

The price of consumed electricity is composed of the price of electrical energy in the Nord Pool Spot Power Market (NPS), network services fee, excise on electricity, renewable electricity fee and VAT (Elering, 2013c). The renewable energy fee (as of 01.01.2013) is 8.7 €/MWh (Elering, 2013d), while the subsidy amounts to 53.7 €/MWh (Elering, 2013e). The revenue for green electricity sold to the grid is composed of the subsidy and the NPS price (Elering, 2013e). The network service fees and the price for electrical energy have been constantly growing. Therefore it is reasonable to assume, that in the current case, PV-panels seem to be the most reasonable to use for producing electricity during peak loads (and thereby peak shaving) for a consumer with a high daytime consumption.

To confirm this hypothesis, the correlation between electricity output from PV-panels and the consumption was found. The specific characteristics of electricity consumption in industries had to be considered: for example the work in shifts and standstills for weeks in summertime due to vacation has strong influence on the electricity consumption. Workdays and holidays were evaluated separately. The calculations were made using hourly-based data. The purpose of the research is to find ways to lower the energy demand of enterprises in times of high prices. The tasks of the research are the description of the object, calculation of the possibilities for a PV power plant.

## MATERIALS AND METHODS

Previous research in this field has been done for the utilization of solar energy for commercial buildings (Braun and Ruether, 2010) and for airports in (Ruether, Braun, 2009). In addition the shaving of peak loads with photo-voltaic systems has been analysed (Ortjohan and Omari, 2002). The before mentioned analyses were made for locations at latitudes closer to the equator. In the current paper a building is analysed, that is located on a northern latitude (58°52' N) in a rural area in Central-Estonia. The electricity consumption of the examined enterprise building in the reference year 2012 amounted to 1668.38 MWh.

The main electricity consumers in the enterprise are: metal bending machines, welding robots, a tube laser, planar laser, plexiglas cutter, sandblaster, pressure washer, powder coating, lathes and mills (Jalax, 2013).

Modern industrial buildings are typically large and have horizontal flat roofs, with few shading if any. These kind of buildings have good conditions for installing PV-systems. The building in consideration has a flat rooftop, with a potential area for the installation of photovoltaic panels amounting to 7 700 m$^2$. Taking into consideration the location of the building and the fact that PV-panels must not cast shadows on each other the proposed installation would amount to 150 kWp of installed capacity (Müür, 2013). Standard PV-panels that would not be integrated to the building are considered for this case, since this makes it possible to choose and adjust the tilt angle freely. The tilt angle of the PV panels was chosen to be 42° (Rowlands et al., 2011). Standard polycrystalline PV modules with 15.4% efficiency, dimensions 1.6 × 1 m and 250Wp were chosen (Marsol, 2013). The average inverter efficiency was chosen to be 90% (Mondol et al., 2006). The necessary spacing between the panel rows was graphically found to be 4 m, to avoid shadows on the panels during the days close to winter solstice, when the sun reaches only 7.5° over the horizon at the location of the building (Müür, 2013).

Previous research suggests the usage of storage equipment for peak shaving (Nykamp et al., 2013). In this current case the possibility of storage equipment was neglected due to the amounts of electricity consumed in the enterprise and the relation of energy consumption and considered PV capacity.

The characteristic consumption of workdays is presented in Figure 1, it differs substantially from the consumption during holidays (weekends, vacations and national holidays) which can be seen on Figure 2.

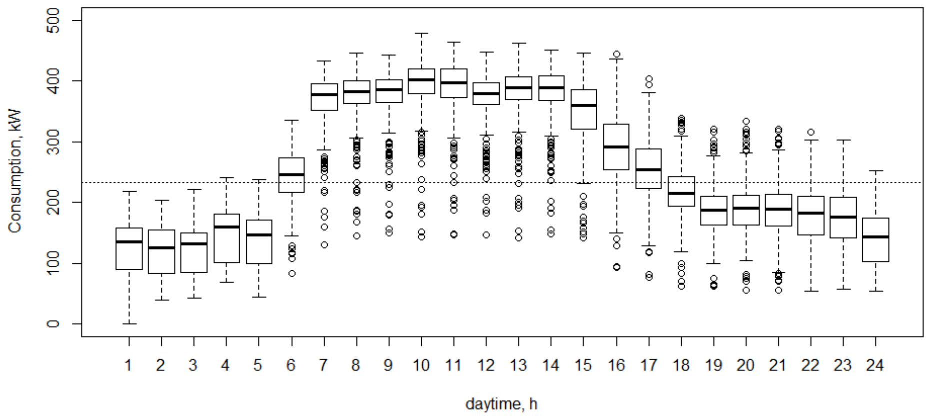


**Figure 1** Boxplot of the hourly electricity consumption in the examined industrial enterprise during workdays in 2012. The dotted line represents the peak load threshold

The work is conducted from Monday to Friday and there is a month-long vacation period, that is usually during July and a second vacation period of two weeks in winter.

Figure 1 represents the quartiles of the total electricity consumption during workdays in the sample case enterprise. The peak load, in this case, is defined as an hourly average power consumption over the base load of 232 kW (Jalax, 2013). The peak loads compose a significant fraction of the electricity consumption, as seen from figure 1. The peak loads occur in the sample case on the mid-workdays. In total, there were 125 holidays in 2012. When following a normal work-schedule there were no peak loads during weekends nor during night-time (Figure 2). The hourly median consumption of holidays was 65 kW which can be seen as idling load of the production building. The energy consumption during peak loads amounts to about 21% of the total energy consumption.

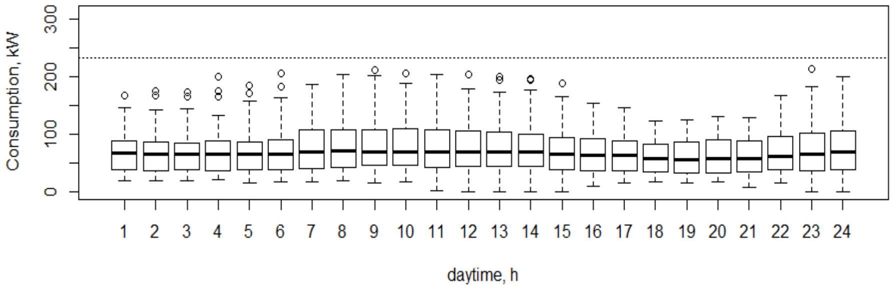


**Figure 2** Boxplot of the hourly electricity consumption of the sample case industry during holidays in 2012. The dotted line represents the peak load threshold

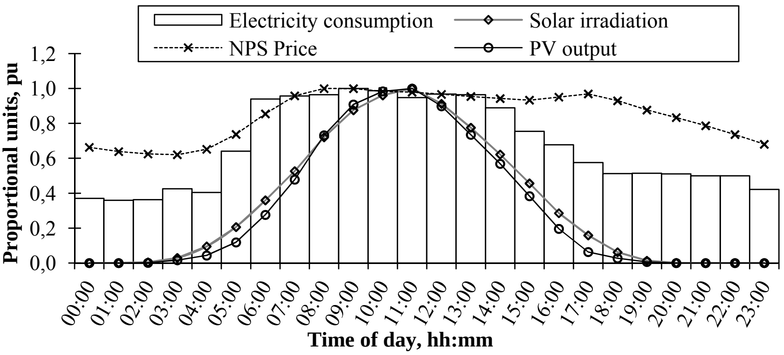


**Figure 3** Coincidence of average hourly electricity consumption (Jalax, 2013), solar irradiation (Estonian Environmental Agency, 2013) and NPS electricity price for Estonia (Nord Pool Spot, 2013) in 2012

The weather data for the analysis was chosen from the respective year 2012 from a weather station that describes the inland conditions of Estonia – Tõravere meteorological station (Estonian Environmental Agency, 2013). Figure 3 shows the hourly averages of the evaluated parameters, they are presented in proportional units to enhance the visual comparability. The mean values of the parameters at the same daytime during all days in the year are calculated and divided with their yearly average to normalize the data. It can be seen that the peaks of NPS price and electricity consumption coincide with the output from PV-panels. Some divergence between solar irradiation and PV output curves is caused by fixed-construction pecularities of PV-panels on the roof. In the mornings and in the evenings the fixed solar panels may face away from direct sunlight, thereby causing the PV production curve to be steeper than the irradiation curve.

To calculate the output of the PV panels the following equation was used (Homer Energy, 2013):

$$P_{PV} = Y_{PV} f_{PV} \frac{\bar{G}_T}{\bar{G}_{T,STC}} \left[1 + \alpha_p \left(T_c - T_{c,STC}\right)\right], \qquad (1)$$

$Y_{PV}$ – the rated capacity of PV array, power output under standard test conditions, kW;

$f_{PV}$ – the PV degrading factor, %;

$\bar{G}_T$ – the solar radiation incident on the PV array in the current time step, kW/m$^2$;

$\bar{G}_{T,STC}$ – the incident radiation at standard test conditions, 1 kW/m$^2$,

$a_P$ – the temperature coefficient of power, %/°C;

$T_c$ – the PV cell temperature in the current time step, °C;

$T_{c,STC}$ – the PV cell temperature under standard test conditions, 25 °C.

Due to cold climate in the evaluated region and for simplifying the calculations the temperature effect was not considered, $a_P = 0$ (Annuk et al., 2012).

To confirm the calculated PV energy production results the capacity factor was calculated with the following formula:

$$C_p = \frac{W_a}{P_n \cdot 8760}, \qquad (2)$$

$C_p$ – capacity factor;

$W_a$ – annual energy production, kWh/year;

$P_n$ – nominal power of PV array, kW.

The capacity factor is a site and device specific parameter that shows the efficiency of energy equipment usage.

## RESULTS AND DISCUSSION

The roof area of 7700 m$^2$ (Estonian Building Registry, 2013) and the latitude described above, makes it possible to install a PV array with 150 kWp (Müür, 2013), which would have produced 138426 kWh in the year 2012, this results according to equation 2 in a capacity factor of 10.53%. Calculated on the basis of (Institute for Energy and Transport, 2012) data, a capacity factor in the range of 10% is found to be typical for PV systems in the observed latitudes.

From the correlation matrix represented in Table 1 it can be concluded that the correlations between hourly electricity consumption of the sample building, the NPS electricity price and the PV output are resulting from the solar irradiation are strong (r > 0.68). Between the evaluated parameters exists a). A strong positive correlation is reflected by r coefficients form 0.68 to 0.9. Coefficients from 0.90 to 1.0 represent very high correlations (Taylor, 1990).

**Table. 1** Pearson correlation matrix between electricity consumption, solar irradiation, production and NPS electricity price

| | Consumption | Solar Irradiation | PV output | Electricity Price |
|---|---|---|---|---|
| Consumption | 1.0000 | 0.8476 | 0.8169 | 0.7652 |
| Solar Irradiation | 0.8476 | 1.0000 | 0.9948 | 0.7550 |
| PV output | 0.8169 | 0.9948 | 1.0000 | 0.7288 |
| Electricity Price | 0.7652 | 0.7550 | 0.7288 | 1.0000 |

The high correlation factor confirms the reasonability to use solar energy for the mitigation of peak loads in consumers with this kind of consumption pattern. The energy can be supplied with on-site renewable energy sources, instead of consuming high price electricity from the grid when the peaks of consumption, PV production and price coincide. Additional fees can be avoided, that may apply when exceeding the consumption limits set by the contract.

Roof area of industries in relation to electricity consumption is generally not sufficient. The same situation is in the described enteripirse, the roof area is by far not sufficient to cover the whole electricity consumption of the building with PV energy as seen from Figures 4 to 7. Below are presented the energy flows of four example weeks from each season during the reference year 2012.

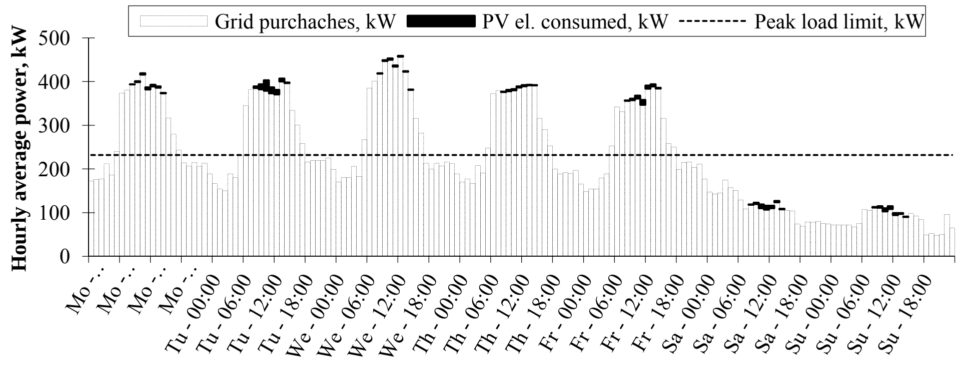


**Figure 4** Electricity consumption from the grid and PV-electricity generation during a winter week (09.01.2012 – 15.01.2012)

The same consumption pattern is reoccurring through out the year, as seen from figures 4 to 7. From Figure 5 it can be seen that the solar irradiation in the example winter week is low and would result only in an insignificant PV production.

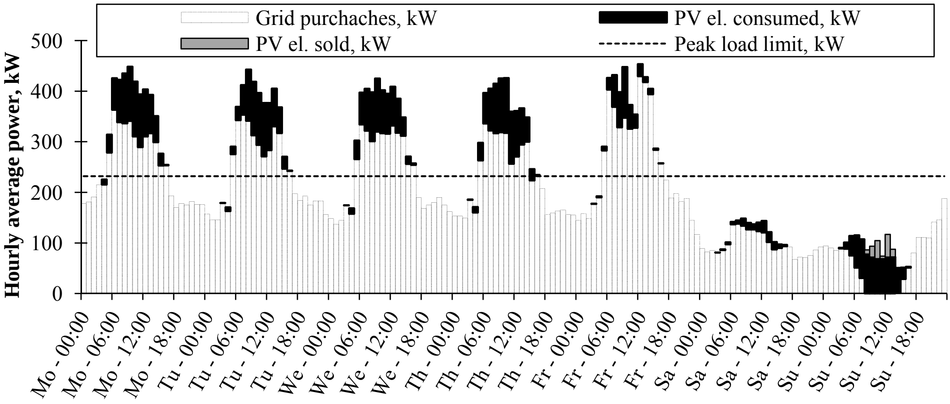


**Figure 5** Electricity consumption from the grid and PV-electricity generation during a spring week (09.04.2012 – 15.04.2012)

The example week from springtime shows a good correlation between PV production and energy consumption during workdays, which is supported by the correlation coefficients presented in Table 2. Almost all of the PV energy produced during workdays can be used during times of peak loads, thereby lowering the consumption from the grid.

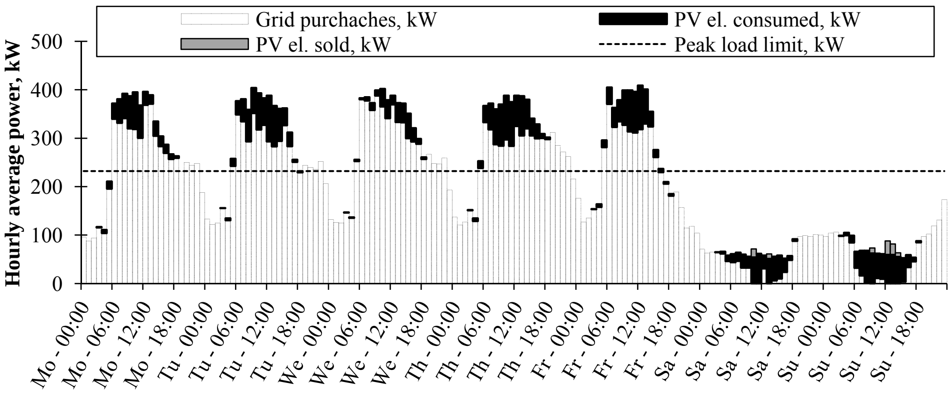


**Figure 6** Electricity consumption from the grid and PV-electricity generation during a summer week (30.07.2012 – 05.08.2012)

The grid sales occur only on the mid-day of holidays, when the consumption is the lowest and PV production is high. During the workdays of the whole year there were no sales of PV energy to the grid.

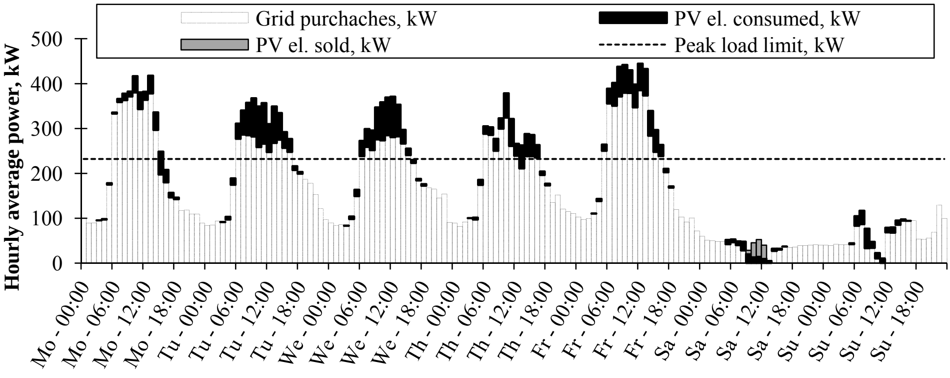


**Figure 7** Electricity consumption from the grid and PV-electricity generation during an autumn week (01.10.2012 – 07.10.2012)

On the basis of the enterprise's electricity consumption in 2012, 94.98% of the calculated PV production could have been consumed on-site. What is more, 57.65% of the PV energy would have supported the consumption during peak loads. In the year 2012 almost the whole month of July was a vacation period. Without the standstill period in mid-summer, the directly consumed renewable energy would exceed 99%. The peak shaving has an effect on the energy management of the enterprise, but the effect on the main energy grid would only be noticeable if this kind of solar energy sources would be used widely. If PV energy generation would be common for peak shaving, then thermal powerplants of the Estonian energy system would have a smoother energy demand to serve.

During the workdays the mean consumption in 2012 was 252.96 kW. With the addition of peak shaving using PV-panels, the mean consumption would have dropped to 239.01kW and the standard deviation of the energy consumption to 114.12 kW. The energy consumption on the hourly basis from the grid would be smoother with the PV application.

**Table 2** Statistical characteristics of the grid electricity purchases of the year 2012

| Parameter | Mean consumption (kW) | Median consumption (kW) | Standard deviation (kW) |
|---|---|---|---|
| During workdays | 252.96 | 230.01 | 112.01 |
| During workdays, with PV | 239.01 | 223.01 | 101.44 |
| During holidays | 70.44 | 65.00 | 37.17 |
| During holidays, with PV | 57.67 | 52.42 | 39.71 |
| Overall year | 190.50 | 162.00 | 127.38 |
| Overall year, with PV | 176.95 | 159.00 | 121.32 |

From Table 2 it can be seen that the effect of the PV production on the energy taken from the grid is moderate, because the nominal output of PV panels that could be installed on the roof is not in the same magnitude as the consumption. The standard deviation of the energy consumption from the main grid is increased on weekends due to the PV energy production. Nevertheless it has to be noted that the PV electricity production depends directly on the solar irradiation, which is stochastic. In the current article the consumption and PV electricity production is evaluated on hourly basis, the fluctuations on the level of minutes and seconds need further research.

The 150 kWp PV-array would have substituted the base load electricity consumption of the year 2012 by 46.48 MWh/y and this would result in 4738 €/y savings (taking into account, that the base energy price of 43.74 €/MWh and average grid fees of 28.05 €/kWh (Jalax, 2013), renewable energy fee of 8.7 €/MWh (Elering, 2013d), excise 4.47€/MWh (Estonian Tax and Customs Board, 2013) and 20% value added tax (Elering, 2013c), resulting in an base load energy price of 101.95 €/kWh. From the peak load electricity consumption 71.83 MWh/y would have been covered by the PV-array. The company pays the NPS market price for the peak load electricity (Jalax, 2013). Considering the hourly NPS electricity prices of 2013 (Nord Pool Spot, 2013) (the price data of November and December is adapted from the year 2012, because the research was made until November 2013) and the grid fees, renewable energy fee, excise and value added tax described above, the company would have saved 7298€/y on the 71.83 MWh/y. The system would have sold 6.28 MWh/y to the grid and considering the hourly market prices (Nord Pool Spot, 2013) and renewable energy subsidy of 53.7 €/MWh (Elering, 2013e) this would result in a 664 € profit.

The the prices for base and peak load energy are almost equal, when considering the year 2013, but it is the first year with free market conditions for this size of electricity consumers in Estonia and it can be estimated, that the peak energy price will differ from the base energy price in the coming years. In this case the PV electricity generated on-site could mitigate price risks. The total energy output of the PV inverter would have been 124.58 MWh/y and all the savings and revenues together would have been 12700 €/y. The investment of a 150kWp PV plant is estimated to be 1.78 €/W (Wesoff, 2012) which results in a total investment of 267 000 €. The simple payback time without considering the rise of electricity prices and any installation subsidies would be 21 years. This is too long to be considered as feasible, but it improves as energy prices are expected to rise and PV energy generation equipment is expected to drop (Wesoff 2012).

## CONCLUSIONS

This paper considers that even industrial buildings in northern regions have a potential to cover a part of their demand with solar resource and thereby mitigate their peak loads and the associated price uncertainties. While there is by far not enough roof area to cover the whole electricity consumption of the sample building (only 7% of the total electricity consumption could be covered when the potential area of the roof is utilized), but there is a strong correlation between the electricity consumption and PV production, so that 95% of the PV-energy produced on site is also consumed directly on site and therein 58% of locally consumed PV-energy is consumed during peak loads. The standard deviation of the enterprise’s energy consumption from the main grid is decreased on workdays, but increased on weekends due to the PV energy production.

## ACKNOWLEDGEMENTS

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42. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

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Expert paper

# AGRIBUSSINESS PROJECTS ASSESSMENT USING COST-BENEFIT ANALYSES

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## SUMMARY

*Cost-benefit analysis is a method used for evaluating a policy which quantifies in monetary terms the value of all the consequences of this policy on all society members. Net social benefit expresses the value of this policy. The main purpose of cost-benefit analysis is to help decision-making and, in the end, to facilitate a more efficient allocation of resources. This paper presents the basic notions that a farmer should know about cost-benefit analyses before starting a business project: various types and methods of cost-benefit analyses. Further, the stages of a proper cost-benefit analysis are described. A pleading for the usage of computer-aided tools, such as expert systems, in order to obtain a more accurate forecast of the profits obtained from an agricultural venture is also sustained.*

***Key words***: *cost-benefit analysis, ex ante cost-benefit analysis, ex post cost benefit analysis, in medias res cost-benefit analysis, investment project, internal rate of return, sustainability analysis, expert system*

## INTRODUCTION

Cost benefit analysis (CBA) is a technique used to determine the monetary social costs and benefits of a given investment project. From this point of view, the execution of a CBA is an action that should be performed by any manager before starting a new project. This is done by evaluating the potential costs and revenues that will occur during the completion of the project. Hence, cost-benefit analysis is a decision-making process whose result is to determine whether a certain project is financially feasible, or not.

According to the Business Dictionary, CBA is a "process of quantifying costs and benefits of a decision, program, or project (over a certain period), and those of its alternatives (within the same period), in order to have a single scale of comparison for unbiased evaluation." CBA estimates the net present value (NPV) rather than the present value (PV) of the decision by discounting the investment and returns. It should be underlined that CBA is not limited only to monetary considerations, but often includes environmental and social costs and benefits that can be reasonably quantified.

After the moment of time when a CBA is performed, one can distinguish between 3 types of CBA.

Ex ante CBA is performed before the project starts. It is used to assist the process of decision making and evaluate the potential costs and benefits. A good ex ante CBA requires a good knowledge of the economic environment or, at least, powerful tools to forecast the feasibility of a project for given scenarios.

Ex post CBA refers to a CBA performed after the project is completed. At this stage, all the costs are known, so that this type of analysis is used to enhance the actual knowledge about certain given situations. Thus, ex post CBA contributes to a better knowledge base when assessing new projects.

In medias res CBA is a CBA performed during the period in which a project is implemented and combines the utility of both the ex ante and ex post CBA.

But what are projects? According to the EU Guide to CBA, elaborated in 2008, a project is defined as "an operation comprising a series of works, activities or services intended to accomplish an indivisible task of a precise economic or technical nature; one which has well defined goals." Thus, the process of starting a new business based on a business plan represents, from this point of view, a project.

Other methods of project evaluation, in addition to the CBA, are:

- cost-effectiveness analysis (CEA), comparing alternative projects with a unique common effect which may differ in magnitude.
- multi-criteria analysis (MCA) selecting alternatives relative to a set of different criteria which cannot be aggregated through shadow prices and welfare weights.
- economic impact analysis – which should be regarded not as an alternative, but as a complement to CBA

The economic environment specific to agriculture requires continuous balanced cost-benefit solutions of the 3 types discussed above in order to achieve long-term sustainability. But a classical CBA may not be correctly performed, because, in this case, a human expertise is not always unbiased and or even available. Thus, in order to evaluate the best applicable solutions, modern techniques, such as Artificial Intelligence methods, become more and more used in this area.

## METHODS

Any cost-benefit analysis should take into account several key phases, which are summarized in Figure 1. Also, these steps will be briefly presented below.

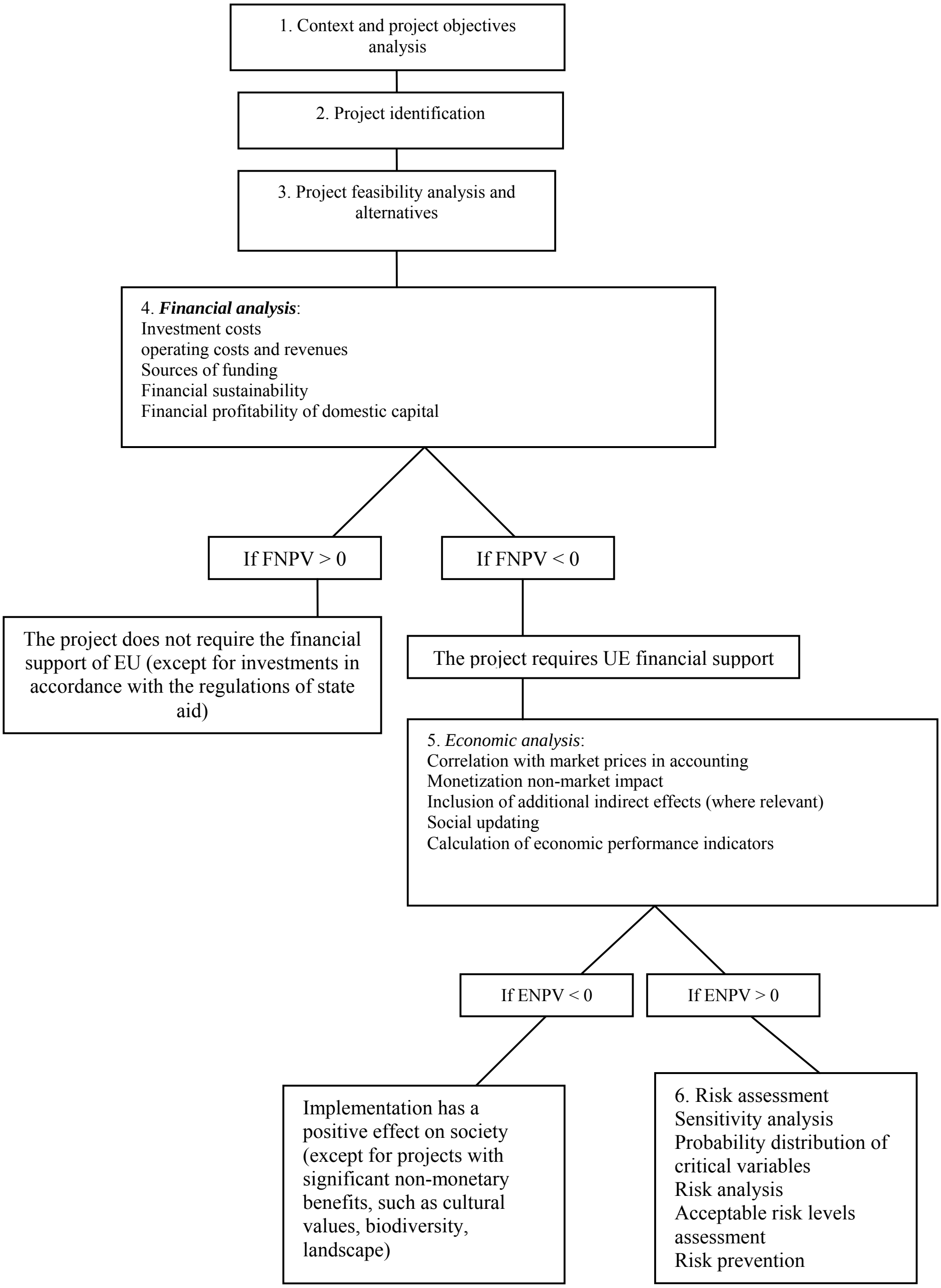


**Figure 1** Structure of project appraisal (source: EU Guide to cost benefit analysis of investment projects, 2008)

*Step 1. Context analysis and project objectives*

The first step to be taken when establishing a new project should be the understanding of the socio-economic and institutional context of the project. The next essential thing is to enunciate as clearly as possible the project's objectives on short-, medium- and long-term. At this phase, the entrepreneur should clearly identify whether his project of investment has any social value or not. Also, social net benefits should be determined, by comparing the social costs to the social benefits. Thus,

$$\text{Social net benefits} = \text{Social benefits} - \text{Social costs}$$

A project is considered to be feasible, if the social costs are exceeded by the social benefits. Last but not least, an investment project should be related and consistent to larger frameworks (regional, national, international).

*Step 2. Project identification*

This second phase of CBA requires a sound knowledge on the activities, services and specific methodologies which are needed during the implementation of the project. After having correctly identified the framework of a project, this next step requires to define the boundaries of the analysis. The impact of the new project should be counted in two ways:

- as direct impact (on workers, investors, suppliers)
- as indirect impact (on third parties).

In order to avoid the double counting of the project benefits, one should take an increased attention when establishing the impact of the project.

Another issue in the phase of impact analysis, which is very important, is to determine whose costs and benefits really count. This phase should be performed properly, in order to achieve a realistic image of the project. Sometimes, the problem of determining the real costs and benefits involved in a project requires acknowledging the presence of some social stakeholders, depending on the geographical level adopted in the appraisal.

*Step 3. Feasibility and option analysis*

The next step to be performed, once identified the socio-economic context and the social demand for the project's output, is to identify various actions and measures leading to the achievement of the objectives.

At this phase, there are identified both the potential constraints and related solutions with respect to various aspects (technical, economic, regulatory, managerial). This is done by performing the so-called feasibility analysis. The identified constrains are classified as follows:

- binding constraints, such as lack of human capital and geographical features, which could be an impediment for the project’s evolution
- soft constraints, such as specific price regulations, which could be removed by suitable agreements and reforms.

As a result, a project is declared feasible if it respects the technical, legal, financial and other constraints relevant to the nation, region or specific area. Since feasibility is a mandatory requirement of any project, it should be checked carefully. In order to cover most of the practical situations that could arise, a good feasibility analysis should consider at least three scenarios: “do-nothing”, “do-minimum” and “do-something”. Often, the “do-nothing” scenario leads to important and obvious damages to the investment, and thus it can be neglected. A simplified CBA should be performed for each feasible “do-minimum” and some alternatives for the “do-something” scenarios. This leads to a classification of the available options by the expected benefit.

*Step 4. Financial analysis*

The main purpose of the financial analysis is to compute net return indicators of a given investment project as a function of cash flow forecasts. Among the net return indicators, there are two particularly important ones: the Financial Net Present Value (FNPV) and the Financial Internal Rate of Return (FRR).

The following data should be processed in order to obtain a good financial analysis:

- Total investment costs (land, buildings, equipment, extraordinary maintenance, licenses, patents, pre-production expenses, changes in working capital, residual value)
- Total operating costs (raw materials, labor, electric power, maintenance, administrative costs, outflows, interest, loans reimbursement, taxes)
- Total operating revenues (outputs)
- Sources of financing (community assistance, national public contribution, national private capital, loans, other resources)

*Step 5. Economic analysis*

The project’s contribution to the economic welfare of the region is estimated by the economic analysis estimates of the project. This should be performed, in contradistinction to the financial analysis, on behalf of the whole society. A good economic analysis uses the so-called “accounting shadow prices” (prices based on the social opportunity cost), as a key concept, instead of observed distorted prices.

*Step 6. Risk assessment*

The risks involved during the project duration should be taken into account in the process of elaboration of an investment project. The project’s performance is measured in terms of FRR or NPV. Thus, risk assessment consists thus in the evaluation of the probability that the project will achieve a satisfactory performance.

Sensitivity analysis is a tool frequently used in the risk assessment. Basically, this means to determine the ‘critical’ variables or parameters of the model. A specific form of sensitivity analysis is scenario analysis. Unlike sensitivity analysis, which evaluates the influence of each variable on the financial and economical performance of a certain investment, the scenario analysis evaluates the combined impact of sets of values assumed by the critical variables. Further, the probability distributions of the critical variables are used in the process of computing the probability distribution of the FRR or NPV of the project. During the risk assessment analysis, a typical source of mistakes in project appraisal is optimism bias. This optimism bias has its cause in the human tendency to be over-optimistic about the estimation of the key project parameters: investment costs, works duration, operating costs and benefits.

In order to minimize the level of optimism bias, one can use classical tools or modern tools. Among the classical tools are increased cost estimates and decreased, or delayed, benefit estimates. Modern tools include specific software, such as Artificial Intelligence methods.

## DISCUSSION

Cost-benefit analysis is an important tool in starting new financial investments in any business. However, in the specific area of agribusiness, there are some specifics that should be taken into account, such as: natural disasters, climatic and geographical conditions, long-term impact on the environment, and so on.

A serious challenge is represented by the natural disasters. Their impact on agricultural projects increases as the economic vulnerability of the region or country increases. European Union is subjected mostly to floods and droughts. However, other natural disasters like fires, prolonged frost and ecological accidents should also be considered. Measures for reducing the disaster risk consist both on policy planning (such as risk insurances) and physical components (such as infrastructure to prevent natural hazards).

All the various risks which could affect an agribusiness project can not be properly evaluated by human mind, due either to the optimism bias or, more likely, to the volume of information that has to be processed, which is very large. These are the main reasons to use Artificial Intelligence tools in evaluating agribusiness projects.

In this point of view, expert systems represent the most affordable solution to use. Expert systems, also known as knowledge-based expert systems, are specific Artificial Intelligence softwares that emulate the knowledge of real experts. The decision of an expert system is comparable to the most competent decision of a real expert (Collopy et al., 2001).

An expert system contains three parts: the inference engine, the knowledge base and the dialogue interface. The inference engine produces reasoning based on logical rules and the knowledge base supplied by the user. The knowledge base is usually a collection of rules of the form “IF condition THEN result.” The dialogue interface is used either to input the rules that form the knowledge base, or to interrogate the output of the inference engine, based on the rules available in the knowledge base.

The advantage of expert systems is that any data amount could be processed. The reasoning is based on previous experience, which was quantified and fed into the computer, rather than on some subjective, optimistic basis. Moreover, a graphical user interface could be constructed, such that the typical end-user (which, supposedly, has not expertise in the domain of Computer Sciences) doesn't need to concentrate on too detailed technical problems, but rather on the practical importance of the forecast. Such expert systems could be implemented using Corvid Exsys.

## CONCLUSIONS

More complex than usual cost-benefit analysis, cost-benefit analysis of an agricultural investment project represents a challenge that must be taken in agribusiness. The complexity of the cost-benefit analysis increases as the number of environmental issues that should be considered increase. Moreover, there are natural disasters that are hard to envision and have effects that are very hard to forecast. The human tendency of over-optimism produces also errors in the human rationalism. On the other hand, computer analysis, performed with expert systems, provide objective evaluation of the costs, risks, benefits and the rate of attraction of the project, for any scenario.

When starting a new agribusiness investment project, the potential entrepreneur is bound to perform a cost-benefit analysis in order to properly evaluate the future outputs of his investment. But, in order to avoid the risk of bankruptcy, the analysis should be performed using modern, computer-aided tools, rather than classical tools in evaluating the project's feasibility.

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42. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

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# OGLJIČNI ODTIS KONVENCIONALNE IN EKOLOŠKE POLJEDELSKE PRIDELAVE

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## IZVLEČEK

*Opravljena je analiza ogljičnega odtisa v primeru, konvencionalne, integrirane in ekološke pridelave poljščin za tri velikosti kmetij. Za vsak sistem pridelave je upoštevan konvencionalni način obdelave tal ter direktna setev. Za analizo ogljičnega odtisa so uporabljene emisije $CO_2$ iz fosilnega goriva (direktna energija), ki se porabi v procesu pridelave: koruze (za silažo in zrnje), pšenice, oljne ogrščice, in sončnice. Poleg emisij iz fosilnega goriva uporabljenega v pridelavi 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 gnojila in organskega gnojila, pri ekološki pridelavi pa samo organskega gnojila. Seštevek emisij $CO_2$, ki nastanejo zaradi uporabe fosilnega goriva in ekvivalentnih emisij $CO_2$ iz gnojil uporabljenih v procesu pridelave, da končno emisijo pridelave. Ugotovili smo, da so emisije $CO_2$/t pridelka pri konvencionalni in integrirani pridelavi približno enake, pri ekološki pridelavi pa so višje v primerjavi s emisijami v konvencionalni in integrirani pridelavi. V primerjavi konvencionalne in ekološke pridelave so emisije $CO_2$/t pridelka v naslednjih razmerjih: koruza za zrnje 1:1,34, koruza za silažo 1:1,52, pšenica 1:1,53, oljna ogrščica 1:1,47 in sončnica 1:1,2 (višja številka za ekološko pridelavo).*

***Ključne besede:** ogljični odtis poljedelske pridelave, direktna poraba energije, emisije iz gnojil, emisije $CO_2$ v konvencionalni, integrirani in ekološki pridelavi*

## UVOD

Kmetijstvo samo prispeva znaten delež emisij toplogrednih plinov, zato bo v prihodnosti soočeno tudi s precejšnjimi zahtevami za zmanjševanje emisij toplogrednih plinov. Vpliv kmetijstva na klimatske spremembe je dvojni, kot ponor in obenem vir ogljikovega dioksida. Ogljikov dioksid se veže iz atmosfere in pretvarja v ogljik vezan v rastlinah, ki se pri razkroju ponovno vrača v atmosfero.Rastline so sposobne vezati ogljikov dioksid iz atmosfere in ga uskladiščiti kot ogljik v strukturi rastline in v samih tleh. Za kmetijstvo bo največji izziv ustvariti pravo ravnotežje med zagotavljanjem zadostnih količin hrane in drugih surovin in emisijami toplogrednih plinov, ki nastajajo v življenskem ciklu kmetijskih produktov (od pridelave do predelave in konca produkta). Najpomembnejši toplogredni plini so ogljikov dioksid, metan in dušikovi oksidi. Ogljikov dioksid se v kmetijstvu sprošča zaradi rabe fosilnih goriv za pogon kmetijskih strojev in druge namene (proizvodnji mineralnih gnojil, različnih procesih, predelavi kmetijskih pridelkov, skladiščenju, hlajenju itn.), del pa zaradi izgub organske mase pri neustrezni rabi in obdelavi tal. Sodoben način pridelave hrane povzroča velike emisije toplogrednih plinov ter odpadnih oziroma stranskih produktov. Gospodarna in ekološko naravnana kmetijska pridelava, ki sedaj prihaja v ospredje pa postavlja še dodatne zahteve: zmanjšati stroške dela in vnosa energije (zmanjševanje emisij toplogrednih plinov, ki nastanejo, kot posledica delovanja kmetijske mehanizacije, uporabe mineralnih gnojil in pesticidov itn.) ter skrčiti intenzivno obdelavo tal le na nujne ukrepe.

## PREGLED LITERATURE

Uporaba energije je definirana, kot fosilna energija merjena v J. 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 kmetijsko proizvodnjo. Ko se omenjeni vnos energije lahko direktno pretvori v energetske enote (porabljeno mineralno dizelsko gorivo, maziva, energija UNP 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 in fito farmacevtska sredstva). Celotna energija za pridelavo kmetijskega pridelka se (Dalgaard in sodelavci 2001) lahko predstavi s pomočjo enačbe (1).

$$EU_{pridelka} = EU_{direktna} + EU_{indirektna}$$

$$EU_{pridelka} = (EU_{dizel} + EU_{ostala}) + EU_{indirektna} \tag{1}$$

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).

Poraba energije se pri konvencionalni obdelavi tal giblje od 1850 MJ/ha do 2550 MJ/ha. Pri minimalni obdelavi tal brez oranja (odpade uporaba lemežnega pluga) in uporabi pasivnih ali aktivnih (gnanih prek priključne gredi traktorja) traktorskih priključnih strojev za osnovno in dopolnilno obdelavo tal in setev (obdelavo tal in setev se opravi v enem prehodu, ker sta stroj za obdelavo tal in sejalnica združena v en kombinirani stroj) se poraba energije giblje v razponu od 620 do 1200 MJ/ha. Pri »zero tillage« sistemu (uporaba sejalnice za direktno setev v strnišče) pa je poraba energije minimalna in znaša od 250 pa do 525 MJ/ha (Hernanz in Ortiz Canavate 1999). Energija, ki se porabi za pridelavo 1 kg pšenice je višja pri uporabi konvencionalnega sistema obdelave tal in setve in znaša 11,78 MJ/kg pridelka v primerjavi z direktno setvijo, kjer znaša 8,81 MJ/kgpridelka (Tabatabaeefar in sodelavci 2009).

Konvencionalni sistem obdelave tal je zahteven s stališča porabe energije in delovnega časa. (Kovačev in sodelavci 2013) ugotavljajo, da je oranje z lemežnim plugom v osnovni obdelavi tal, najpomembnejši porabnik energije z 64 % od celotne porabe energije za obdelavo tal (osnovno in dopolnilno) in setev v poljedelstvu.

## MATERIAL IN METODA DELA

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 in živilsko predelovalni industriji 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 pridelave oziroma so nezanesljivi. Celotna energija, ki se porabi za pridelavo nekega kmetijskega pridelka na površini enega hektarja pridelovalne površine, je ugotovljena z dodajanjem posameznih energetskih porab vsakega posameznega energetskega vnosa. Pri energetski analizi so razčlenjeni vnosi energije (direktna energija), ki je kompletno porabljena v obdobju pridelave različnih poljedelskih pridelkov. 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 tem prispevku. Za ugotavljanje porabe energije v pridelavi smo izbrali deset vzorčnih kmetij, ki so usmerjene v živinorejsko, poljedelsko in mešano pridelavo. Živinorejske kmetije in kmetije z mešano pridelavo proizvajjao tudi krmo za lastne potrebe (npr. silažna koruza, koruza za zrnje, olja ogrščica itn.). Kmetije so bile razporejene po različnih delih Slovenije tako, da so bili zajeti različni pedoklimatski faktorji in kompleksnost pridelave.

Poraba energije je ugotavljana pri opravljanju delovnih operacij s traktorskimi priključnimi stroji (agregat traktor + stroj), ki so namenjeni za osnovno in dopolnilno obdelavo tal, setev, gnojenje, nego, varstvo rastlin itn. Merjena je porabljena količina mineralnega dizelskega goriva, ki se porabi pri delu traktorjev z različnimi priključnimi stroji oziroma delu samovoznih strojev (npr. kombajni ali silokombajni za koruzo). Poleg tega je zajeta poraba energije za žetev in interni transport pridelkov na sami kmetiji (transport s traktorji). Poraba energije pri obdelavi tal je ugotovljena pri konvencionalni obdleavi tal z lemežnim plugom.Kot alternativa konvencionalni obdelavi je predvidena direktna setev (brez obdelave tal, angl. no tillage ali zero tillage).

Izračuni so narejeni na osnovi povprečnih porab goriva za osnovno in dopolnilno obdelavo tal, setev, gnojenje, varstvo rastlin, žetev in transport. V primeru osnovne obdelave tal je predvidena uporaba večbrazdnega obračalnega pluga. Za dopolnilno obdelavo tal je v enem primeru predvidena uporaba krožnih bran ali predsetvenikov, v drugem pa rotacijskih strojev (vrtavkasta brana ali prekopalnik - freza). Pri setvi je predvidena uporaba konvencionalnih sejalnic za presledno setev (koruza) in strnjeno setev (pšenica, oljna ogrščica in sončnica). V primeru direktne setve pa so predvidene posebne izvedbe sejalnic, ki omogočajo setev v strnišče. Za gnojenje je predvidena uporaba centrifugalnih trosilnikov mineralnih gnojil v granulah oziroma trosilnikov hlevskega gnoja (integrirana in ekološka pridelava). Spravilo silažne koruze se opravlja s pomočjo silažnih samohodnih ali traktorskih izvedb silokombajnov, pri spravilu koruze v zrnju pa se uporabljajo samohodne izvedbe kombajnov. Za transport pri pridelavi je predvidena uporaba traktorjev s prikolicami, za razliko od transporta po predelavi, kjer se uporablja vozila različne nosilnosti. 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 uporaba organskega gnoja (hlevski gnoj ali gnojevka). 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 zaščitna sredstva, ki so dovoljena v ekološki pridelavi, zamenjavo za herbicide pa predstavlja uporaba mehanskih metod za zatiranje plevelov (npr. traktorski priključni stroj – česalo, ki je namenjeno zatiranju plevelov). Količine gnojil so preračunane na količino pridelka za posamezno pridelavo. Za količine pridelkov so uporabljeni podatki KGZS in SURS (povprečje zadnjih deset let). Pri ekološki pridelavi pa so predvideni pridelki, ki so nižji v primerjavi s konvencionalno in integrirano pridelavo.

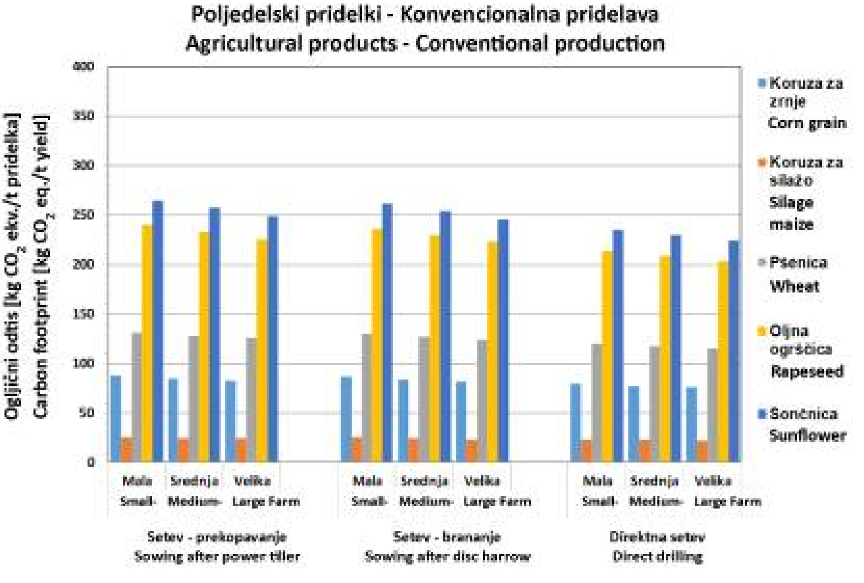
Pri konvencionalni, integrirani in ekološki pridelavi se uporabljajo večinoma enaki delovni postopki. Razlika je da se pri konvencionalni pridelavi uporablja gnojenje z mineralnimi gnojili. V primeru integrirane pridelave je predvidena uporaba mineralnega in hlevskega gnoja ter gnojevke. Za primer ekološke pridelave pa je predvideno, da se uporablja hlevski gnoj. Poraba goriva je pri ekološki pridelavi nekoliko višja, ker je predvidena uporaba strojev za raztros gnoja in aplikacijo gnojevke. Oba omenjena stroja sta večja porabnika energije v primerjavi s trosilnikom mineralnega gnojila.

## REZULTATI RAZISKAV

Emisije $CO_2$ nastanejo zaradi uporabe dizelskega goriva pri vseh mehaniziranih opravilih v pridelavi: osnovna in dopolnilna obdelava tal, setev, gnojenje varstvo rastlin, žetev in 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 goriva in gnojil (mineralnih in organskih) nam da končno emisijo $CO_2$.

V raziskavi so določeni ogljični odtisi za poljedelske pridelke po velikosti kmetije (mala, srednja, velika) in vrsti pridelave (konvencionalna, integrirana, ekološka) za dva načina dopolnilne obdelave tal (prekopavanje ali brananje) in za direktno setev. Integrirana pridelava je namenjena za kmetije, ki se usmerjajo s konvencionalne pridelave postopoma na ekološko pridelavo. Za malo kmetijo je določena velikost obdelovalnih površin do 10 ha, srednjo od 10 do 50 ha in veliko nad 50 ha.

Ogljični odtisi so določeni iz povprečne porabe goriva, ki je izmerjena na več kmetijah ter predvidenih količin gnojila (organskega in anorganskega), ki so predvideni v izračunani za naslednje poljedelske pridelke: koruza za zrnje in za silažo, pšenica, oljna ogrščica in sončnica.




**Slika 1** Ogljični odtisi poljedelskih pridelkov za konvencionalno pridelavo, za koruzo (silažno in v zrnju), pšenico, oljno ogrščico in sončnico, vzete so tri velikosti kmetij (mala, srednja, velika), konvencionalna obdelava tal in direktna setev
**Figure 1** Carbon footprint of agricultural crops for conventional farming of maize (silage and grain), wheat, rapeseed and sunflower, for three farm size (small, medium, large), conventional tillage and direct seeding

Glede emisij $CO_2$ ekvivalentnih na tono pridelka smo ugotovili da so emisije $CO_2$ najnižje pri silažni koruzi, sledijo pa koruza za zrnje, pšenica, oljna ogrščica in sončnica. Analiza emisij toplogrednih plinov pri pridelavi poljščin za primer male kmetije je pokazala, da so emisije v konvencionalni pridelavi poljščin najnižje pri koruzi za silažo in se gibljejo od 25,1 kg $CO_2$/t pridelka pri konvencionalni setvi do 23,6 kg $CO_2$/t pridelka pri direktni setvi. Precej višje so že pri koruzi za zrnje in se gibljejo od 87,3 kg $CO_2$/t pridelka pri konvencionalni setvi do 78,8 kg $CO_2$/t pridelka pri direktni setvi. Velika razlika pri emisijah toplogrednih plinov v pridelavi koruze za silažo in koruze za zrnje je zaradi količine pridelka, ki je precej višji pri koruzi za silažo v primerjavi s koruzo za zrnje, poraba energije za mehanizirana opravila pa je približno enaka pri koruzi za zrnje in koruzi za silažo.

**Tabela 1** Ogljični odtisi poljedelskih pridelkov določeni za tri velikosti kmetij (mala, srednja, velika) in dva načina setve (konvencionalna pridelava)
**Table 1** Carbon footprintof agriculturalcropsforthreefarm size(small, medium, large) and twosowing method(conventionalproduction)

| | Setev v tla dopolnilno obdelana s prekopalnikom<br>Sowing after power tiller | | | Setev v tla dopolnilno obdelana z brano<br>Sowing after disc harrow | | | Direktna setev<br>Direct drilling | | |
|---|---|---|---|---|---|---|---|---|---|
| | [kg $CO_{2,ekv.}$/ton pridelka]<br>[kg $CO_{2,eq.}$/tof yield] | | | [kg $CO_{2,ekv.}$/ton pridelka]<br>[kg $CO_{2,eq.}$/tof yield] | | | [kg $CO_{2,ekv.}$/ton pridelka]<br>[kg $CO_{2,eq.}$/tof yield] | | |
| | Mala<br>Small | Srednja<br>Medium | Velika<br>Large | Mala<br>Small | Srednja<br>Medium | Velika<br>Large | Mala<br>Small | Srednja<br>Medium | Velika<br>Large |
| Koruza za zrnje<br>Corn grain | 87,3 | 85,1 | 82,9 | 86,3 | 84,1 | 82,0 | 78,8 | 77,3 | 75,8 |
| Koruza za silažo<br>Sillage maize | 25,1 | 24,5 | 23,8 | 24,9 | 24,3 | 23,6 | 23,6 | 23,1 | 22,5 |
| Pšenica<br>Wheat | 131,4 | 128,4 | 125,5 | 129,9 | 127,0 | 124,2 | 119,3 | 117,3 | 115,4 |
| Oljna ogrščica<br>Rapeseed | 239,9 | 232,8 | 225,8 | 236,6 | 229,8 | 223,0 | 213,3 | 208,5 | 203,7 |
| Sončnica<br>Sunflower | 264,7 | 256,9 | 249,2 | 261,0 | 253,6 | 246,1 | 235,4 | 230,1 | 224,7 |

Pri pšenici se emisije toplogrednih plinov v primeru male kmetije gibljejo od 131,4 kg $CO_2$/t pridelka pri konvencionalni setvi do 119,3 kg $CO_2$/t pridelka pri direktni setvi. Najvišje emisije so pri oljnicah in znašajo od 239,9 kg $CO_2$/t pridelka pri konvencionalni setvi do 223 kg $CO_2$/t pridelka pri direktni setvi za oljno ogrščico, ter od 264,7 kg $CO_2$/t pridelka pri konvencionalni setvi do 235,4 kg $CO_2$/t pridelka pri direktni setvi za sončnico. Obe omenjeni oljnici imata precej nižje hektarske pridelke v primerjavi s koruzo in pšenico, poraba energije za mehanizirana delovna opravila pa je pri obeh enaka.

Pri integrirani pridelavi so emisije toplogrednih plinov še nekoliko nižje v primerjavi z emisijami pri konvencionalni pridelavi. Emisije so ponovno najnižje pri koruzi za silažo in najvišje pri oljnicah (oljna ogrščica in sončnica).

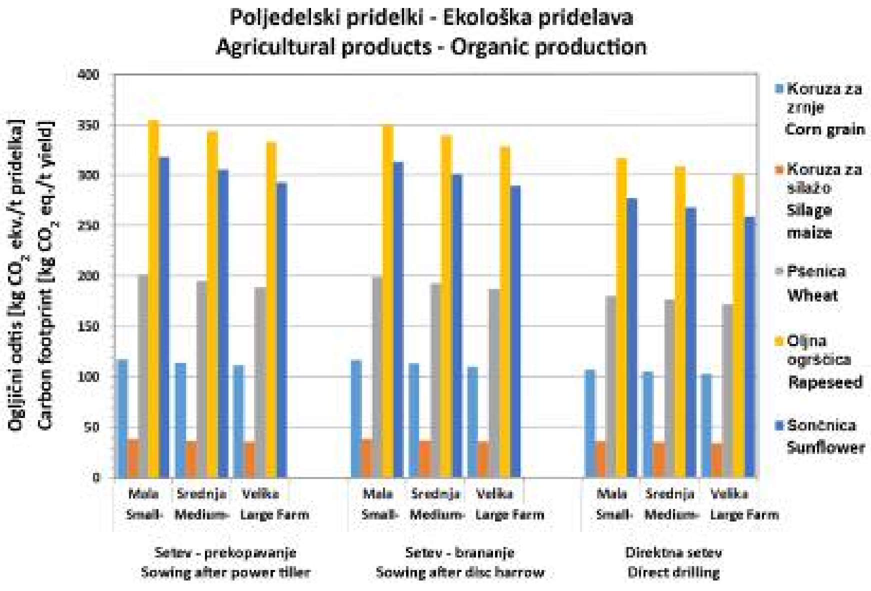
**Tabela 2** Ogljični odtisi poljedelskih pridelkov določeni za tri velikosti kmetij (mala, srednja, velika) in dva načina setve (integrirana pridelava)
**Table 2** Carbon footprintof agricultural crops for three farm size (small, medium, large) and two sowing method (integrated production)

| | Setev v tla dopolnilno obdelana s prekopalnikom Sowing after power tiller | | | Setev v tla dopolnilno obdelana z brano Sowing after disc harrow | | | Direktna setev Direct drilling | | |
|---|---|---|---|---|---|---|---|---|---|
| | [kg $CO_{2,ekv.}$/ton pridelka] [kg $CO_{2,eq.}$/tof yield] | | | [kg $CO_{2,ekv.}$/ton pridelka] [kg $CO_{2,eq.}$/tof yield] | | | [kg $CO_{2,ekv.}$/ton pridelka] [kg $CO_{2,eq.}$/tof yield] | | |
| | Mala Small | Srednja Medium | Velika Large | Mala Small | Srednja Medium | Velika Large | Mala Small | Srednja Medium | Velika Large |
| Koruza za zrnje Corn grain | 98,64 | 95,80 | 93,04 | 97,58 | 94,82 | 92,16 | 90,14 | 88,01 | 85,96 |
| Koruza za silažo Sillage maize | 27,655 | 26,859 | 26,080 | 27,462 | 26,682 | 25,919 | 26,110 | 25,443 | 24,792 |
| Pšenica Wheat | 148,70 | 144,95 | 141,29 | 147,18 | 143,56 | 140,03 | 136,56 | 133,82 | 131,17 |
| Oljna ogrščica Rapeseed | 262,59 | 254,58 | 246,66 | 259,27 | 251,54 | 243,90 | 236,03 | 230,23 | 224,53 |
| Sončnica Sunflower | 262,84 | 253,49 | 244,25 | 259,17 | 250,13 | 241,19 | 233,53 | 226,62 | 219,82 |

Tudi pri ekološki pridelavi so najnižje emisije pri koruzi za silažo in se v primeru male kmetije gibljejo od 38,35 kg $CO_2$/t pridelka pri konvencionalni setvi do 35,92 kg $CO_2$/t pridelka pri direktni setvi. Ponovno so precej višje pri koruzi za zrnje in se gibljejo od 117,7 kg $CO_2$/t pridelka pri konvencionalni setvi do 107,06 kg $CO_2$/t pridelka pri direktni setvi.Pri ekološki pridelavi pšenice se emisije toplogrednih plinov gibljejo od 201,17 kg $CO_2$/t pridelka pri konvencionalni setvi do 179,92 kg $CO_2$/t pridelka pri direktni setvi. Najvišje emisije so ponovno pri oljnicah in znašajo za oljno ogrščico od 354,68 kg $CO_2$/t pridelka pri konvencionalni setvi do 316,05 kg $CO_2$/t pridelka za direktno setev ter od 318,41 kg $CO_2$/t pridelka pri konvencionalni setvi do 275,92 kg $CO_2$/t pridelka za direktno setev za sončnico.

**Tabela 3** Ogljični odtisi poljedelskih pridelkov določeni za tri velikosti kmetij (mala, srednja, velika) in dva načina setve (ekološka pridelava)
**Table 3** Carbon footprintof agriculturalcropsforthreefarm size(small, medium, large) and twosowing method(organicproduction)

| | Setev v tla dopolnilno obdelana s prekopalnikom<br>Sowing after power tiller | | | Setev v tla dopolnilno obdelana z brano<br>Sowing after disc harrow | | | Direktna setev<br>Direct drilling | | |
|---|---|---|---|---|---|---|---|---|---|
| | [kg $CO_{2,ekv.}$/ton pridelka]<br>[kg $CO_{2,eq.}$/tof yield] | | | [kg $CO_{2,ekv.}$/ton pridelka]<br>[kg $CO_{2,eq.}$/tof yield] | | | [kg $CO_{2,ekv.}$/ton pridelka]<br>[kg $CO_{2,eq.}$/tof yield] | | |
| | Mala<br>Small | Srednja<br>Medium | Velika<br>Large | Mala<br>Small | Srednja<br>Medium | Velika<br>Large | Mala<br>Small | Srednja<br>Medium | Velika<br>Large |
| Koruza za zrnje<br>Corn grain | 117,69 | 114,24 | 110,88 | 116,36 | 113,03 | 109,77 | 107,06 | 104,51 | 102,02 |
| Koruza za silažo<br>Sillage maize | 38,358 | 37,010 | 35,679 | 38,054 | 36,732 | 35,426 | 35,929 | 34,784 | 33,655 |
| Pšenica<br>Wheat | 201,17 | 195,06 | 189,02 | 198,51 | 192,62 | 186,81 | 179,92 | 175,58 | 171,31 |
| Oljna ogrščica<br>Rapeseed | 354,689 | 343,578 | 332,600 | 349,860 | 339,151 | 328,576 | 316,056 | 308,164 | 300,406 |
| Sončnica<br>Sunflower | 318,41 | 305,67 | 293,08 | 313,10 | 300,80 | 288,66 | 275,92 | 266,72 | 257,67 |




**Slika 2** Ogljični odtisi poljedelskih pridelkov za ekološko pridelavo, za koruzo (silažno in v zrnju), pšenico, oljno ogrščico in sončnico, vzete so tri velikosti kmetij, konvencionalna obdelava in direktna setev
**Figure 2** Carbon footprint of agricultural crops for organic farming of maize (silage and grain), wheat, rapeseed and sunflower, for three farm size (small, medium, large), conventional tillage and direct seeding

## ZAKLJUČEK

Ugotovili smo, da so emisije CO2/t pridelka pri ekološki pridelavi višje v primerjavi s emisijami v konvencionalni in integrirani pridelavi. V primerjavi konvencionalne in ekološke pridelave so razlike v emisijah CO2/t pridelka: za koruzo za zrnje v razmerju 1:1,34, za koruzo za silažo v razmerju 1:1,52, pri pšenici 1:1,53, oljni ogrščici 1:1,47 in sončnici 1:1,2 (pri vseh vrednostih je višja številka za ekološko pridelavo). Vzrok za višje emisije CO2 t pridelka je v tem da so pridelki v ekološki pridelavi nižji, preračun CO2/t pridelka da posledično višje emisije. V ekološki pridelavi se uporabljajo organska gnojila (gnoj in gnojevka), ki imajo nižje emisije toplogrednih plinov v primerjavi z anorganskimi gnojili (mineralna gnojila) v konvencionalni pridelavi. Poleg tega se v ekološki pridelavi lahko tudi uporablja kombinacija organskih gnojil v kombinaciji s počasi topnimi mineralnimi gnojili. Pri porabi mineralnega dizelskega goriva pa so emisije pri ekološki pridelavi minimalno višje, ker se za gnojenje z organskimi gnojili uporabljajo traktorski priključni stroji (trosilniki hlevskega gnoja ali cisterne za razvoz in aplikacijo gnojevke), ki porabijo nekoliko več energije v primerjavi s traktorskimi priključnimi stroji, ki so namenjeni za raztros mineralnega gnojila (trosilniki mineralnih gnojil v granulah). Vse emisije CO2/t pridelka za poljščine se razlikujejo tudi glede velikosti kmetij in so tako višje za kmetije, ki imajo manjše površine pod poljščinami in obratno nižje za večje površine pod poljščinami. Zaradi manjše porabe energije (manjša količina mineralnega dizelskega goriva ali biogoriva se porabi za pogon traktorskih agregatov) pri direktni setvi in manjšega števila prehodov traktorskih agregatov je omogočena večja produktivnost (manjša poraba časa za izvedbo delovne operacije) in posledično boljša ekonomičnost celotne pridelave poljščin, poleg tega je manjša obremenitev okolja s toplogrednimi plini, mehanske poškodbe tal pa so minimalne.

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# CARBON FOOTPRINT OF CONVETIONAL AND ORGANIC CROP PRODUCTION

## ABSTRACT


*An analysis of the carbon footprint of conventional, integrated and organic crop production, and three sizes of farms was made. Conventional tillage and direct seeding were used in mentioned production systems. For the analysis of the carbon footprint, $CO_2$ emissions from fossil fuel (direct energy) consumed in the process of production of corn (for silage and grain), wheat, rapeseed, and sunflower were used. In addition to emissions from fossil fuels used in the production of mentioned crops, greenhouse gas emissions resulting from the use of organic and mineral fertilizers in the production and converted to $CO_2$ equivalents were also used.*

*In the case of conventional production mineral fertilizers were used, in integrated production combination of mineral fertilizers and organic fertilizers and in organic production only organic fertilizer was used. The sum of emissions arising from fossil fuel use and emissions from fertilizers used in the cultivation process, make final emission from crop production. It was estimated that the emissions of $CO_2$/t of yields in conventional and integrated production are about the same. In organic production emissions of $CO_2$/t of yields are higher in comparison with emissions $CO_2$/t of yields in conventional and integrated farming. $CO_2$ emissions in conventional and organic production ($CO_2$/t of yield) arein the following proportions: cornfor grain 1:1,34, corn for silage1:1,52, wheat 1:1,53, rapeseed 1:1,47and sunflower1:1.2 (the higher is the number of organic production).*

***Key words:*** *carbon footprint of crop production, direct energy consumption, emissions of fuel, emissions from fertilizers, $CO_2$ emissions in conventional, integrated and organic crop production*

42. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

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Expert paper

# PRVE IZKUŠNJE MEHANIZIRANEGA ZBIRANJA KORUZNIH KLASINCEV V SLOVENIJI

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## IZVLEČEK

*Dograditev kombajna omogoča poleg spravila zrnja tudi zbiranje koruznih klasincev. Sortni makro poskus z štiriindvajsetimi hibridi koruze smo zastavili v letu 2013 v vzhodni Sloveniji na težjih tleh. Ob spravilo smo pobrali klasince pri vsakem hibridu (kombajn je bil adaptiran tako, da je v posebni – dodaten zalogovnik – bunker zajemal še klasince). Povprečna masa tako zbranih suhih klasincev je bila 1,3 tone na hektar, kar je primerljivo s podobnimi tujimi tehničnimi rešitvami za ločeno zbiranje klasincev. V Sloveniji bi lahko v letu 2013 potencialno pridelali okrog 54 tisoč ton suhih klasincev. Koruzni klasinci se trenutno uporabljajo predvsem v energetske namene, kot gorivo v navadnih pečeh ali pa v kotlih za sekance, kjer je izkoristek boljši. Uporaba klasincev za druge namene pri nas še ni zaživela.*

***Ključne besede**: koruza, klasinec, mehanizirano spravilo, obnovljivi vir energije, biogorivo, trdna kmetijska biomasa*

## UVOD

Koruzo pridelujemo predvsem za hrano ljudi in krmo živali. Uporabna pa je tudi za druge namene. V zadnjih letih se mnogo koruze uporabi za proizvodnjo bioetanola in bioplina. Uporaba, predvsem celih rastlin, za proizvodnjo bioplina je lahko sporna s stališča zagotavljanja prehranske varnosti.

Koruza je enodomna rastlina, cvetovi so združeni v socvetja. Moška so metlice in ženska storži. Žensko socvetje ali storž je na koncu enega ali več stranskih poganjkov na sredini rastline. Stranski poganjek je zgrajen podobno kot steblo, le da so internodiji kratki. Iz njih izhajajoči listi (ličje) pokrivajo odebeljeno klasno vreteno – klasinec z zrnjem in svilo.

Koruzni storž in klasinec (koruzni storž brez zrnja) imata po slovenskih fitogeografskih območjih različna poimenovanja, kar kaže na bogastvo slovenskega jezika. Zupančič (1999) ugotavlja, da se v predalpskem območju za koruzni storž uporabljajo izrazi čerh, štor, storž, strž, sterž, klas. V dinarskem območju uporabljajo izraze češarek, štok in storž, v preddinarskem območju pa štok, štrok, rog, klas in storž. Za subpanonsko območje so značilna poimenovanja (v)lat, rog, štrok, štruček, za submediteransko območje pa penola, panola, klas, štruček, štrok, štorž, štruc in glava.

Za prazen storž brez zrnja se na Gorenjskem, Dolenjskem, Koroškem in zahodni Štajerski tudi uporablja izraz koruzni storž (Benedik, 1996). Za odstranjevanje listov s koruznega storža so najbolj razširjeni izrazi kožuhati, ličkati, slačiti ter majiti. Uporablja pa se še: lupiti, luščiti, fožati, beliti. Tudi za odstranjevanje zrnja je veliko izrazov. Najbolj razširjen je luščiti, sledita pa ružiti, robkati.

V Slovarju slovenskega knjižnega jezika (Bajec, 1975) je naveden narečni izraz klasina, kar pomeni koruzni storž brez zrnja. Tanjšek (1980, 1991) piše o klasincu. Ta izraz kmetijska stroka (Čergan, 2008) v zadnjih letih še največ uporablja. Nekatere semenarske hiše pa v svojih publikacijah pišejo tudi oklasek, kar naj bi pomenilo koruzni storž brez zrnja. Ta izraz prihaja iz hrvaščine (srbščine).

Spravilo koruze namenjene za zrnje lahko opravljamo na različne načine. V Sloveniji je bilo razširjeno spravilo koruznih storžev. Možno je ročno ali mehanizirano spravilo koruznih storžev. Za mehanizirano spravilo koruznih storžev se uporablja enovrstne ali dvovrstne vlečene obiralnike koruze v storžu. Tako pobrane koruzne storže nato sušijo v koruznjakih. Ti stroji so s prehodom na tehnologijo spravila koruznega zrnja izgubili svoj pomen. Za spravilo koruznega zrnja se uporablja univerzalne žitne kombajne, ki imajo spredaj prigrajeno specialno koruzno ustje. V mlatilni del kombajna gredo večinoma neoličkani odtrgani storži, včasih pa tudi zgornji deli stebel. Pri takem spravilu koruze imamo v zalogovniku čisto zrnje.

Ob ročnem obiranju koruznih storžev ali uporabi obiralnikov koruze v storžu so po odstranjevanju zrnja iz storža (luščenju, ruženju, robkanju) pridelovalcem poleg zrnja ostali še klasinci. Ti so se že od nekdaj uporabljali kot kurivo v štedilnikih na drva, kaminih in keramičnih pečeh (krušnih pečeh). Zaradi uporabnosti klasincev so se za njihovo zbiranje pojavile tehnične rešitve tudi ob spravilu zrnja s kombajni. Tehnične rešitve za zbiranje klasincev so različne, najbolj pogoste so v obliki adaptiranih kombajnov ali pa specialnih prikolic za prebiranje klasincev.

Handler in sod. (2010, 2012, 2011, 2011) ugotavljajo, da sta sposobnost za skladiščenje in kurilna vrednost klasincev tesno povezana z vsebnostjo vode v klasincih. Vsebnost vode v klasincih je večja kot vsebnost vode v zrnju koruze. Pri ločenem spravilu zrnja in klasincev s kombajnom so ugotovili, da je v bunkerju za klasince 89,2 % klasincev, 6,7 % zrnja, 3,0 % ličja in stebla ter 1,2 % drobnih delcev. Nasipna gostota materiala, zbranega v zalogovniku za klasince, je med 93 in 136 kg suhe snovi na kubični meter prostornine. Povprečje je 117 kg/m³ SS. Povprečna nasipna gostota svežih klasincev pa je 163 kg/m³ (razpon pa od 131 do 223 kg/ m³). Tudi pri mehaniziranem spravilu klasincev nastopajo izgube. Te izgube klasincev so v veliki meri odvisne od hibrida koruze. Handler ugotavlja, da je vozna hitrost kombajna manjša kot pri običajnem spravilu zrnja. Hitrost je omejena na 4,5 km/h zaradi prepustne sposobnosti kombajna za klasince (da ne pride do zamašitve dodatnega sklopa za transport klasincev). Zaradi tega se zmanjša storilnost. Potreben delovni čas se poveča tudi zaradi dodatnega praznjenja zalogovnika s klasinci. Čas, potreben za praznjenje zalogovnika s klasinci, je odvisen od sistema praznjenja (bunker prekucne izvedbe ali transportni trak). Ugotovili so tudi, da je delež klasincev v storžu med 8,5 in 12,1 % suhe snovi celotnega koruznega storža. Ta delež pa je odvisen od hibrida koruze.

Lasselsberger (2011, 2012) piše o evropskih in avstrijskih standardih za trdna biogoriva, o njihovih specifikacijah in razredih. V Avstriji so sprejeli tudi svoje standarde za trdna kmetijska goriva (zrnje za energijo, peleti miscanthusa, sekanci miscanthusa, peleti slame). Avstrija je sprejela tudi ustrezno zakonodajo za uporabo kmetijskih trdnih goriv (emisijske mejne vrednosti). Avtor ugotavlja, da je spodnja kurilna vrednost klasincev 17,5 MJ/kg, vsebnost pepela je 1,51 % (pri 815 °C). Suha snov klasinca vsebuje 41,1 % C, 1,46 % N, 6,27 % H, 0,20 Cl ter 0,04 % S. Pri uporabi kmetijskih goriv v pečeh - kotlih obstaja možnost korozije in nastajanja oblog,

Gebeshuber (2012) ugotavlja, da je povprečen pridelek klasincev 1,1 tona suhe snovi na hektar, kar ustreza 9,5 $m^3$ prostornine. Izpostavlja tudi problem korozije v kotlih (pečeh) zaradi klora. Za deželo Gornja Avstrija pa je za leto 2011 ob 50.759 ha koruze za zrnje izračunal pridelek klasincev 60.911 ton. Ob predpostavki, da se ena tretjina koruze požanje s primernimi kombajni, je pridelek zbranih klasincev 20.300 ton. Ob njihovi energetski rabi lahko v Gornji Avstriji privarčujejo 9,2 milijona litrov kurilnega olja in 28.000 ton $CO_2$.

Jansen (2012) ugotavlja, da je klasinec zaradi svoje sestave primeren za proizvodnjo etanola, pa tudi kot trdno gorivo. Potreba po pridobivanju klasincev pa usmerja tudi selekcijo koruze.

Namen prispevka je analiza mehaniziranega spravila klasincev z adaptiranim kombajnom za zrnje.

## MATERIAL IN METODE DELA

Na kmetiji Štefana Števaneca iz Borejec je bil postavljen 23. 4. 2013 v vzhodni Sloveniji na težjih tleh sortni makro poskus koruze z štiriindvajsetimi hibridi. Medvrstna razdalja setve je bila 70 cm, razdalja v vrsti pa 17 cm. Velikost osnovne parcele je bila 460 $m^2$. Prejšnji posevek je bila pšenica. Osnovno gnojenje je bilo opravljeno z NPK 5:15:30 v odmerku 400 kg/ha. Koruza je bila sredi junija dognojena s KAN-om (337 kg/ha). Za zatiranje enoletnega ozkolistnega in širokolistnega plevela smo maja uporabili selektivni herbicid Lumax (aktivna snov mezotrion, S-metolaklor in terbutilazin, odmerek 3,5 l/ha).

Spravilo koruze za zrnje smo izvedi 19. 10. 2013 s kombajnom CASE IH 2388. Glavni tehnični podatki za kombajn so podani v preglednici 1. Kombajn je bil adaptiran tako, da je v posebni – dodaten zalogovnik – bunker zajemal še klasince. Kombajn ima aksialno mlatilno napravo. Koruzna masa (neoličkani storži) vstopa in se pomika vzporedno z osjo mlatilnega bobna in s smerjo vožnje kombajna. Adaptacijo na kombajnu predstavlja dodaten sklop, ki zajame klasince v poseben bunker (slika 1).

**Preglednica 1** Tehnični podatki za uporabljen kombajn za ločeno spravilo zrnja in klasincev koruze (Case IH, 2005)

| | |
|---|---|
| Proizvajalec | Case IH |
| Model | 2388 |
| Nazivna moč motorja | 213 kW (285 KM) |
| Maksimalna moč motorja | 242 kW (325 KM) |
| Transmisija | Hidrostatična, 3 stopnje |
| Premer mlatilnega aksialnega rotorja | 762 mm |
| Dolžina mlatilnega aksialnega rotorja | 2,8 m |
| Vrtilna frekvenca rotorja | 250 – 400 vrt./min<br>400 – 700 vrt./min<br>700 – 1125 vrt/min |
| Čistilna površina | 5,1 $m^2$ |
| Vrtljaji ventilatorja | 450 – 1250 vrt/min |
| Zalogovnik za zrnje | 7,4 $m^3$ |


**Slika 1** Kombajn za spravilo koruznega zrnja z aksialnim rotorjem ter dodatnim sklopom za zajem klasincev

Za čistilnim sklopom kombajna je nameščeno lovilno korito, v katerega padajo klasinci in tudi nekaj ličja. Večina ličja za kombajnom običajno pada na tla. V lovilnem koritu se nahaja polžasti transporter, ki prenaša klasince prečno na levo stran kombajna. Od tu pa se klasinci dovajajo v dodaten bunker za začasno shranjevanje klasincev. Ta bunker ima zadnjo steno premično, tako da se prostornina lahko poveča glede na potrebo pri žetvi. Iz bunkerja pa poseben transportni trak odloži klasince v prikolico zraven kombajna. To se lahko opravi pri mirujočem kombajnu ali med vožnjo po njivi.

Po žetvi vsake parcele s posameznim hibridom smo stehtali maso zrnja in klasincev s tehtnico Welvaarts Weighingcomputer Type W-2000. Vlago koruznega zrnja smo določili z merilnikom vlage KEET AQUASEARCH PM – 600. Vlaga klasincev je odvisna od vlage zrnja. Izračunali smo jo po enačbi Handlerja (Handler, 2011).

## REZULTATI Z DISKUSIJO

Pri proučevanju mehaniziranega spravila klasincev ob žetvi koruze za zrnje z adaptiranim kombajnom smo tehtali maso svežega zrnja in maso svežih klasincev. Iz sveže mase smo nato izračunali hektarski pridelek suhe snovi klasincev in hektarski pridelek koruznega zrnja s 14 % vlage. Rezultati so podani v preglednici 2.

Masa klasincev, zbranih z adaptiranim kombajnom pri različnih hibridih, je primerljiva s podatki iz literature, kjer so za zbiranje klasincev uporabljene podobne ali pa drugačne tehnične rešitve. Povprečni pridelek klasincev pri štiriindvajsetih hibridih koruze, vključenih v poskus v letu 2013, je bil 1.295 kg SS/ha. Najnižji pridelek je bil 954 kg SS/ha, največji pa 1.741 kg SS/ha. Rezultati dobljeni v letu 2013 so primerljivi s preliminarmimi raziskavami (rezultati), ki so izvedene leto prej. V letu 2012 je bil povprečni pridelek klasincev pri enajstih hibridih koruze vključenih v poskus 1.285 kg SS/ha. Najnižji pridelek je bil 995 kg SS/ha, največji pa 1.570 kg SS/ha.

### *Teoretični pridelek klasincev v Sloveniji*

Po začasnih podatkih Statističnega urada RS (SURS, 2013) je bilo v letu 2013 s koruzo za zrnje posejanih 41.799 hektarjev. Ob povprečnem pridelku klasincev 1.295 kg/ha, kot je bil izmerjen na naših poskusih, je teoretični potencial znašal 54129 ton suhih klasincev. Ob upoštevanju kurilne vrednosti 17,5 MJ/kg je kurilna vrednost teh klasincev 947,2 TJ, kar odgovarja kurilni vrednosti 22.554 ton plinskega olja. Uporaba klasincev kot obnovljivega vira energije vpliva tudi na ogljični odtis, saj je saj je pri njihovi uporabi faktor emisije nula. Z uporabo klasincev torej zmanjšamo ogljični odtis, ki bi sicer nastal ob uporabi kurilnega olja. S tem pa tudi vplivamo na nastanek toplogrednih plinov in klimatkse spremembe. Uporaba klasincev ali drugih virov obnovljive energije, bo imala še večji pomen takrat, ko bodo kmetije računale svoj ogljični odtis, oziroma ga bodo lahko zmanjšale z uporabo klasincev. Poleg teoretičnega potenciala je za samo prakso pomemben še ekonomski, tehnični in uporabni potencial klasincev, ki pa so bistveno nižji.

**Preglednica 2** Hektarski pridelek suhih klasincev in hektarski pridelek zrnja s 14 % vlage za posamezne hibride v letu 2013

| Hibrid koruze | Zrelostni razred (FAO) | Vlaga zrnja (%) | Pridelek zrnja s 14 % vlage (kg/ha) | Pridelek klasincev (kg S.S./ha) | Opomba * |
|---|---|---|---|---|---|
| P9578 | 350 | 25,2 | 12181 | 1246 | A |
| PR38N86 | 320 | 24,8 | 11356 | 1126 | C |
| P9027 | 330 | 23,2 | 12854 | 1229 | C |
| P9400 | 310 | 22,8 | 13776 | 1491 | C |
| MAXXALIA | 280 | 21,2 | 11999 | 954 | A |
| SHEXXPIR | 380 | 21,2 | 14300 | 1391 | A |
| FERARIXX | 390 | 21,6 | 15677 | 1370 | A |
| ROXXY | 400 | 23,0 | 14893 | 1254 | A |
| ALEXXANDRA DUO | 400 | 23,1 | 14525 | 1287 | A |
| SUSANN | 300 | 23,9 | 13963 | 1741 | A |
| SUNMARK | 300 | 24,1 | 14060 | 1352 | B |
| ES FLATO | 340 | 20,8 | 13703 | 1334 | B |
| ES CORTES | 400 | 22,8 | 13057 | 1402 | B |
| LG 30.325 | 310 | 20,7 | 13941 | 1455 | C |
| DKC 4014 | 320 | 21,6 | 15042 | 1180 | A |
| CHAPALU | 330 | 21,8 | 14190 | 1201 | A |
| DODIXX | 350 | 22,1 | 14644 | 1155 | C |
| LG 33.50 | 340 | 23,6 | 15145 | 1397 | C, D |
| DKC 4964 | 380 | 24,2 | 14501 | 1296 | C |
| FUTURIXX | 380 | 22,2 | 14656 | 1297 | B |
| DIEGO | 260 | 23,2 | 11227 | 1517 | C |
| VINCENTO | 290 | 21,5 | 9584 | 963 | B |
| ANDORO | 330 | 20,6 | 12926 | 1230 | B |
| ESV ANTALYA | 430 | 26,6 | 15190 | 1212 | C |
| Povprečje | | 22,7 | 13641 | 1295 | |

*A - čisti klasinec, zelo malo ličja, B - malo več ličja, C - veliko ličja, D – beli klasinec

*Uporaba klasincev*

Že od nekdaj so se klasinci uporabljali kot dodatno kurivo v različnih pečeh na drva (štedilniki, kamini, keramične peči – krušne peči). Tudi danes se še klasinci tako uporabljajo. Zaradi boljšega izkoristka je bolj primerna njihova uporaba v kotlih za sekance za etažno ali centralno ogrevanje. Priporoča se mešanje klasincev z lesnimi sekanci. Slovenija je že sprejela številne standarde SIST EN, kjer je govora o trdnih biogorivih (njihovih splošnih zahtevah, specifikacijah in razredih itd.). Ti standardi veljajo za lesne pelete, lesne brikete, lesne sekance, drva, nelesne pelete za neindustrijsko uporabo. Za trdna goriva iz kmetijstva pa pri nas še nimamo standardov. Avstrija je že sprejela lastne standarde za trdna goriva iz kmetijstva, v pripravi pa so tudi mednarodni standardi. Pri uporabi klasincev za gorivo je tudi potrebna ustrezna zakonodaja zaradi emisij, ki jih povzroča kmetijska trdna biomasa. Država mora pripraviti ustrezno »okolje«, da se bo uporaba klasincev razširila. Sprejeti standardi so tudi temelj za korektno trgovanje s temi biogorivi.

Klasinec pa ima še vrsto drugačnih možnosti za uporabo (sestavni del pohištvenih plošč, protihrupna izolacija, vpojno sredstvo za razlite tekočine, nastilj za male hišne živali, nosilec aktivnih snovi pri pesticidih, nosilec aktivnih snovi pri zdravilih, etanol itd.). Taka uporaba klasincev (Jansen, 2012) je relativno dobro razvita v ZDA.

## SKLEPI

Že od nekdaj se je klasince uporabljalo kot kurivo v pečeh. Ob spravilu koruze za zrnje s sodobnimi kombajni se razen zrnja vso ostalo rastlinsko maso odloži nazaj na njivo. Zaradi potrebe po pridobivanju klasincev so se po svetu porodile različne tehnične rešitve za zbiranje klasincev. Tudi slovenska adaptacija kombajna za ločen zajem klasincev je primerljiva z drugimi tehničnimi rešitvami. Poskus z štiriindvajsetimi hibridi koruze je ob spravilu pokazal, da je količina tako zbranih klasincev primerljiva s podatki iz literature, in sicer je bila v letu 2013 od 954 do 1.741 kg SS/ha glede na hibrid, v povprečju pa 1295 kg SS/ha. Ocenjeni delež ličja med klasinci je odvisen od hibrida koruze. V Sloveniji se tako zbrani klasinci nato uporabijo kot gorivo v navadnih pečeh, zaradi boljšega izkoristka se priporoča uporaba v kotlih za sekance. V Sloveniji še ni razvita uporaba klasincev za druge namene!

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# FIRST EXPERIENCE ON MECHANIZED COLLECTING OF CORN COBS IN SLOVENIA

## SUMMARY

*Upgrading combine allows the collection of grain and corn cobs. With adapted combine with on-board cob collection corn cobs of 24 different corn hybrids were harvested in 2013. The average weight of the dried collected cobs is 1.3 tonnes per hectare, which is comparable to other similar technical solutions. In 2013, Slovenia had the theoretical potential of approximated 54,000 tonnes of dry cobs. Corn cobs are nowadays primarily used for energy purposes in ordinary fuel in furnaces, or in boilers for wood chips, which are more efficient. Use cobs for other purposes are not yet in progress.*

***Keywords**: corn, corn cob, mechanized collecting - harvesting, renewable energy source, biofuel, solid agricultural biomass*

# PRVA ISKUSTVA MEHANIZIRANOG SAKUPLJANJA KUKURUZNOG OKLASKA U SLOVENIJI

## SAŽETAK

*Adaptacija kombajna omogućava pored žetve zrna kukuruza i sakupljanje kukuruznog oklaska. Makro eksperiment sa dvadesetičetiri hibrida kukuruza izveden je u 2013 u istočnoj Sloveniji na teškim tlima. Kod žetve kukuruza sa adaptiranim kombajnom za svaki hibrid kukuruza je u dodatni bunker sahranjen oklasak. Prosječna težina ovako sakupljenog suhog oklaska je 1,3 tona po hektaru, što je uspoređivo sa sličnim tehničkim rješenjima drugdje u Evropi ili Ameriki. U Sloveniji u 2013 potencijalno bi mogli sakupiti oko 54.000 tona suhog oklaska. Oklasak trenutno koristi se u Sloveniji uglavnom za energetske svrhe, kao gorivo u običnim pećima ili kotlovima na drvnu sječku, koji imaju bolje izkoriščenje. Korištenje oklaska za druge svrhe u Sloveniji još nije razvijeno.*

***Ključne riječi**: kukuruz, oklasak, mehanizirana žetva, obnovljivi izvor energije, biogoriva, čvrsta poljoprivredne biomasa*

42. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

UDK 662.6/.9
Stručni rad
Expert paper

# MANJŠA PORABA GORIVA KOT NOVI IZZIV ZA TRAJNOSTNO KMETIJSTVO IN MANJŠI OGLJIČNI ODTIS

TOMAŽ POJE

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## IZVLEČEK

*Ne glede na izobrazbo kmetov je njihovo znanje o postopkih bolj varčnega dela s kmetijsko mehanizacijo majhno. V šolah, kjer izobražujejo za kmetijstvo, reducirajo predmete s kmetijsko tehniko. Potreba po manjši porabi goriva pa postaja vedno bolj ena izmed osnovnih zahtev za ekonomično kmetijsko pridelavo. V anketi smo ugotovili, da 42 % kmetov želi uvesti ukrepe za prihranek goriva, vendar pa ne vedo, kako naj to storijo. Slaba 2 % kmetov pa še ne čuti potrebe, da bi zmanjševalo porabo goriva. Za povečanje znanja o postopkih za manjšo porabo goriva obstajajo priročniki, vendar jih 41 % kmetov sploh ne pozna. Le 9 % kmetov pa take priročnike dobro pozna. Opisana je tudi vsebina programov za zmanjševanje porabe goriva in tečaji eko vožnje s traktorji. Izpostavljen je tudi pomen komunikacijske kampanje za razširitev teh znanj. Manjša poraba goriva za kmetijsko pridelavo pomeni na državni oziroma evropski ravni prispevek k manjšemu ogljičnemu odtisu.*

***Ključne besede**: kmetijstvo, manjša poraba goriva, traktor, eko vožnja, EFFICIENT 20*

## UVOD

Slovenija se je zavezala, da bo zmanjšala izpuste toplogrednih plinov in postala nizkoogljična družba. Najpomembnejši toplogredni plin je ogljikov dioksid, ki nastaja tudi (ali predvsem) zaradi zgorevanja goriv. Pri ogljičnem odtisu kmetije se upošteva direktne komponente (kot je poraba dizelskega goriva, bencina, elektrike, itd.) in indirektne komponente (energija potrebna za izdelavo mineralnih gnojil, pesticidov, strojev itd.). Ogljični odtis na kmetiji lahko zmanjšamo z različnimi ukrepi, eden izmed njih je tudi manjša poraba goriva pri delu na kmetiji.

Goscianska (2011) piše o potrebi po bolj učinkoviti izrabi energije v Evropski uniji tudi v kmetijstvu. Za to pa je potrebno tudi večje znanje končnih porabnikov energije – kmetov. Poje (2013a, 2013b) piše, da je v Sloveniji najbolj enostavna možnost za zniževanje stroškov kmetijske pridelave in stroškov goriva vlaganje zahtevkov za vračilo trošarine. Kmetje pa lahko stroške povezane s porabo goriva zmanjšajo na številne načine, med drugim tudi z bolj varčnim delom pri uporabi traktorjev in drugih kmetijskih strojev. O bolj varčnem delu s kmetijskimi stroji in traktorji se v Sloveniji do pridobitve projekta Efficient 20 dejansko ni veliko govorilo. Kmetje pa so bili za bolj varčno delo iz stališča porabe goriva prepuščeni sami sebi. Kmetijska svetovalna služba v Sloveniji za področje mehanizacije nima veliko specialistov, njihova dejavnost pa tudi ni bila usmerjena v bolj varčno delo s traktorji. Varčevanje z gorivom pri delu s traktorji in drugo kmetijsko mehanizacijo pa postaja ob vedno ostrejših ekonomskih razmerah na kmetijah vedno bolj aktualno. Že pri nakupu oziroma izboru traktorja mora biti kmet pozoren na tehnične lastnosti traktorja povezane s porabo goriva. Poraba goriva je v veliki meri odvisna tudi od samega traktorista – od njegovega načina vožnje in dela s traktorjem. Ravno on s svojim ravnanjem dela varčno ali pa bolj razsipno.

Evropski program Intelligent Energy Europe (IEE) poleg drugega promovira tudi učinkovito rabo energije. V letih 2010 do 2013 je sofinanciral projekt Efficient 20, ki je imel za cilj zmanjšati porabo goriva v kmetijstvu. V ta projekt je bila vključena tudi Slovenija. V okviru projekta so se izvajale aktivnosti za manjšo porabo goriva na lokalnih ravneh v 9 evropskih državah, ki sodelujejo v projektu.

Namen prispevka pa je prikazati nekatere izsledke anket, ki smo jih opravili v okviru projekta Efficient 20, prikazati programe za zmanjševanje porabe goriva, vsebino tečajev eko vožnje in pomena komunikacijske kampanje.

## MATERIAL IN METODE DELA

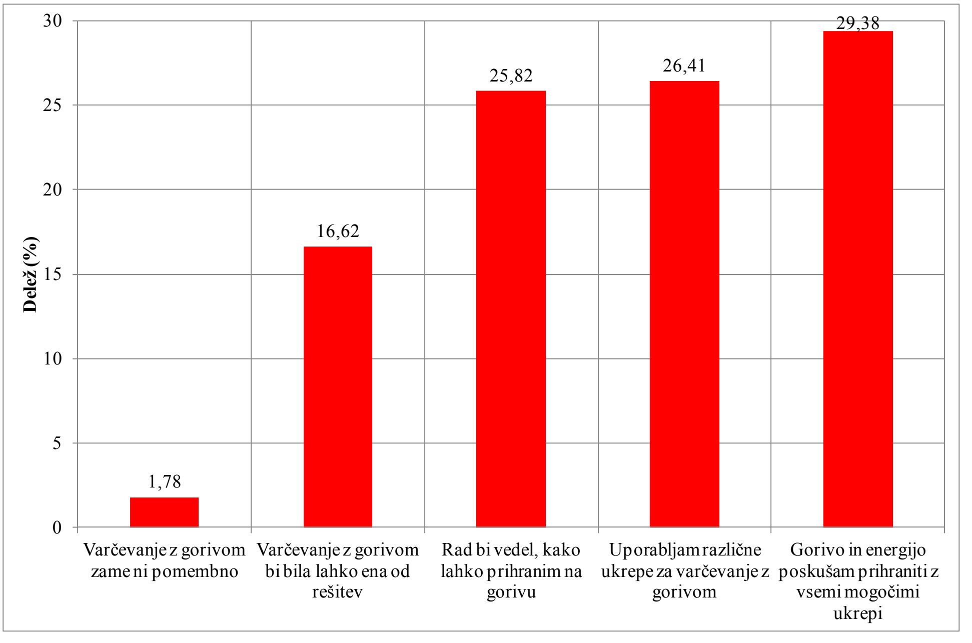
Kot vir podatkov za analizo smo uporabili podatkovno bazo pridobljeno na delu v evropskem projektu Efficient 20. V prispevku so prikazani deli anket, ki smo jih opravili v 9 evropskih državah. V ankete zajeti podatki so obdelani z ustreznimi statističnimi analizami (opisna statistika).

## REZULTATI Z DISKUSIJO

### *Stopnja poznavanja problematike porabe goriva pri uporabnikih*

Cilji Evropske skupnosti in njenih posameznih držav so glede potrebe po zmanjševanju porabe goriva jasni. Za prispevek kmetijstva in gozdarstva pri teh ciljih pa je potrebno veliko aktivnosti na osveščanju kmetov in gozdarjev o pomembnosti zmanjševanja porabe goriva. Na začetku takih aktivnosti je potrebno analizirati odnos kmetov do porabe goriva pri njihovem delu v kmetijstvu oziroma gozdarstvu. Narediti je potrebno splošno oceno o trenutni situaciji na tem področju. Poleg tega pa je potrebno narediti tudi bolj tehnično naravnano oceno stanja, ki pomaga ovrednotiti nivo uporabnikovega poznavanja nove kmetijske mehanizacije in strojev.

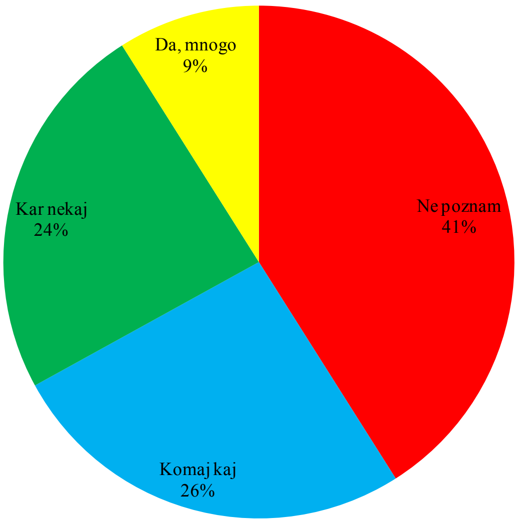
Zanimivo je, da več kot 42 % kmetov želi uvesti ukrepe za prihranek goriva, vendar pa ne vedo, kako naj to storijo. Vzrok temu je dejstvo, da so spoznanja s področja praktičnih načel in tehnike eko vožnje v kmetijstvu maloštevilna in težko dostopna (strokovne publikacije, mediji ali navodila ter usposabljanja proizvajalcev opreme).



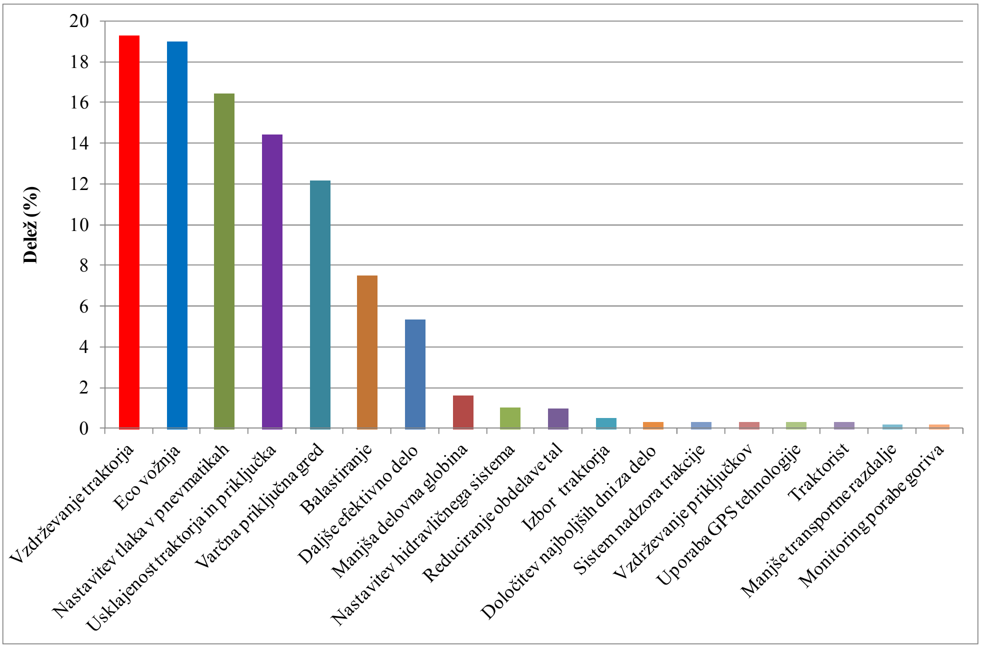

**Slika 1** Odnos kmetov do ukrepov za zmanjševanje porabe goriva

Seznanjenost kmetov o postopkih za varčno delo je odvisno od njihovega znanja. V izobraževalnih ustanovah, ki izobražujejo za kmetijske poklice, se poučevanje kmetijske tehnike vse bolj reducira. Tako, da za temo varčevanja z gorivom zmanjka učnih ur. Kmetje morajo, do teh informacij priti na drug način. Tako, da je dobro da npr. Slovenija propagira oziroma subvencionira programe vseživljenjskega izobraževanja kmetov. Do novih znanj lahko pridejo kmetje na primer tudi s pomočjo priročnikov s smernicami za varčno delo v kmetijski pridelavi. Poznavanja takih priročnikov pa je pri kmetih slabo. Kar 41 % kmetov vključenih v anketo ne pozna nobenega priročnika na temo varčevanja z gorivom. Nadaljnjih 26 % slabo pozna te priročnike. Le 9 % kmetov pa trdi da dobro pozna take priročnike.

Na sliki 3 vidimo kateri postopki za varčevanje z gorivom se zdijo kmetom najbolj ustrezni. V vprašanju je bilo danih sicer samo 5 možnih postopkov za varčevanje, vendar so kmetje povečali te postopke kar na 18 različnih postopkov. Iz slike je razvidno, da 5 najpomembnejših postopkov predstavlja kar 81,29 % vseh odgovorov. Ti najzanimivejši postopki za kmete so tudi podrobno opisani s praktičnimi primeri v posebni publikaciji, ki je služila za širjenje znanja o teh varčevalnih postopkih in smo jo izdali v okviru Efficient 20.




**Slika 2** Odgovori kmetov ali poznajo kakšne priročnike, ki navajajo smernice za varčno vožnjo.




**Slika 3** Delež kmetov in njihove odločitve glede ustreznosti posameznih postopkov za varčevanje z gorivom.

Te ugotovitve pa stroki narekujejo nadaljnje korake za širjenje znanja o postopkih za manjšo porabo goriva v kmetijstvu. Te programe bi morala financirati (subvencionirati) država ali ustrezno ministrstvo. Res je, da ima kmet kot posameznik pri zmanjšanju porabe goriva ekonomske koristi. Država kot celota pa poleg tega dosega tudi okoljske prednosti, kot je manj nastalega ogljikovega dioksida (toplogrednih plinov). V nadaljevanju navajamo nekaj ciljev in metod, ki jih bi moral vsebovati takšen državni pospeševalni program. V tozadevno bolj razvitih državah kot je na primer Avstrija so tudi ugotovili, da je potrebno programe ozaveščanja ponavljati, da jih kmetje res osvojijo in da jih začnejo tudi uporabljati.

*Poznavanje lastne porabe goriva*

Poznavanje lastne porabe goriva je prvi korak k zmanjševanju porabe. Če želimo ugotoviti potencial za prihranke, moramo natančno zabeležiti podatke o porabi za vsako parcelo na kmetiji in vsak delovni postopek posebej. To je potrebno opraviti za vsa dela na kmetiji. Meritve porabe goriva traktorjev in drugih samovoznih strojev ali strojev na motorni pogon lahko kmet na svojem posestvu opravi na:

1. Volumetrične način – izmeri porabo z beleženjem količine goriva ob dopolnjevanju rezervoarja po opravljeni aktivnosti,
2. Uporabi elektronske naprave za meritev porabe goriva, ki jih je potrebno dodatno vgraditi na traktor (delujejo pa na principu meritev pretoka goriva),
3. Uporabi računalnik traktorja, ki ima vgrajeno funkcijo spremljanja porabe.

Zadnji način zavzema pomembno mesto pri meritvah porabe, saj je na tržišču vedno več traktorjev v standardni ali opcijski opremi opremljenih s takimi računalniki. Medtem ko nekateri vgrajeni računalniki omogočajo široko paleto načinov prikaza porabe, drugi nudijo le preprost prikaz trenutne porabe v litrih na uro. Specialni gozdarski stroji (John Deere, Komatsu - Valmet, Ponsse) na splošno ponujajo zelo bogat nabor funkcij spremljanja porabe.

Na podlagi ugotovitve stanja lahko sedaj izdelamo načrt za uvedbo učinkovitih ukrepov pri zmanjševanju porabe goriva.

*Programi za zmanjšanje porabe goriva*

Ključnega pomena je, da se pomembnost zmanjševanja porabe goriva uporabnikom (kmetom, gozdarjem) predstavi tako, da bo sporočilo prilagojeno ciljnemu uporabniku in bo vzbudilo zanimanje. V praksi smo dokazali, da se na tak način motivacija za pridobivanje novih znanj pri udeležencih znatno poveča.

Pri motivacijsko naravnani predstavitvi programa je potrebno:

1. osvetliti vidike in pomen ukrepov za zmanjševanje porabe goriva: ekonomski, konkurenčni, proizvodni, okoljski…, če želimo ugotoviti potencialne možnosti za izboljšave in prihranke na posameznikovem nivoju,
2. prikazati pomen stroška goriva za ekonomske rezultate pridelave in s tem pri udeležencih vzbuditi interes za uvedbo ukrepov; poznati moramo porabo goriva za vsako posamezno kmetijsko aktivnost (zbirka podatkov).

Najboljši način za razširjanje znanja s tega področja so zagotovo usposabljanja, tečaji in strokovne ekskurzije. Da bi pri tem dosegli kar najboljše rezultate, moramo tečaje za usposabljanje in aktivnosti s tem v zvezi posvetiti elementom, ki so za porabo goriva še posebej pomembni. Glavni dejavniki, ki jih omenjajo kmetje, so povezani z mehanizacijo (uporaba, način vožnje, hitrost) in obdelovalnimi površinami (vrsta in stanje tal). Najprimernejši način, kako udeležencem predstavimo posledice načina njihovega dela, je izvedba učnih delavnic, na katerih sodelujejo izkušeni in vplivni kmetje, ki sodelujočim predstavijo svoje izkušnje, saj bo tak praktični prikaz udeležence, ki še niso razmišljali o uvedbi takih ukrepov, zagotovo najbolj spodbudil k varčevanju pri porabi goriva in dal potrebne napotke tistim, ki so z uvedbo ukrepov za zmanjšanje porabe že pričeli.

Za posredovanje takega sporočila so nam na voljo številne možnosti:

1. predstavitev (združena z drugimi aktivnostmi),
2. obisk strokovnjakov, proizvajalcev ali raziskovalnega inštituta,
3. kviz,
4. tekmovanje v eko vožnji…

*Tečaj eko vožnje s traktorji*

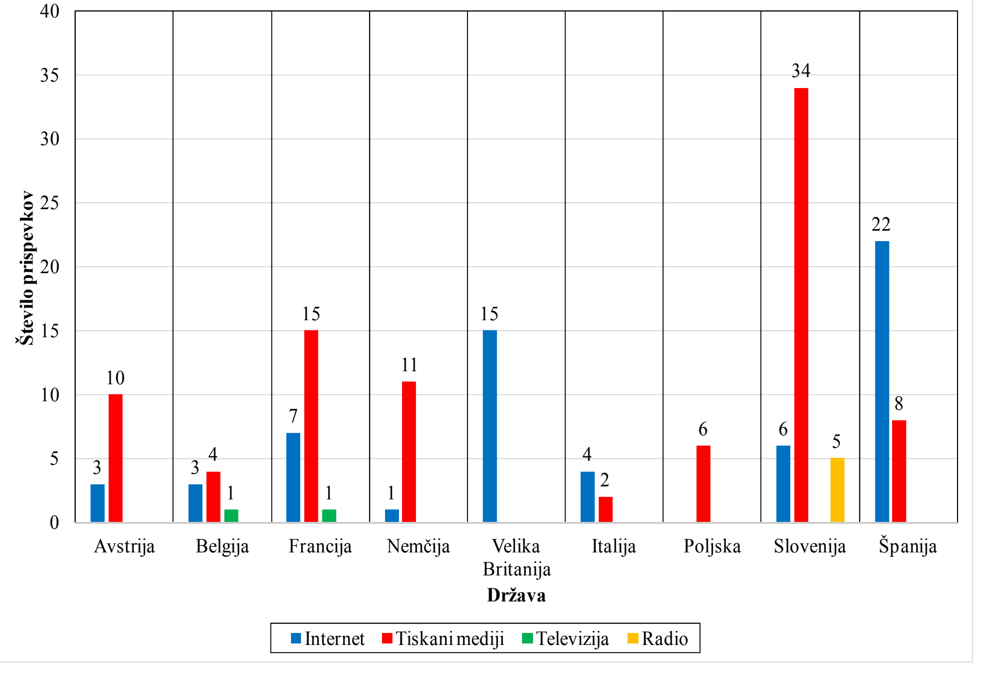
Eden od najboljših načinov za povečanje motiviranosti in znanja kmetov in gozdarjev je izvedba usposabljanja v eko vožnji, ki je posvečena zmanjševanju porabe goriva. Tečaj eko vožnje mora biti sestavljen iz teoretičnega in praktičnega dela. Za udeležence je v povprečju potrebno organizirati vsaj enodnevne tečaje tehničnih spretnosti. Če želimo ohraniti pozornost udeležencev, mora biti teoretični del izveden na kar najbolj zanimiv način, s praktičnimi primeri in vključevanjem sodelujočih. Pri tem je potrebno osvetliti glavne dejavnike, ki vplivajo na porabo goriva in prikazati upravičenost uvedbe ukrepov za zmanjšanje porabe. Teoretični del naj sestavljajo naslednji sklopi:

1. Uvod (cena goriva, celotni strošek traktorja v njegovi življenjski dobi, primeri dobre prakse pri porabi goriva),
2. Razvrstitev motorjev in menjalnikov traktorjev,
3. Vpliv števila vrtljajev motorja,
4. Vpliv strukture obdelovanega zemljišča,
5. Specifični ukrepi pri oranju
6. Specifični ukrepi pri spravilu krme
7. Izbira optimalnega transportnega vozila,
8. Meritve porabe goriva,
9. Ključni človeški faktor

Praktični del tečaja naj vključuje primere aktivnosti, v katerih bo mogoče primerjati porabo goriva pri običajni vožnji in ob uvedenem ukrepu za zmanjšanje porabe goriva. Take primere je mogoče prikazati na številnih kmetijskih in gozdarskih aktivnostih, kot so transport, nalaganje, oranje, raztros gnoja, žetev itd. Izbira naj bo odvisna od interesa udeležencev. Relativno enostavno se pri praktičnem delu tečaja pokaže naslednje ukrepe za zmanjšanje porabe goriva:

1. Učinek stopnje vzdrževanosti traktorja z mobilno testno napravo (dinamometrom),
2. Učinek globine brazde (oranja), balasta, tlaka pnevmatik,
3. Učinek načina vožnje,
4. Učinek varčne (ekonomične) priključne gredi,
5. Učinek pravilne nastavitve priključkov.

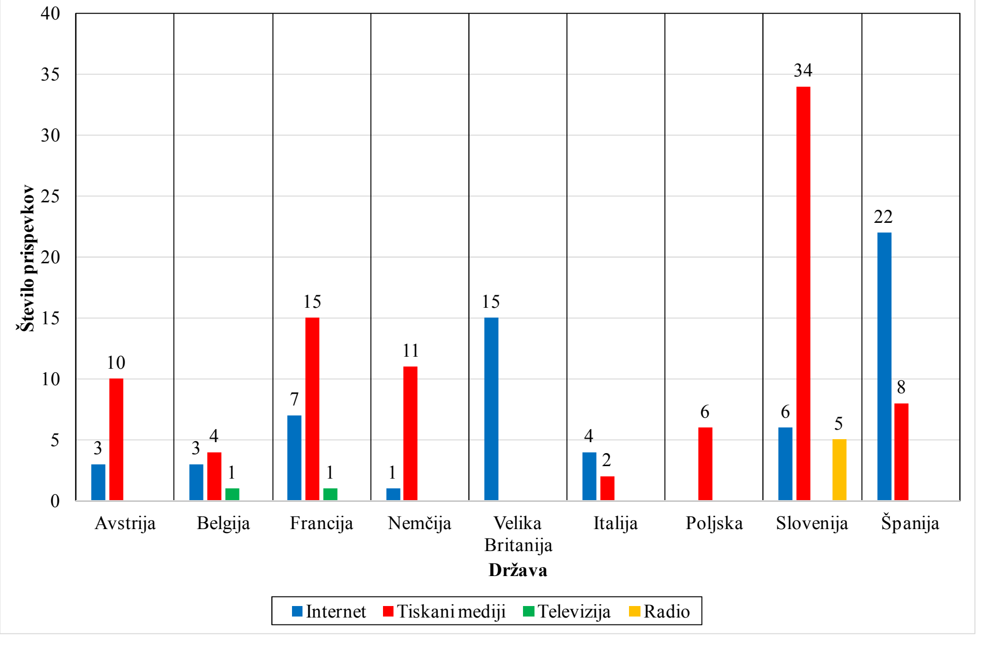
Udeleženci morajo na tečaju preizkusiti svoj lasten način dela (vožnje) in ga primerjati z drugimi ali z učinkom, ko isto vožnjo ponovijo pod vplivom nasveta predavatelja. Pogosto so presenečeni nad spremenljivostjo porabe goriva pri različnih voznikih, ki opravljajo nalogo v istih razmerah in nad izjemnim učinkom eko načina vožnje na porabo goriva. Pri eko vožnji pa je potrebno paziti na skupni ekonomski učinek, saj se pri eko vožnji lahko tudi podaljša časa izvedbe naloge (kar pa predstavlja dodatne stroške dela in opreme). Zato morajo biti praktični primeri izvedeni tako, da prikažejo možnost izvedbe dela v istem času in z znatnim prihrankom goriva. Opisani nasveti temeljijo na izkušnjah več kot 30 organiziranih tečajev ekološke vožnje v 8 različnih državah, v katerih je v projektu Efficient 20 sodelovalo več kot 300 udeležencev.




**Slika 4** Število prispevkov povezanih s postopki za manjšo porabo goriva po državah in po vrsti medija

*Komunikacijska kampanja*

Med izvajanjem projekta Efficient 20 je bilo v vseh vključenih državah 158 prispevkov v medijih. Prispevki so govorili ali o samem projektu ali pa o napotkih za zmanjšanje porabe goriva v kmetijstvu in gozdarstvu. Pri tiskanih medijih je Slovenija imela kar 34 prispevkov. Taka medijska kampanja je potrebna zato, da informacije o zniževanju porabe goriva pridejo do čim širšega kroga uporabnikov (kmetov). Marsikateri namreč ne more obiskati specializiranih tečajev za varčno delo s traktorji.




**Slika 4** Število prispevkov povezanih s postopki za manjšo porabo goriva po državah in po vrsti medija

## SKLEPI

V sklopu vseživljenjskega izobraževanja kmetov je potrebno pozornost posvetiti tudi postopkom bolj varčnega dela s kmetijsko mehanizacijo. V šolah, ki izobražujejo za kmetijstvo, teh vsebin ni ali pa so le bežno omenjene, saj se predmeti iz kmetijske tehnike zmanjšujejo. Anketa je pokazala da 42 % kmetov želi uvesti ukrepe za prihranek goriva, vendar pa ne vedo, kako naj to storijo. 12 % kmetov pa sploh ne pozna priročnikov, ki govorijo o bolj varčnem načinu dela v kmetijstvu. Osnove programov za izobraževanje na področju zmanjševanja porabe goriva pri delu s kmetijskimi stroji obstajajo, vendar je ozaveščanje kmetov dolgotrajen proces, ki ga je potrebno tudi ponavljati. Poleg tečajev eko vožnje je zelo pomembna tudi medijska kampanja, tako da se informacije o ukrepih za bolj varčno pridelavo prenašajo v širši krog uporabnikov.

**ZAHVALA**

Ta prispevek je nastal na osnovi dela na evropskem projektu IEE Efficient 20. Zahvaljujemo se Evropski skupnosti za sofinanciranje, sodelavcem na projektu pa za posredovanje informacij.

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# LOWER FUEL CONSUMPTION AS NEW CHALLENGE FOR SUSTAINABLE AGRICULTURE AND A SMALLER CARBON FOOTPRINT

## SUMMARY

*Notwithstanding the good farmers' education, their knowledge about the fuel saving techniques at work with farm machinery is poor. At secondary agriculture schools where educated for, the objects dealing with agricultural techniques are reduced to. But the reduction of the fuel consumption in the process of crop production is one of the basic economic requirements. In the survey 42 % of the farmers realized that saving of the fuel is possible through the measures, but they do not know the right way; less than 2 % of farmers still do not think so. There are several manuals available dealing with the decreasing fuel consumption in agriculture but 41 % of farmers do not have this information. Only for 9 % of farmers manuals are known. In that article we described the content of the eco - driving tractors courses program dealing with the reduction of fuel consumption. The main focus is the importance to organize the communication campaigns to expand these skills. Lower fuel consumption for agricultural production also contributes to the reduction of the carbon footprint at the national and at the European level.*

***Key words:*** *agriculture, reduced fuel consumption, tractor, eco - driving, Efficient 20*

# MANJA POTROŠNJA GORIVA KAO NOVI IZAZOV ZA ODRŽIVU POLJOPRIVREDU I MANJI UGLJIČNI OTISAK


## SAŽETAK

*Bez obzira na edukaciju poljoprivrednika, njihovo znanje o postupcima za manju potrošnju goriva kod rada sa poljoprivrednim strojevima je malo. U poljoprivrednim školama smanjuju se predmeti vezani sa poljoprivrednom tehnikom. Potreba, da se smanji potrošnja goriva, sve više postaje jedan od osnovnih uvjeta za ekonomičnu poljoprivrednu proizvodnju. Sa anketom ustanovili smo, da je 42 % poljoprivrednika koji žele uvesti mjere za uštedu goriva, ali ne znaju kako to učiniti. Manje od 2 % poljoprivrednika još uvijek ne osjeća potrebu da smanji potrošnju goriva. Za povećanje znanja o postupcima za manju potrošnju goriva postoje priručnici ali 41 % poljoprivrednika ne poznaje. Samo 9 % poljoprivrednika takve priručnike dobro pozna. Opisan je i sadržaj programa za smanjenje potrošnje goriva i tečaj eko - vožnje s traktorima. Istaknuto je značenje komunikacijske kampanje za proširenje ovih znanja. Manja potrošnja goriva za poljoprivrednu proizvodnju na nacionalnoj i na europskoj razini pridonosi ka manjem ugljični otisak.*


***Ključne riječi:*** *poljoprivreda, manja potrošnja goriva, traktor, eko - vožnje, Efficient 20*

42. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

UDK 378.663:631.17
Prethhodno priopćenje
Preliminary communication

# ZNANJE O POLJOPRIVREDNOJ MEHANIZACIJI STUDENATA AGRONOMIJE

IVO GRGIĆ[1], MAGDALENA ZRAKIĆ[1] , JOSIP GUGIĆ[2]

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## SAŽETAK

*Poljoprivredna proizvodnja mora ispuniti nekoliko ciljeva. Prvi je proizvodnja količinski i kvalitetom dostatnih količina proizvoda koji su cjenovno prihvatljivi proizvođačima i potrošačima. Ne manje bitan cilj je što manje onečišćenje proizvodnog prostora. U postizanju tih ciljeva značajno mjesto zauzima poljoprivredna mehanizacija odnosno njeno korištenje.*

*Jedna od pretpostavki dobrom gospodarenju poljoprivrednom mehanizacijom, tehnološki i ekonomski, su i dosadašnja te tijekom studiranja stečena znanja budućih poljoprivrednih stručnjaka.*

*U radu se pošlo od pretpostavke da studenti prvih godina Agronomskog fakulteta nedovoljno poznaju poljoprivrednu mehanizaciju te zbog toga tijekom studija trebaju dobiti više znanja o njoj.*

*Anketirane su 141 osobe od čega je veći dio (77,3%) bio prve te manji (22,7%) druge godine preddiplomskih studija. Anketom nisu obuhvaćeni studenti/ce studija Poljoprivredna tehnika i Krajobrazna arhitektura.*

*Najveći dio anketiranih (68,8%) su studentice, odrasli u urbanoj sredini (68,1%) te sa završenom gimnazijom (62,4%). Samo 5,7% ispitanika završilo je srednju poljoprivrednu školu.*

*Znanje ispitanika o poljoprivrednoj mehanizaciji je ipak zadovoljavajuće iako ih čak 71,6% ne zna upravljati niti jednim poljoprivrednim strojem Preko 80% ispitanika zna za što se koristi kombajn, nešto manje ih je koji znaju da se rolopreša primjenjuje pri sakupljanju sijena (74%) te da je rigolanje oranje na dubinu više od 50 cm (65,2%). Većina ispitanika prepoznaje važnost mehanizacije za poljoprivrednu proizvodnju kao i potrebu njene što primjerenije uporabe. Međutim, najveći dio ispitanika (67%) ne bi, kao izborni, upisali modul koji izučava poljoprivrednu mehanizaciju.*

*Bolje poznavanje mehanizacije zabilježeno je kod muškog dijela anketiranih te onih koji dolaze odnosno odraslih u ruralnom području.*

***Ključne riječi**: poljoprivredna mehanizacija, studenti, agronomija*

## UVOD

Suvremena poljoprivredna proizvodnja je mnoštvo kombinacija tri proizvodna činitelja: zemlje, rada i kapitala. Svaka kombinacija treba postići nekoliko temeljnih ciljeva: proizvesti dovoljno hrane koja će količinom i kvalitetom zadovoljiti sve veću svjetsku potražnja koja je posljedica porasta stanovništva i tržnih špekulacija; proizvedena hrana treba cjenovno biti prihvatljiva i proizvođačima i potrošačima te u cijelom poljoprivredno prehrambenom lancu uvažiti jedan od principa održivosti a to je očuvanje proizvodnog okoliša. Okolišni ciljevi gospodarskim razvitkom i postizanjem drugih ciljeva postaju dominantni. Najčešće spominjani okolišni ciljevi su smanjenje i kontrola onečišćenja tla, onečišćenja voda, onečišćenja zraka, buke te opasnog zračenja.

Odgovori na pitanja ŠTO proizvesti, KAKO proizvesti i ZA KOGA proizvesti usmjerili su svjetsku proizvodnju hrane prema tri sustava proizvodnje i to tradicionalni, konvencionalni i ekološki.

Tradicionalno gospodarstvo koristi postojeće resurse na tradicionalan, zastarjeli način, a kod njih su naglašeni nedostatak znanja, mogućnosti i/ili financijskih sredstava.

Konvencionalno gospodarstvo povećava svoju proizvodnju koristeći sve mogućnosti svojih proizvodnih resursa i sva neophodna ulaganja najčešće do optimalnog odnosa troškovi-dohodak.

Ekološko gospodarstvo primjenjuje pravila ekološke poljoprivrede određena zakonima i propisima.

Niti jedan od navedenih sustava, posebice ako je proizvodnja namijenjena tržištu, teško je zamisliti bez korištenja poljoprivredne mehanizacije.

Od svoje pojave, druge polovice 19. stoljeća, do danas, traktori su najvažniji poljoprivredni pogonski strojevi polivalentne namjene. Kombajni su po važnosti drugi poljoprivredni strojevi koji su izazvali krupne proizvodno-tehnološke promjene u poljoprivrednoj proizvodnji. Prema Popisu poljoprivrede Hrvatske iz 2003. godine, većina (92,6%) poljoprivredne mehanizacije je na obiteljskim gospodarstvima, a manje kod poljoprivrednih tvrtki (Ratko, 2011). U njihovom je vlasništvu 86.243 jednoosovinska te 185.953 dvoosovinska traktora kao i 6.132 kombajna te 15.883 stroja za berbu (DZS, Popis poljoprivrede 2003).

Značajan problem predstavlja relativno niska iskoristivost poljoprivredne mehanizacije što loše utječe na ekonomske efekte proizvodnje. Autori upozoravaju da je prosječno mala veličina i velika rascjepkanost posjeda jedan je od glavnih ograničavajućih čimbenika boljeg korištenja drugih raspoloživih resursa te s time i napretka obiteljskih poljoprivrednih gospodarstava i razvitka cjelokupne hrvatske poljoprivrede (Svržnjak 2001). Ovakvu agrarnu strukturu drugi autori ocjenjuju kao trenutak „za čvršći pristup restrukturiranju poljoprivrednih gospodarstava i usklađivanja veličine posjeda s kvalitetom zemljišta, raspoloživom radnom snagom, mehanizacijom.“ (Zmaić, Petrač i Sudarić 2007). Za treće je put postupak komasacije kojom „se rješavaju imovinsko-pravni odnosi na zemljištu i dovodi do boljeg korištenja mehanizacije." (Ivković, Džapo i Dolanjski 2008).

Za upravljanje poljoprivrednom mehanizacijom odnosno što boljim iskorištenjem njenog potencijala neophodno je stručno znanje proizvođača odnosno potrebno je njihovo stalno osposobljavanje tj. edukacija.

Međutim, za promišljanje što bolje primjene te osmišljavanje što kvalitetnijih tehničko tehnoloških rješenja u poljoprivrednoj proizvodnji neophodno je imati visoko obrazovane stručnjake koji će nuditi određena rješenja kako industriji poljoprivredne mehanizacije tako i korisnicima tj. poljoprivrednim proizvođačima.

Zbog toga se na Agronomskom fakultetu Sveučilišta u Zagrebu poljoprivredna mehanizacija izučava na preddiplomskom studiju Poljoprivredna tehnika te na diplomskom Poljoprivredna tehnika-Mehanizacija, a kod drugih studija znatno manje i to vrlo često kao izborni predmet. Zbog toga i nismo u ovo istraživanje uključili studente Poljoprivredne tehnike za koje smo pretpostavili da već u prvim godinama stječu dovoljno znanja o poljoprivrednoj mehanizaciji.

## MATERIJAL I METODE

Istraživanje je provedeno početkom mjeseca studenog na Agronomskom fakultetu Sveučilišta u Zagrebu. Anketirano je ukupno 141 student/studentica prve i druge godine različitih studija. Većina anketiranih (77,3%) je bila prve (Agrarna ekonomika, Animalne znanosti, Hortikultura i Zaštita bilja), a manji dio (22,7%) druge godine studija (Agroekologija, Biljne znanosti i Ekološka poljoprivreda). Uzorak je bio slučajan jer je anketa bila nenajavljena i obavljena je za vrijeme nastave iz modula Osnove agroekonomike.

U radu se pošlo od pretpostavke da studenti prvih godina Agronomskog fakulteta nedovoljno poznaju poljoprivrednu mehanizaciju te zbog toga tijekom studija trebaju dobiti više znanja o njoj. Sljedeća pretpostavka je da postoje određene razlike u znanjima/odgovorima s obzirom na studij, spol te mjesto odrastanja (ruralno/urbano).

Za potrebe rada dizajnirana je anketa koja se sastojala od ukupno 17 pitanja otvorenog, poluotvorenog i otvorenog tipa. Za određene tvrdnje korištena je Likertova skala od pet stupnjeva. Nakon logičke kontrole, kodiranja i unosa obrada podataka je obavljena pomoću statističkog paketa SPSS 17.0. Odgovori su križani s nezavisnim varijablama (mjesto odrastanja, spol, studij), a u analizi rezultata primijenjen je statistički hi$^2$-test. 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, 2004)

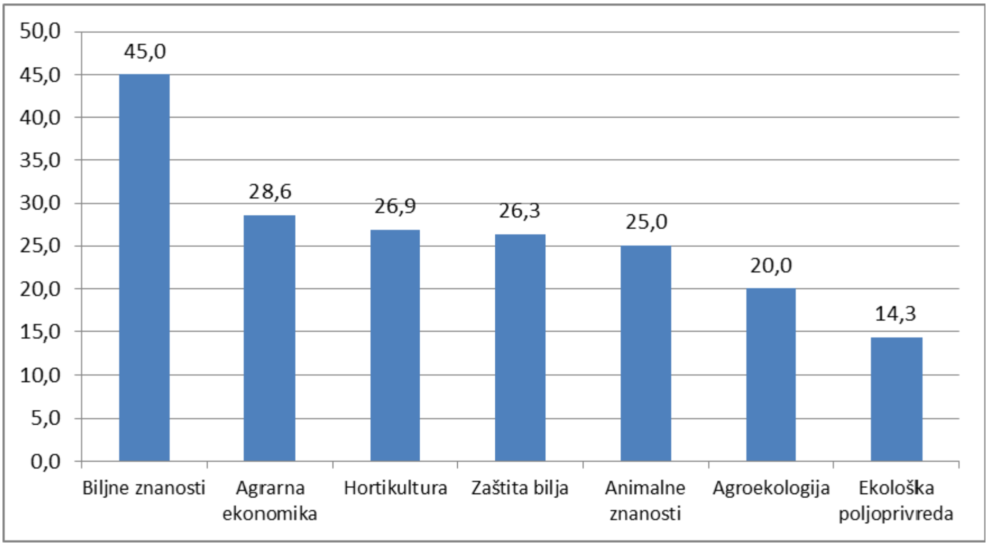
## REZULTATI I DISKUSIJA

Od devedesetih godina prošlog stoljeća kod upisa na Agronomski fakultet primjetan je porast udjela žena kao i onih koji dolaze iz urbanih sredina. Tako je i u ovom istraživanju većina anketiranih (68,8%) bilo žena te preko dvije trećine (68,1%) ih potječe iz urbanih sredina. Također dolazi i do promjene strukture studenata s obzirom na završenu srednju školu. Kod anketiranih najveći dio (62,4%) ih je završio gimnazijsko obrazovanje a poljoprivrednu srednju školu samo njih 5,7%. Ostali (31,9%) su završili neku drugu srednju školu i to od tehničkih, ekonomskih do medicinskih i drugih.

Od 2000/10. školske godine kada se uvodi Državna matura, potencijalni studenti pri upisu stvaraju osobnu rang listu prioriteta fakulteta te je Agronomski za njih 41,8% bio prvi izbor, a za 75,8% je bio među prva tri odabrana fakulteta (Postoje značajne razlike po navedenim obilježjima između ukupno upisanih i našeg uzorka. Već nakon nekoliko mjeseci nastave dolazi do „osipanja“ slušača te jedan dio, najčešće onih kojima je Agronomski fakultet bio četvrti i na više odabir, rjeđe pohađaju nastavu ili čak i odustaju od studija.).

Najveći dio anketiranih (27%) bili su studenti Zaštite bilja, zatim Hortikulture (18,4%), Animalnih znanosti (17%), Agrarne ekonomike (14,9%), Biljnih znanosti (14,2%) te Ekološke poljoprivrede (5%) i Agroekologije (3,5%).

Podrijetlo, spol i vrsta završene srednje škole značajno su utjecali na mogućnost korištenja odnosno upravljanja nekim od poljoprivrednih strojeva od strane anketiranih. Čak 71,6% anketiranih ne zna upravljati niti jednim poljoprivrednim strojem. Značajne su razlike s obzirom na studij.




**Grafikon 1** Postotak onih koji znaju upravljati nekim poljoprivrednim strojem s obzirom na studij, izvor: Anketa

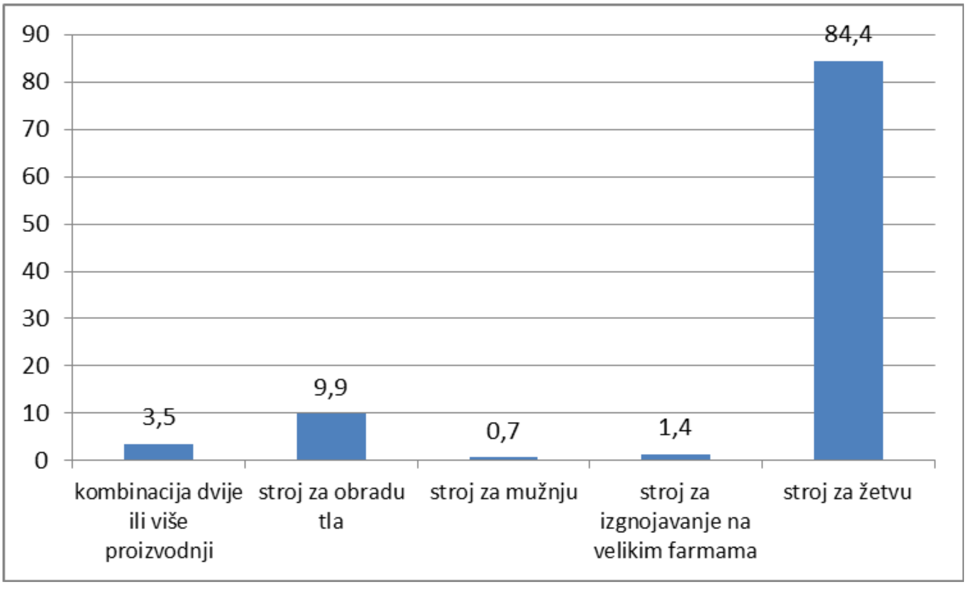
Najveći postotak onih koji znaju koristiti neki od strojeva su kod studija Biljne znanosti, a najmanji Ekološka poljoprivreda.

Statistički je značajna ($\chi^2$-17,984; p-0,000) razlika poznavanja upravljanja strojevima s obzirom na spol anketiranih pri čemu je veći postotak muških (52,3%) nego žena (17,5%).

Također su značajne razlike i s obzirom na podrijetlo pri čemu je znatno više koji znaju upravljati iz ruralnih (44,4%) nego urbanih (20,8%) sredina. Najveći dio ih zna upravljati traktorom, zatim frezom, motokultivatorom te najmanje sa kombajnom.

Za početak smo pokušali dobiti informacije o razini njihovih općih znanja o poljoprivrednoj mehanizaciji te smo im i ponudili nekoliko jednostavnih pitanja.

Prvo pitanje je bilo „Što se ne koristi u obradu tla“ pri čemu smo im kao odgovore ponudili traktor, motokultivator, kombajn i drljaču. Dvije trećine anketiranih (65,2%) je znalo da je to kombajn, skoro trećina (26,2%) misli da je to motokultivator, znatno manje (7,1%) drljača te da je to traktor njih 1,4%. Muški ispitanici su u znatnom većem postotku (77,3%) točno odgovorili u odnosu na žene (59,8%). Također, ispitanici iz ruralnih sredina više su znali točan odgovor (80,0%) nego oni iz urbanih (58,3%). Na izravno pitanje „Što je poljoprivredni kombajn?“ većina ih je dalo točan odgovor.



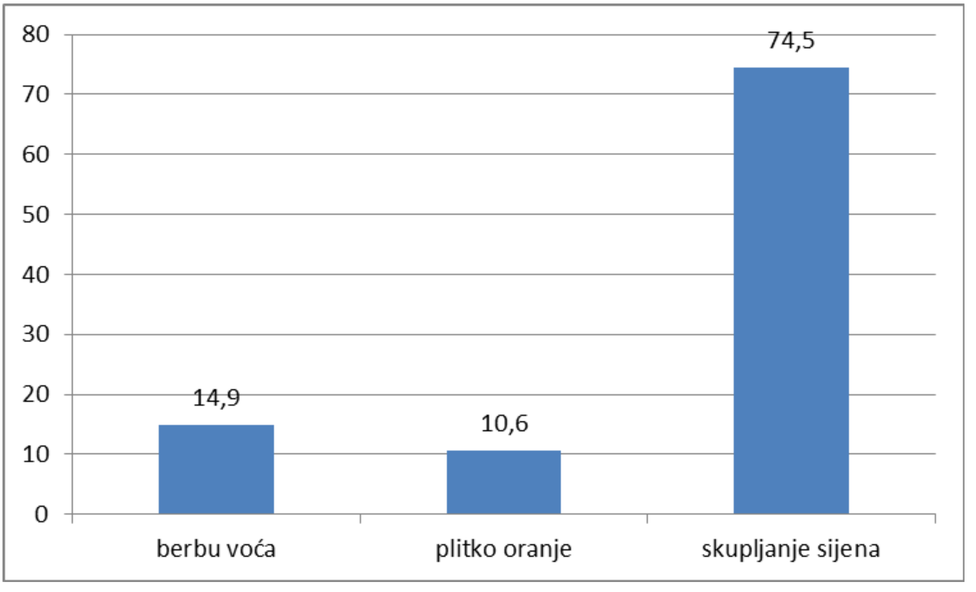

**Grafikon 2** Što je poljoprivredni kombajn, izvor: isti kao za Grafikon 1

Kod odgovora na ovo pitanje nisu zabilježene značajnije razlike s obzirom na spol i podrijetlo ($\chi^2$-5,741; p-0,219).

Na pitanje koliko redova sije četveroredna sijačica većina ispitanika (83,%) odgovorilo je *četiri reda*, dok njih 6,4% smatra da se broj redova *može podesiti*. Mogućnost ostalih odgovora bila je da četveroredna sijačica sije *dva* (2,8% anketiranih), *šest* (3,5%) ili *osam* (3,5%) redova.

Rigolanje je uobičajen zahvat kod obrade tla. Većina ispitanih (65,2%) točno je odgovorilo da je rigolanje *oranje na dubinu više od 50 cm*, dok ih 24,1% misli da je to *postupak usitnjavanja prije sjetve*, *postupak kod žetve pšenice* (7,8%) te *problem kod* *preživača* (2,8%). U točnosti na ovo pitanje nisu utvrđene statistički značajnije razlike s obzirom na spol i podrijetlo, ali jeste s obzirom na studij anketiranih ($\chi^2$-42,217; p-0,001).

Na pitanje o primjeni rolopreše većina ispitanika (74,5%) je odgovorila točno tj. da se primjenjuje pri sakupljanju sijena.




**Grafikon 3** Za što se koristi rolopreša, izvor: isti kao za Grafikon 1

Kod točnosti odgovora nema razlika s obzirom na spol (muški 75% i žene 74%), ali su značajnije razlike s obzirom na podrijetlo (urbano 68,8% i ruralno 867%).

Anketiranim smo ponudili nekoliko tvrdnji za koje su mogli izraziti svoju suglasnost i to sa „opće 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 poljoprivredna mehanizacija jedan od preduvjeta uspješne proizvodnje. Ispitanici pod pojmom uspjeha misli na količinu proizvodnje po jedinici kapaciteta te na manji utrošak rada ljudi tj. živog rada.

Jedan od značajnih problema kod poljoprivredne mehanizacije je njena visoka cijena. Anketirani ispravno i sa visokom suglasnošću prihvaćaju tvrdnju da bi se udruživanjem proizvođača smanjili troškovi mehanizacije po gospodarstvu. Postoji statistički značajna razlika s obzirom na spol ispitanika ($\chi^2$-14,842; p-0,002) pri čemu to misli 84,1% muških te 62,8% ženskih.

Zajednički kupljena mehanizacija imala bi više dana godišnje iskoristivosti što bi u konačnici troškovno manje opteretilo proizvodnju odnosno smanjilo cijenu koštanja. Upotreba mehanizacije pridonijela je povećanju proizvodnje što je dijelom utjecalo na smanjenje prosječnih troškova proizvodnje (Matić, 2004).

**Tablica 1** Suglasnost s nekim tvrdnjama o poljoprivrednoj mehanizaciji

| | Min | Max | Srednja vrijednost | Standardna devijacija |
|---|---|---|---|---|
| Mehanizacija je preduvjet uspješnoj proizvodnji | 1 | 5 | 4,16 | 0,931 |
| Udruživanjem proizvođača smanjili bi se troškovi mehanizacije | 1 | 5 | 3,94 | 0,868 |
| Mehanizacija smanjuje troškove proizvodnje | 1 | 5 | 3,74 | 0,929 |
| Za bolje korištenje mehanizacije potrebno je i formalno obrazovanje | 1 | 5 | 3,30 | 1,019 |
| Poljoprivrednici rado prihvaćaju inovacije kod mehanizacije | 1 | 5 | 3,04 | 0,944 |
| Mehanizacija je u RH u odnosu na druge države EU u prosjeku „mlađa“ | 1 | 5 | 3,03 | 1,265 |
| Primjena mehanizacije smanjuje onečišćenje okoliša | 1 | 5 | 2,26 | 0,938 |
| Primjena mehanizacije smanjuje produktivnost u poljoprivredi | 1 | 5 | 2,04 | 0,977 |

Izvor: isti kao za Grafikon 1

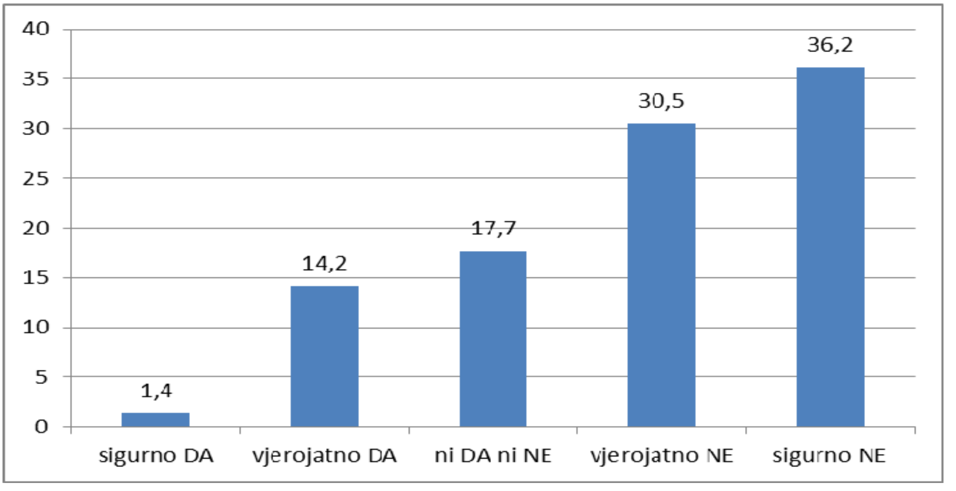
Anketirani nisu sigurni koliko bi formalno obrazovanje pripomoglo boljem korištenju mehanizacije kao i da poljoprivrednici rado prihvaćaju inovacije kod mehanizacije. Također su svjesni da poljoprivredna mehanizacija utječe na onečišćenje okoliša ali i da značajno djeluje na povećanje produktivnosti rada u poljoprivredi.

Prilikom upisa na fakultet mnogi pristupnici su loše informirani o studijima i studijskim programima. Tako i nakon nekoliko mjeseci studija njih jedna trećina ne zna da na Agronomskom fakultetu postoji preddiplomski studij koji izučava poljoprivrednu mehanizaciju. S obzirom na spol ne postoji razlika u znanju (68,2% muški te 65,9% žene), ali je veća razlika s obzirom na podrijetlo (59,4% urbano te 80,0% ruralno). Od onih koji znaju da postoji veći dio (85%) ih zna da se radi o studiju Poljoprivredna tehnika.

Manji postotak (47,5%) ih zna da na Agronomskom fakultetu postoji diplomski studij na „kojem se izučava poljoprivredna mehanizacija“. Ne postoje statistički značajne razlike s obzirom na spol i podrijetlo, a nešto su veće s obzirom na studij (najveći udjel koji zna su studija Ekološka poljoprivreda, a najmanji Agrarna ekonomika).

Brkić i sur. (2002) su došli do zaključka da je stav studenata prema stručnom obrazovanju poljoprivrednika u tijesnoj vezi s njihovim profesionalnim aspiracijama u pogledu obiteljske poljoprivrede. Studenti će stoga, upisati one module, koje mogu primijeniti u svojoj budućoj profesionalnoj karijeri. Na pitanje o mogućem upisu izbornog modula koji izučava poljoprivrednu mehanizaciju preko dvije trećine ispitanika vjerojatno ili sigurno ne bi upisalo takav modul.

Od onih koji su izrazili želju za upisom takvog modula, iako ne postoji statistički velike razlike, ipak veći udjel je muških, iz ruralnog područja, sa završenom srednjom poljoprivrednom školom te studija Biljne znanosti.




**Grafikon 4** Biste li upisali izborni predmet koji izučava poljoprivrednu mehanizaciju, izvor: isti kao za Grafikon 1

## ZAKLJUČAK

Suvremena poljoprivreda nezamisliva je bez upotrebe mehanizacije koja zbog tehničkog napretka traži i sve veću razinu znanja onih koji je koriste. Agronomski fakultet je davno prepoznao potrebu za takvim znanjima i kod poljoprivrednih stručnjaka te im to i omogućava u većoj (preddiplomski i diplomski studij Poljoprivredna tehnika) ili manjoj mjeri (drugi studiji Fakulteta).

Iako je došlo do značajne promjene strukture osoba 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 zadovoljavajuće. Višu razinu znanja imaju muškarci i oni odrasli u ruralnoj sredini te studija Biljne znanosti.

Iako većina anketiranih prepoznaje važnost mehanizacije za poljoprivrednu proizvodnju, relativno mali dio bi ih upisao izborni modul u kojem bi dobili više znanja o toj problematici.

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# AGRONOMY STUDENTS' KNOWLEDGE ABOUT THE AGRICULTURAL MECHANIZATION

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## ABSTRACT

*Agricultural production has to fulfill several objectives. The most important is the quantity production and quality sufficient quantities of products that are cost-effective to producers and to consumers. No less substantial goal is to minimize pollution of the manufacturing area. Agricultural machinery and its use occupy an important position in achieving these objectives. One of the prerequisites of good agricultural mechanization management, in technological and economic regard, is current knowledge and as well the knowledge acquired during the study of the future of agricultural experts. This paper is based on the assumption that the first year students of the Faculty of Agriculture are insufficiently familiar with agricultural machinery and therefore during the study students should get more knowledge about it. The survey involved 141 persons, of whom the greater part (77.3%) was the first and smaller (22.7%) in the second year of undergraduate study. Survey does not include students of agricultural engineering and landscape architecture studies. The largest part of respondents (68.8%) is female students, grew up in urban areas (68.1%), with gymnasium high school (62.4%). Only 5.7% of respondents completed the agriculture high school.*

*Respondents' knowledge about agricultural mechanization is still satisfying although 71.6% of them do not know how to manage any agricultural machine.*

*Over 80% of respondents know for what is harvester used a little less of them who know that baler is applied in collecting hay (74%) and that the deep plowing is a plowing to a depth of more than 50 cm (65.2%).*

*The most respondents recognize the importance of mechanization for agricultural production as well as the need for its appropriate use. However, the majority of respondents (67%) would not enroll collegium that studied agricultural machinery as an elective collegium.*

*Better knowledge of machinery was observed in the male part of the respondents and those who come and adults in rural areas.*

***Key words**: agricultural machinery, students, agronomy*