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Operating, ecological and economical properties of biofuels on rape oil basis

A. Podolák, P. Lenďák, R. Škulec

Slovak University of Agriculture, Nitra, Slovak Republic

ABSTRACT: Methylester rape oil (RME) is an alternative, renewable fuel for diesel combustion engines. It is obtained by transesterification of rape oil, because unrefined rape oil is not suitable for direct application in common types of diesel engines. There is an assumption that approximately up to 10% of diesel fuel can be replaced by RME, or RME – based mixed fuels (BIOMON and BIOMON 97). In this paper, a notice is given of a comparison of working and ecological properties of biofuels and diesel fuel (MN). A Z-8701.12 engine was used for testing. The biological degradability of RME was to be over 99% during 21 days. CO_2 generated at combustion of biofuels does not increase the greenhouse effect as it is absorbed by photosynthesis of the plant growth. The intensity of smoking of exhaust gases at nominal engine speed is only 46.1% for RME, 50% for BIOMON and 54% for BIOMON 97, as compared with diesel. If the results for diesel fuel are considered to be 100%, the values with the use of RME, BIOMON and BIOMON 97 at nominal engine speed are following: power is decreased by 3–6% (an effect of lower combustion efficiency), fuel consumption increases by 7.2% for RME, decreases by 3.1% for BIOMON 97 and decreases 7.5% for BIOMON (an effect of difference in fuel specific weight), and specific fuel consumption shows 11.5% increase for RME, 0.3% increase for BIOMON 97 and 2.3% decrease for BIOMON.

Keywords: diesel fuel; RME; mixed biofuel BIOMON and BIOMON 97; smoking; biological degradability; specific fuel consumption

Development of living standard in present society causes a permanent increase of energy consumption, that at present are mainly obtained from fossil fuel. In Slovak Republic (SR) there are only about 10% of local energy sources. As for fuels for combustion engines the situation is much worse, only 2% of petroleum consumption come from local sources. Petroleum is an exhaustible resource and there is a theorem that the production of petroleum based fuels wills rapidly decrease in next 30–40 years. Extracting, processing, distribution and consumption of petroleum-based fuels brings lot of ecological problems. Plant based oils (from rape, sunflower...) are a promise of the optimal approach to the problem of finding a new line of fuel acquisition which would decrease the ecological load of environment and would also be renewable. Rape is the most advantageous oil plant in our climatic conditions (PETRANSKÝ et al. 1997; PODOLÁK et al. 1997).

Plant based oils are suitable for application to diesel internal combustion engines with direct fuel injection, because they have high specific weight (around 880 g/mol). Their volatile ability is low which causes imperfect combustion and carbonization of the working area. This problem has been solved by transesterification of rape oil using methanol – MeOH and alkaline catalyst NaOH. The product of this process is rape methylester – RME and glycerol. In SR the RME is produced under PN 7601 in ZŤS Martin. Properties and components of oil produced under PN 7601 are very close to standards ÖNORM C 1190 and CSN 65 6507. RME is an ecologic and renewable fuel for direct application in diesel combustion engines, it has no demands for engine adaptation. In SR there exist five RME producers with the capacity of production 500 t per year and two producers with the capacity of production 1,500 t per year.

We think of the ecological fuel as a fuel that is biologically degradable over 90% during 21 days (according to CEC L-33-T-82). RME is degradable accoring to the abovementioned test close to 99% during 21 days. Diesel oil fuel is degradable according to the above-mentioned test by 72%. RME is suitable for direct application to diesel combustion engines and it is possible to mix it with petroleum based diesel fuel in an arbitrary ratio. RME have not find application in agriculture practice because of 50% higher production cost as sale price of diesel oil. This is the reason for producers to mix biofuels with diesel fuel. This product is called BIODIESEL. Biodiesel consists of 30% weight RME and the rest are degradable aliphatic carbohydrates or diesel fuel, by this they reach 90% degradability. In SR there are established three producers of mixed biodiesel: BIO plus, a. s., Spišská Nová Ves produces BIOMON and BIOMON 97; EKOIL, a. s., Bratislava produces Biopal and PETROCHEMA, a. s., Dubová produces Enviropal 4,22.

In SR does have not exist a STN (Slovak Technical Norm) for mixed biodiesel production as yet. The authors tested mixed biodiesel BIOMON produced under PN 010395 by BIO-BHMG, s. r. o., Sp. Hrušov. This is a mixture of RME and light alifatic carbohydrates. For BIOMON 97 there is a PN only in form of draft. This fuel consists of RME mixed light alifatic carbohydrates and diesel fuel.

As effect of food over-production the agricultural land is being released for non-food production. It is a realistic assumption that in SR it is possible to use about 100,000 ha agricultural land (especially contaminated ones) for non-food activities like RME production. This makes possible to produce 100,000 t RME yearly and that is 10% from the yearly diesel fuel consumption. The same scopes are in the Czech Republic and other western European countries.

MATERIAL AND METHODS

The scope of this work involves valuation of operational, ecological and economical properties of RME, BIOMON and BIOMON 97 biodiesel and their comparison with diesel fuel as applied in diesel combustion engines.

The scientists of the Department of Vehicles and Heating Devices of the Faculty of Engineering at the Slovak Agricultural University in Nitra deal with above mentioned theme as with a partial theme in the Grant project *Theoretical analysis and experimental checking of internal combustion engines, transmissions and hydraulic mechanisms of agricultural tractors with respect to the application of biodegradable liquids – biofuels and bio-oils.*

The measurements were make at the department laboratory by loading of diesel internal combustion engine Z-8701.12 built-in in a ZTS 122 45 tractor. This tractor was P.T.O. loaded under STN ISO 789-1 (30 0441) standard. Speed range was installed between the P.T.O. and the comutator load cell. A gearbox with conversion to fast.

The units arrangement enabled to measure directly:
- load cell operating speed,
- load factor of load cell,
- engine speed,
- the time of selected fuel consumption,
- temperature: ambient, cooling liquid, engine oil, exhaust gas,
- atmospheric pressure,
- the pressure of engine oil,
- relative air humidity,
- smoking of engine.

From measured units following data were calculated:
- engine power,
- fuel consumption,
- specific fuel consumption.

The mechanical efficiency of performance transmission to P.T.O. was determined by comparing of results of direct engine measurement with results of measurements of the same tractor through P.T.O. and gearbox.

RESULTS AND CONCLUSION

We can compare three types of biodiesels properties with the properties of diesel fuel based on measurement evaluation from following aspects:

OPERATIONAL PROPERTIES

RME application results in the engine oil thinning and it is necessary to change it 30–50% sooner. Thinning is caused by high concentration of heavy carbohydrates of RME and fuel saturated to engine oil is slowly evaporation and that is reason of the oil viscosity drop down. The thinning effects as bigger as the performance of engine is higher (lower oil temperature). At present by adding of additives to RME is above-mentioned effect reduced and is not needs to abbreviate the change intervals (change it sooner). By application of mixed biodiesel is the thinning of engine oil negligible.

By application of RME was registered the defection coating composition and etching of fuel pipeline as sealing rings. This negative effect is possible to eliminate by using superior material of sealing rings, fuel pipelines and coating composition. By application of mixed biodiesel is this problem negligible. At the beginning was problem to start the engine by temperature –5 to –10°C. By application of additives is starting of engine till –20°C temperature good.

TECHNICAL PARAMETERS OF ENGINE

The difference at engine power P_e and torque moment M_k is 3–6% lower by biodiesels than diesel fuel.
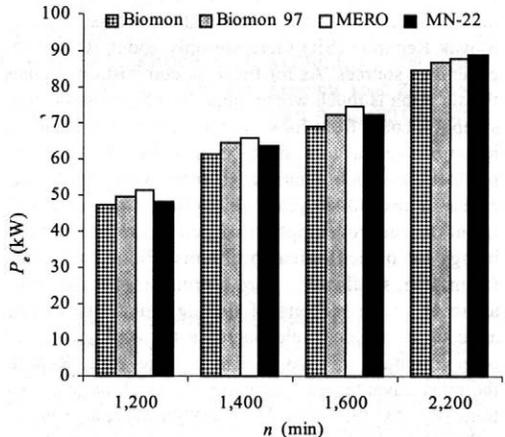
Fig. 1. Engine power

Differences are relatively more acceptable for RME as it follow from heat value difference of each fuel (MN 42.5 MJ/kg, RME 37.1 MJ/kg, BIOMON 42.5 MJ/kg, BIOMON 97 42.7 MJ/kg). The reason of this is that by injection of same geometric size of fuel is different its weight that is effect of different mass ratio (MN 825 kg/m^3, RME 890 kg/m^3, BIOMON 778 kg/m^3, BIOMON 97 811 kg/m^3). The engine power by RME application is highest against other fuels by overloading and

1,400 min engine speed n. Specific fuel consumption m_{pe} is most less by BIOMON application (is a probability of more ideal aliphatic carbohydrates combustion). The worst acceptable are results by RME application, but they are no worse as 10% against diesel fuel.

Fig. 2. Specific fuel consumption

ECOLOGICAL PROPERTIES

The biodiesels have much better biological degradability (RME 99%, BIOMON 93%, BIOMON 97 92%, MN 72%). In some Europe countries the application of mixed biodiesel consists of RME and diesel fuel has become a routine. Till 30% part of RME in mixed biodiesel is this fuel markedly ecological then diesel fuel. This point has big influence on eco-food producing and for established of ecological agriculture as whole.
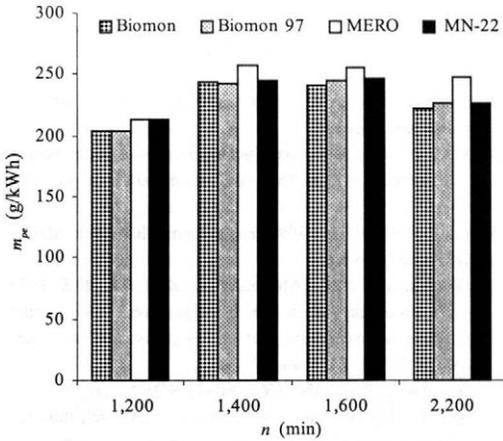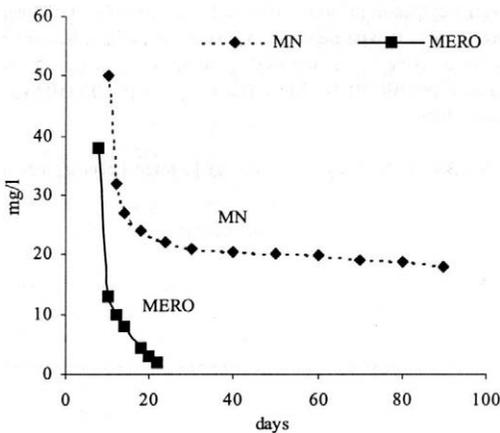

Fig. 3. Biological degradability of fuel (ANONYM 1995)
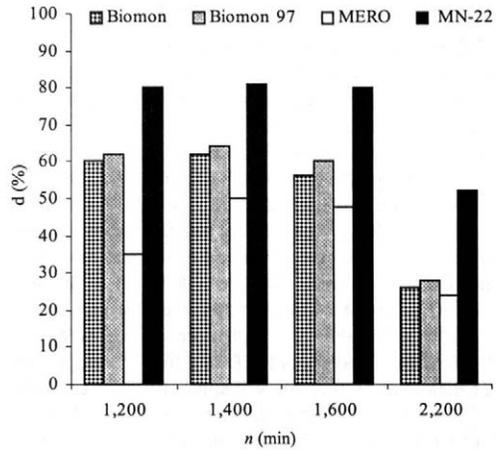
Fig. 4. Smoking of engine

The indicator of diesel fuel combustion effectively is degree of smoking that is more acceptable by biofuel application than as diesel fuel. If we take the parameters of diesel fuel as 100%, than decrement of biodiesels smoking units is by nominal engine speed n_n following: RME = −53.9%, BIOMON = −50%, BIOMON 97 = −46%. The results of smoking measurements are more acceptable for biodiesels by engine overload. The SO_2, CO and CH_x capacity is markedly decrease and the NO_x capacity is bigger and depended of engine type.
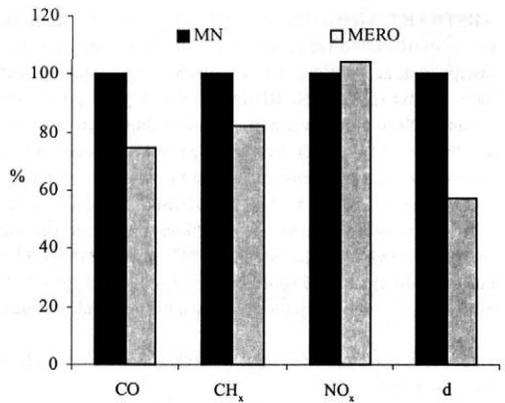
Fig. 5. Emission content in exhaust gases (KNOR, FRAŇO 1993)

Important unit of biodiesels combustion is CO_2 capacity. The CO_2 produced by biodiesels combustion is consumed for biomass growing that is a reason of greenhouse effect non-increasing. The oxygen capacity higher degree cause more ideal combustion (decrease smoking degree, decrease CO, CH_x and carcinoma elements capacity).

ECONOMIC PERFORMANCES

According to data *Report about situation of Slovak agriculture and food industry* from 1997, as according to producers data the outgoings for RME production in SR was from 30 till 32 SKK/kg, that is approximately about 50% more than diesel fuel sale price.

Even through the amendment of 316/93 z.z. law cover to excise duty of carbohydrates based on which the biodiesel as RME (maximal petroleum based carbohydrates 5%) is tax exemption and ecological fuel (minimal RME contents is 30%) which be up to standard of CEC L-33-T-82 test and then is biologically degradable to minimum 90% and more daring 21 days is 1,000 SKK/t taxation, is RME as a fuel to transport and mechanizations machines inapplicable for economical reasons. The cost price of mixed biodiesels is 15–18 SKK/kg because of lower price of aliphatic carbohydrates; its sale price is 16–18 SKK/kg. The RME price decreasing cause the 20% subsidy of cost price from SR Agricultural Ministry to RME produced in SR in 1996 and 1998.

Following to measurement results of biodiesels application to internal combustion diesel engine with direct injection we can to state following results: application of rape based biodiesels is real, mixed biodiesels as revival fuel, have good physical, technical and economical properties comparable with the petroleum based fuels by markedly acceptable level of ecological properties above mentioned fuels. The results of measurements accredit the results of other tests and measurements at Department of Vehicles and Heating Devices, Faculty of Engineering, Slovak Agricultural University in Nitra performed as the results of other institution and authors tests. In SR is a real ability to change 10% of diesel fuel consumption by biodiesel.

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Prevádzkovo-ekologické a ekonomické vlastnosti biopalív na báze repkového oleja

ABSTRAKT: Metylester repkového oleja (MERO) je alternatívna náhrada motorovej nafty v spaľovacom motore. Je získaný reesterifikáciou repkového oleja, pretože čistý repkový olej nie je vhodný pre priame použitie v naftovom motore. Je predpoklad, že približne 10 % spotrebovanej motorovej nafty možno nahradiť alebo MERO, alebo zmesnými palivami na báze MERO (BIOMON, BIOMON 97). V práci porovnávame prevádzkovo-ekologické a ekonomické vlastnosti biopalív s vlastnosťami motorovej nafty. Na skúšobné účely bol použitý motor Z-8701.12. Biologická rozložiteľnosť MERO je viac ako 99 % za 21 dní. CO_2 vytváraný pri spaľovaní biopalív nezvyšuje skleníkový efekt, lebo je absorbovaný v procese fotosyntézy pri pestovaní rastlín. Intenzita dymenia výfukových plynov pri nominálnych otáčkach motora je pre MERO len 46,1 %, pre BIOMON 50 % a pre BIOMON 97 54 % v porovnaní s dymením pri motorovej nafte. Ak hodnoty motorovej nafty považujeme za 100 %, tak pokles výkonu je pre biopalivá 3–6 % (závisí najmä od výhrevnosti paliva), hodinová spotreba je vyššia o 7,2 % pre MERO, pre BIOMON 97 je nižšia o 3,1 % a pre BIOMON je nižšia o 7,5 % (závisí od hustoty paliva) a merná spotreba paliva pre MERO je o 11,5 % vyššia, pre BIOMON 97 je vyššia o 0,3 % a pre BIOMON je nižšia o 2,3 % ako pre motorovú naftu pri nominálnych otáčkach motora.

Kľúčové slová: motorová nafta; MERO; zmesná bionafta BIOMON a BIOMON 97; dymenie; biologická rozložiteľnosť; merná spotreba paliva

Corresponding author:

Doc. Ing. ANTON PODOLÁK, PhD., Slovenská poľnohospodárska univerzita, Mechanizačná fakulta, Trieda A. Hlinku 2, 949 76 Nitra, Slovenská republika, tel.: + 421 87 651 32 44, fax: + 421 87 741 70 03, e-mail: lendak@mech.uniag.sk

Ethanol production by Debranning method in grain processing

L. Sychra, J. Mareček

Mendel University of Agriculture and Forestry, Brno, Czech Republic

ABSTRACT: During a whole technological process of ethanol production, cellulose coat layers of grain play an adverse role and particularly take part in the production of distiller's solubles. Therefore, the study was focused on a technological process of removing the grain cellulose coat layer. A traditional milling process, a very good method to separate grain cellulose coat layers, increases starch content in milled fractions providing flour. This processing, however, would be too expensive for ethanol production from cereals. Therefore, a new technique for removing cellulose coat layers of wheat grain by a new modern method of debranning was used. Very important parameter of grain for milling process is content of fibre in grain before Debranning and after Debranning. Content of fibre before using Debranning method was 1.76%. Content of fibre after using Debranning was 0.69%.

Keywords: wheat variety *Astella*; triticale variety *Ring*; protein; fat; starch; fibre

Considering the cereal grain processing for ethanol, a primary step of the whole process is an enzymatic hydrolysis of plant polysaccharide starch, which is present in grain endosperm as a storage substance, to fermentable monosaccharides by means of syntetically produced alfa-amylase. These are then subjected to a distillery fermentative process using yeast *Saccharomyces cerevisae* ending with distillation that results in production of ethanol (VELÍŠEK 1999) and the distiller's solubles that are a suitable raw material for feed production due to higher protein and amino acid content (ROSENBERGER, WALTER 1984; WU et al. 1984; WU 1986). Through the whole process, cellulose coat layers of grain play an adverse role and particularly take part in the production of distiller's solubles. Therefore, the study was focused on a technological process for removing the grain cellulose coat layers.

Grain abrasion using a machine for production of pearled barley was tested first, however, it did not fit at all. Then, a classical milling process was used to separate the grain endosperm in a set of rolling mills and sieves. The final product is flour – grain endosperm containing particularly polysaccharide starch and grain storage protein, and coat layers (POMERANZ 1988). Grain of the variety *Astella* (a variety suitable for ethanol production) was milled. Classical milling is a suitable process to separate cellulose coat layers of grain and increases starch content in milling fractions producing flour similarly to both bread wheat *Hana* and the variety *Astella* that showed to be a suitable variety

for ethanol production at an average flour-milling yield of 70% (Table 1). However, this technology would be too expensive to produce ethanol from cereals.

Table 1. Evaluation of milling process of variety *Hana* and *Astella*

Variety	Starch (%)	Protein (%)	Quantity (kg)	Yield (%)
Hana	65.6	11.6	500.0	
Hana – flour	81.4	11.4	355.0	71.0
Hana – bran	32.0	14.8	139.0	
Astella	68.3	11.0	500.0	
Astella – flour	83.0	10.4	341.0	68.0
Astella – bran	38.5	15.3	150.0	

Therefore, a new method known as Tkac's process (MÜLLER, TRNKA 1997; DEXTER et al. 1994) was applied to remove the grain layers (debranning). This method which combines peeling and abrasion allows the grain layers of wheat and triticale, to be separated into three fractions designated A, B and C.

The first fraction (A) contains insoluble (mostly ballast cellulose) and soluble fibre with arabinoxylans and beta-glucans (CUI et al. 1999). The second (B) and the third (C) fractions contain nutritionally valuable substances of aleurone and subaleurone layers. They can be added to distiller's solubles to thicken and increase the nutritional value of the solubles and to use them as a suitable feed or in products for human nutrition

(DEXTER, WOOD 1996; CUI et al. 1999). The last fraction is starch endosperm (debranned grain) that can be used for fermentative production of ethanol. The yield of the process is up to ca. 85–86%.

MATERIAL AND METHODS

The milling experiment according to Tkac's method was conducted in co-operation with Prokop Milling Machines in Pardubice (Czech Republic) using their device. The wheat variety *Astella* (suitable for ethanol production) and triticale variety *Ring* were used in this experiment. Analyses of three obtained coat fractions A, B and C, and debranned grain of the mentioned varieties were carried out.

Both layers obtained and the debranned grain of wheat and triticale of the *Astella* and *Ring* varieties were analysed for the following parameters: protein, fat, starch, phosphorus, potassium, calcium and magnesium, and fibre. These parameters were assessed using standard methods according to AOAC (1990), ICC (1996) and AACC (1995).

RESULTS AND DISCUSSION

All measured analytical values for individual fractions of debranning in comparison with whole grain are presented in Table 2 and 3.

Protein content (Table 2) increased in grain after debranning both in fractions B and C in both wheat and triticale in comparison with non-processed grain. By contrast, fraction A (cellulose coat layer of grain) exhibited a several times lower protein content. All fractions in triticale contained a higher proportion of pro-

tein than wheat fractions while the whole grain of the triticale variety *Ring* had 1.3% higher protein content than grain of the wheat variety *Astella*.

A significant increase of starch content (Table 2) in wheat and triticale grain was determined after debranning and its decrease was found in all the three coat fractions (A, B, C) when the lowest proportion among coat fractions was in fraction A and the highest one in fraction B for non-processed wheat grain. Fraction C in triticale showed higher starch content than in wheat and fraction B showed contrary values. An important finding of increased starch content in grain after debranning, a fraction that is determined for further process of ethanol production, allows to increase ethanol yield in both cereals.

Further, a considerable decrease (2.6 – fold) in fibre content in comparison with whole grain was observed in wheat and triticale (Table 2). The results show that the highest portion of insoluble fibre was found in fraction A. Fractions B and C did not contain such amounts of fibre. Its content vs. non-processed grain was 105.1% higher in fraction B and 107.9% higher in fraction C.

In both fractions and whole grain before debranning, triticale exhibited a lower portion of fibre than wheat. A lower portion of fibre in the fraction after debranning will allow to decrease the content also in distiller's solubles that are part of ethanol production from cereals and are promising raw materials for feed-stuff industry. Lower fibre content associated with increased fat content (see below) in fractions B and C enables to add these fractions to liquid distiller's solubles without problems.

Fat content (Table 2) showed considerable increase, again in fractions B and C in both wheat and triticale when higher portion of fat in fraction B was found in

Table 2. Structure of grain and fractions after Debranning (%)

	Protein		Fat		Starch		Fibre	
	wheat	triticale	wheat	triticale	wheat	triticale	wheat	triticale
Grain before Debranning	10.26	11.52	1.56	1.43	72.30	70.10	1.76	1.50
Grain after Debranning	10.53	11.75	1.62	1.38	76.20	72.90	0.69	0.57
Fraction A	7.22	8.38	1.36	1.32	33.40	33.50	16.38	14.69
Fraction B	11.25	14.38	3.02	3.51	52.10	45.05	3.61	3.06
Fraction C	12.35	14.38	3.44	3.48	47.00	53.10	3.66	1.54

Table 3. Chemical substitution in grain and in fractions after Debranning (%)

	Phosphorus		Potassium		Calcium		Magnesium	
	wheat	triticale	wheat	triticale	wheat	triticale	wheat	triticale
Grain before Debranning	0.35	0.36	0.48	0.50	0.07	0.07	0.12	0.12
Grain after Debranning	0.31	0.34	0.43	0.46	0.06	0.05	0.11	0.11
Fraction A	0.34	0.31	0.75	0.63	0.13	0.13	0.15	0.14
Fraction B	0.84	1.06	1.23	1.31	0.09	0.09	0.33	0.39
Fraction C	0.96	0.95	1.41	1.18	0.09	0.08	0.40	0.35

triticale than in wheat. The decrease was determined in fraction A as compared to whole grain of wheat and triticale.

Phosphorus and potassium (Table 3) content in processed grain of wheat and triticale after debranning was slightly decreasing. On the contrary, their content in both wheat and triticale increased several times in fractions B and C. A value of phosphorus in fraction A was almost identical with the content in non-processed grain. The increase in potassium content in fraction A vs. whole grain is higher in wheat than in triticale.

In calcium content (Table 3) the decrease was determined in debranned grain, which was more distinct for triticale, and increase in fractions A, B and C. The highest amount of calcium in both wheat and triticale was found in fraction A.

Magnesium, a very important mineral element, with its increased concentration was present mostly in fractions B and C vs. whole grain of both wheat and triticale (Table 3). Its highest content was determined in fraction C for wheat and in fraction B for triticale. This analytical finding along with a higher level of potassium and phosphorus improve a favourable effect of adding fractions B and C to liquid distiller's solubles. There was only a slight increase in fraction A. In processed whole grain, by contrast, magnesium content decreased.

CONCLUSION

All obtained results clearly indicate the importance of debranning in the pre-final processing of cereals used for ethanol production. Yield of debranned grain is ca. 15% higher than in a classical milling process. Moreover, obtained fractions separate ballast cellulose coat layers (fraction A) for feeding purposes from nutritionally beneficial aleurone and subaleurone layers (fractions B and C). These contain lower content of fibre, increased content of protein, fat, phosphorus, potassium and magnesium in both wheat and triticale. Therefore, these fractions can be used to thicken syrup-like grain distiller's solubles and thus to improve the feeding value.

Very important parameter of grain for milling process is the content of fibre in grain before Debranning and after Debranning. Content of fibre before using Debranning method was 1.76%. Content of fibre after using Debranning was 0.69%.

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Výroba etanolu s použitím metody Debranning pro úpravu zrna

ABSTRAKT: Veškeré výsledky zcela jasně ukazují na významnost metody Debranning při prefinalizačním procesu obilovin, určených pro výrobu etanolu. Výtěžnost oloupaného zrna je asi o 15% vyšší než u klasického mlýnského procesu a získané frakce oddělují z hlediska krmivářského použití balastní celulózovou obalovou vrstvu (frakce A) od nutričně zajímavých

aleuronových a subaleuronových vrstev (frakce B a C). Ty obsahují jak u pšenice, tak u tritikale snížený obsah vlákniny, zvýšený obsah bílkovin, tuku, fosforu, draslíku a hořčíku. Proto tyto frakce mohou být použity k zahuštění sirupovitých destilačních obilních výpalků, u kterých budou zvyšovat jejich krmivářskou hodnotu. Velmi významným parametrem pro zrno, použité pro mletí a následnou produkci etanolu, je obsah vlákniny v zrnu před Debranningem a po této operaci. Obsah vlákniny v zrnu před použitím metody Debranning byl 1,76 %. Obsah vlákniny v zrnu po použití metody Debranning byl 0,69 %.

Klíčová slova: pšenice *Astella*; tritikale *Ring*; bílkoviny; tuk; škrob; vláknina

Corresponding author:

Dr. Ing. LUBOŠ SYCHRA, Mendelova zemědělská a lesnická univerzita, Zemědělská 1, 613 00 Brno, Česká republika, tel.: + 420 5 45 13 29 18, fax: + 420 5 45 13 29 14, e-mail: sychra@mendelu.cz

Control of the quality of operation of industrial fertilizer spreaders in the system of "precision farming"

P. Sedlák[1], F. Bauer[1], A. Neischl[2]

[1] Mendel University of Agriculture and Forestry, Department of Agricultural Machinery, Brno
[2] MJM Group, a. s., Litovel, Czech Republic

ABSTRACT: The Twin Bin pneumatic spreader mounted on the Terra Gator 8103 self-propelled undercarriage was used to control the quality of application of mineral fertilizers in the system of "precision farming". The machine is fitted with a Falcon board computer and has a receiver of the DGPS signal to locate the immediate position. The variable dosing of fertilizers from both bins is based on data from application maps inserted into the board computer and from data of the navigation system about the position of the machine. In the trials we used the amofos and potassium salt fertilizers. First of all we checked the transversal and longitudinal evenness of application for a constant fertilizer dose of 150 kg/ha, 254 kg/ha and 260 kg/ha. The calculated variance coefficient for transversal and longitudinal unevenness was not more than 5.8%. Measurements of the variable application showed that the required dose of amofos ranged between 53.2 and 158.4 kg/ha and of potassium salt between 0 and 336.3 kg/ha. The absolute deviation of the actual dose of both fertilizers applied simultaneously was not more than 4.6%. The results were processed statistically and plotted in diagrams. The test of linear independence proved that deviations from the required doses of both simultaneously applied fertilizers were not dependent on the speed of operation or on the dose. The results of all the measurements proved that the machine maintains the required dose with a high accuracy.

Keywords: precision farming; spreader; variable dosing of fertilizers; accuracy of application

To achieve competitive strength on the world market, the costs of the Czech agricultural machinery will have to be reduced. One approach that has lately been adopted in the world and in the Czech Republic is the so-called precision farming system. Recently precision agriculture technologies have spread mainly in the USA and in some countries of Western Europe (DABERKOW, MCBRIDE 2000; DINGEMANS 1997). According to this system the land is a spatial differentiated environment with a variable approach to its individual parts. One practical area in the system of precision farming is the variable application of mineral fertilizers. The Global Positioning System (GPS) using navigation satellites pinpoints the exact position of the machine in the field. The satellites send signals defining their position and the receiver on the machine is able to process the signals and pinpoint its exact position. To prevent any misuse the signal has been equipped with an error message that is removed by the so-called differential GPS (DGPS) from the ground.

Maps of the supply of nutrients in the soil obtained from the network of soil samples are used as initial information for variable application of fertilizers, indicated as Variable Rate Technology (VRT). Basing on these maps and on what the plants require to reach the expected yields, so-called application maps are set up giving information about the quantity of the dose in the respective parts of the field. The board computer of the machine controls fertilizer dosing based on a digital application map inserted in its memory and on the immediate DGPS-defined position (LAWTON 1995; ESCH 1998).

The application of the specified fertilizer dose to the accurate place poses high demands on the control and regulation circuits of the machine, which must consider the changing travel speed, the rate of flow of the material through the machine, the inertia of the individual parts etc. Otherwise the operation will be very inaccurate.

Although many authors have recently pursued the issue of precision farming in technical literature, we have not come across any publication offering results of specific measurements of the quality of mineral fertilizer applications under variable fertilizing. That is the reason why we decided to deal with this issue. The measurements were conducted at the MJM Group, a. s., Litovel. This firm has been involved in services in the area of precision farming since 1997.

MATERIAL AND METHODS

The self-propelled Terra Gator 8103 Twin Bin distributor spreader was used to test the accuracy of application of industrial fertilizers. The machine is designed as a self-propelled tricycle undercarriage allowing change of the operation superstructures. The undercarriage is equipped with low-pressure flotation tyres reducing the risk of damaging the soil structure and the fertilizer-supplemented stand. The self-propelled undercarriage was equipped with a Twin Bin spreader. The bin is divided into two chambers allowing alternative dosing of two kinds of fertilizers. The fertilizer is conveyed from the bins to the rear part of the machine on a longitudinal conveyer and from there by air flow to the diffusers on the application frame. The FALCON (Fertilizer Applicator Local Control Operating Network) board system is mounted on the machine and is used to monitor the travel speed of the machine, regulates the doses and mixing of the single fertilizers, controls the working parts of the spreader and measurement of the fertilized area. The self-propelled spreader is also equipped with a receiver of the DGPS signal to pinpoint the immediate position. Based on data from the application maps inserted into the board computer and on data of the navigation system showing the position of the machine, variable dosing of the fertilizer is conducted from both chambers. The application maps are compiled beforehand on the basis of localized soil sampling, soil analyses and requirements of the crops.

Since inaccurate dosing is the most frequent in the place where the changes in dosage are the highest, we chose places where the maximal dose is changed on short distances for measurements of the quality of operation of the spreader. To avoid errors caused by the uneven spreading of the fertilizer, the quality of operation of the machine had to be checked in the first place. Before measuring the accuracy of fertilizer dosing in the course of variable application, we adjusted a constant fertilizer dose and controlled the transversal and longitudinal evenness of spreading.

In the course of the measurements of the transversal unevenness, the collectors measuring 0.5 × 0.5 m and distant 0.5 m from each other are spread out normal to the travelling direction. As the machine is equipped with a tricycle undercarriage with wide flotation tyres, the collectors could not be placed between the traversing wheels. Seven collectors were placed under each arm in such a way that the outer arms were under the outside diffusers. As the spreader moved over the collectors, the fertilizer was weighed. Measurements of the transversal unevenness were repeated 5 times. A variance coefficient was calculated from the measured data as follows:

$$V = \frac{1}{\bar{x}}\sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}} \cdot 100 \qquad (\%)$$

where: x_i – weight of the fertilizer in the i-th collector (g),
$\bar{x}$ – the average weight of the fertilizer in the collector (g),
n – number of measurements (–).

During the measurements of the transversal unevenness the collectors were placed parallel with the direction of the passage of the machine. The procedure of measurements and interpretation of the measured data was the same as in the previous test.

The quality of the spreader operation during the application of nitrogenous fertilizers the calculated value of the variance coefficient for transversal and longitudinal unevenness may not exceed 15%; for the application of the other fertilizers 20% and for calcareous fertilizers 30%.

After the control of the transversal and longitudinal evenness of spreading a fixed constant fertilizer dose we began to measure the actual dose during variable application. We used data from the application maps to select places in the field where the change of the dose was the highest. With an off-road automobile equipped with a satellite navigation system we placed three collectors in these places one after the other in distances of 31–80 m. On five selected places on each field we situated 15 collectors. For the accurate localized position of the collectors (accuracy of the navigation system is 0.4 m) situated on the field the required fertilizer doses were obtained from the board computer. After the spreader passed over the collectors, the retained fertilizer was analysed in the laboratory and the components were weighed. For variable fertilization, pellets of phosphorus fertilizer amofos were used in one of the chambers and crystalline potassium salt in the other. It was very easy to separate the original components in the retained mixture and evaluate them separately because the structure of the fertilizers was so different. The actual doses were calculated from the weight of the retained fertilizers. At the same time in each trial the time of the passage of the path between the collectors was measured. From the known path and time the average speed of operation of the spreader was calculated. The deviations from the required dose in dependence on the speed of operation and dose were evaluated statistically using linear regression. Along with the regression coefficients other statistical characteristics were calculated, the regression coefficient, the zone of reliability around the regression coefficient and the confidence interval. The calculated functions were plotted in diagrams.

Whether the measured deviations in the fertilizer dose are dependent on the speed of operation or on the required dose was assessed using the test of linear independence, i.e. test of the zero rate of the correlation coefficient. This test is based on the assumption that the compared data sets are independent if the correlation coefficient is equal to zero. The criterion for the correlation coefficient is the ratio between the selective cor-

Fig. 1. Diagram of transversal unevenness of fertilizer application with the Twin Bin spreader. Adjusted constant dose of 260 kg/ha
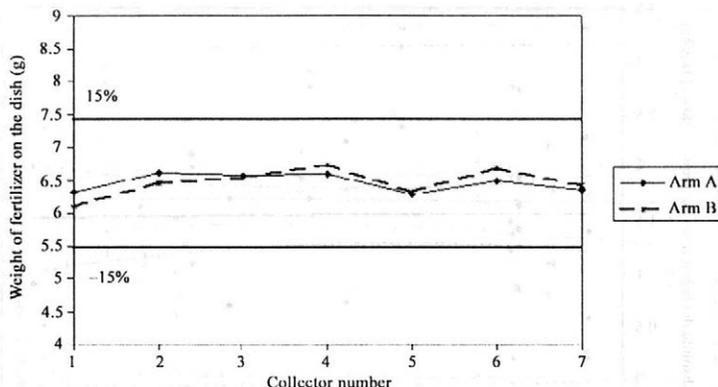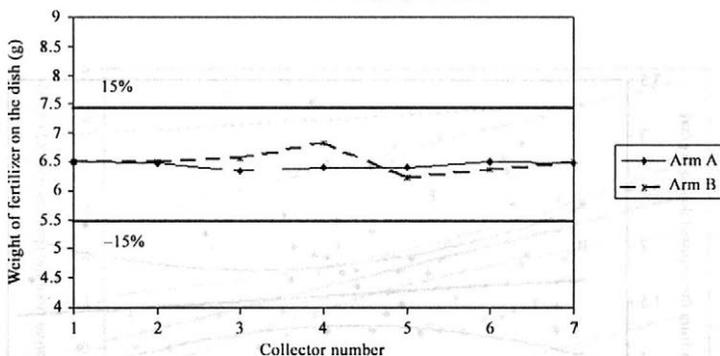

Fig. 2. Diagram of longitudinal unevenness of fertilizer application with the Twin Bin spreader. Adjusted constant dose of 260 kg/ha

relation coefficient and the estimation of its standard deviation. We reject the zero hypothesis when the value of the test criterion is higher than the critical value of the *t*-division to the selected level of significance. Before the test was carried out, the normality of empirical values was verified using the Kolmogorov-Smirnov test of good consistency. In all the measured values of required doses and detected deviations in the doses good consistency was proved with the normal division on the level of significance higher than $\alpha = 0.05$.

RESULTS OF MEASUREMENTS

Control of the transversal and longitudinal evenness of the application was conducted for three constant fertilizer doses, i.e. 260 kg/ha, 254 kg/ha and 150 kg/ha, each in 5 repetitions. Fig. 1 shows the diagram of transversal unevenness of application of 260 kg/ha. Fig. 2 shows the diagram of longitudinal unevenness of the same dose. The calculated variance coefficient for the transversal and longitudinal unevenness ranged between 3.1 and 5.8% and between 2.8 and 4.6%, respec-

tively. However, in all cases the spreader by far met the requirements for even application.

The required dose of the amofos fertilizer for variable dosing ranged between 53.2 kg/ha and 158.4 kg/ha and of the simultaneously spread potassium salt between 0 and 336.3 kg/ha. The measurements revealed deviations from the actual dose of the amofos and potassium salt fertilizers, i.e. between 0.2% and 4.53%, and between 0 and 4.48%, respectively.

During the evaluations of variable applications we observed whether the deviations from the required doses of the fertilizers were dependent on the speed of operation of the spreader or on the amount of the required dose. The measured values were therefore plotted in diagrams (Figs. 3–6) and statistically evaluated using linear regression. At the same time the 95% confidence interval of each regression line (dot-and-dash line) and the 95% zone of reliability around the calculated function (dashed line) were calculated for all dependencies and plotted in diagrams.

Table 1 shows the equations of calculated straight lines together with the 95% zone of reliability around the regression function, correlation coefficients and re-
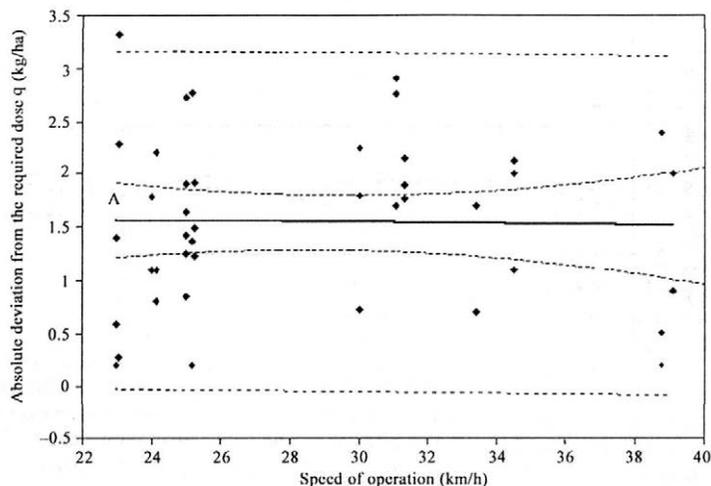
Fig. 3. Correlation between the absolute deviations from the required dose and the speed of operation. Amofos fertilizer
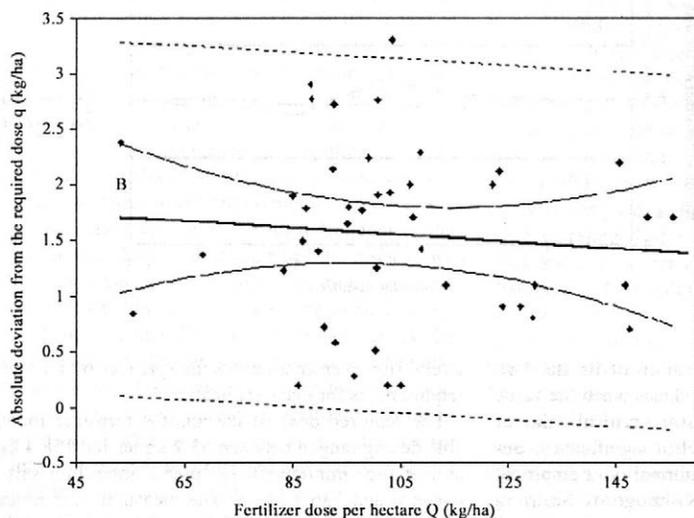

Fig. 4. Correlation between absolute deviations and fertilizer dose. Amofos fertilizer

sults of the test of the zero rate of the correlation coefficient of deviations from the required dose.

Evaluations of the correlation between the absolute deviations from the required dose of the amofos fertilizer and the speed of operation (Figs. 3 and 5) showed that the deviations did not change with the changed speed of operation, as can be seen on the regression lines that are virtually parallel with the x axis, along with the low correlation coefficient values. The test also verified the correlation between the deviations of the dose and the speed. In both cases the results of the test (Table 1) confirmed that on the α = 0.01 level of significance we cannot reject the zero hypothesis, i.e. that the deviations in the doses are not dependent on the travelling speed of the spreader.

The results were similar when we evaluated the correlation between the deviations and the fertilizer dose (Figs. 4 and 6). It can be said that the deviation from the required dose does not change even when the fertilizer dose is changed. A proof of this conclusion was the result of the test of the zero rate of the correlation coefficient (Table 1).

CONCLUSION

Measurements of the quality of application of mineral fertilizers with the Twin Bin spreader on a Terra Gator 8103 undercarriage that is used in the system of precision farming showed that the machine by far
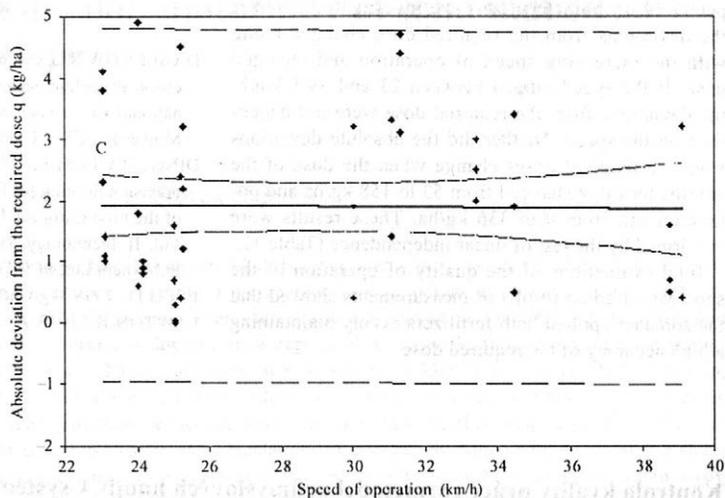
Fig. 5. Correlation between absolute deviations from the required dose and speed of operation. Potassium salt fertilizer
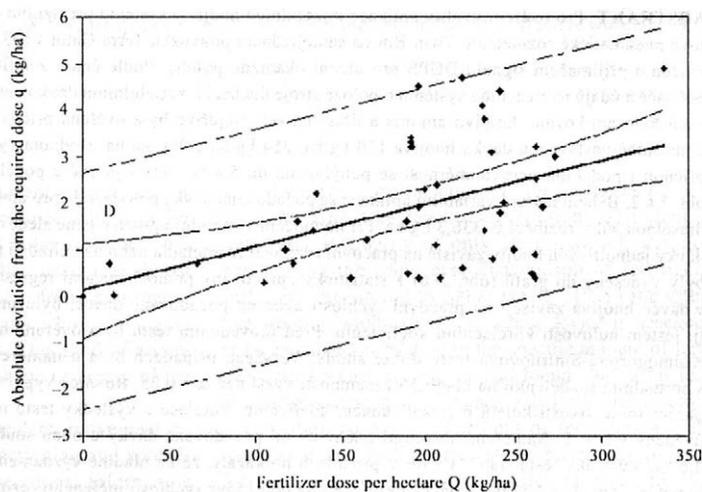

Fig. 6. Correlation between absolute deviations and fertilizer dose. Potassium salt fertilizer

meets the demands for even application under a constant fertilizer dose. The values of the variance coefficient for transversal and longitudinal unevenness during the trials did not exceed 8%.

The average absolute deviation from the required dose of the amofos fertilizer and of potassium salt during the variable application of two simultaneously spread fertilizers was 1.54 kg/ha and 1.9 kg/ha, res-

Table 1. Calculated regression functions with the test of linear independence

Straight line	Zone of reliability around the regression function	Correlation coefficient r	Test of linear independence	
			t_{cal}	t-table $\alpha = 0.01$
A	$q = -0.0033v + 1.6396 \pm 1.5983$	0.023248	0.9807	2.962952
B	$q = -0.003Q + 1.8573 \pm 1.5924$	0.088700	1.1028	2.962952
C	$q = -0.004v + 2.0109 \pm 2.8758$	0.015557	0.9535	2.962952
D	$q = 0.0092Q + 0.1197 \pm 2.5330$	0.473638	2.0474	2.962952

Legend: q – absolute value of deviation from required dose (kg/ha), v – speed of operation of the machine (km/h), Q – required fertilizer dose per hectare (kg/ha), t_{cal} – calculated value of the test criterion (–)

pectively. In both fertilizers we investigated whether the deviations from the required dose changed along with the increasing speed of operation and changed dose. If the speed ranged between 23 and 39.1 km/h, the deviations from the required dose were not dependent on the speed. Neither did the absolute deviations from the required doses change when the dose of the amofos fertilizer changed from 53 to 158 kg/ha and potassium salt from 0 to 336 kg/ha. These results were confirmed by the test of linear independence (Table 1).

Total evaluations of the quality of operation of the spreader based on results of measurements showed that the spreader applied both fertilizers evenly maintaining a high accuracy of the required dose.

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Kontrola kvality práce rozmetadel průmyslových hnojiv v systému „precision farming"

ABSTRAKT: Pro ověření kvality aplikace minerálních hnojiv v systému precizního zemědělství bylo vybráno dvoukomorové pneumatické rozmetadlo Twin Bin na samojízdném podvozku Terra Gator 8103. Stroj je opatřen palubním počítačem Falcon a přijímačem signálu DGPS pro určení okamžité polohy. Podle údajů z aplikačních map vložených do palubního počítače a údajů navigačního systému o poloze stroje dochází k variabilnímu dávkování hnojiva z obou zásobníků. Při zkouškách bylo aplikováno hnojivo amofos a draselná sůl. Nejdříve byla ověřena příčná a podélná rovnoměrnost hnojení pro konstantně nastavenou dávku hnojiva 150 kg/ha, 254 kg/ha a 260 kg/ha. Hodnota vypočteného variačního koeficientu pro příčnou i podélnou nerovnoměrnost se pohybovala do 5,8 %. Grafy příčné a podélné nerovnoměrnosti jsou uvedeny na obr. 1 a 2. Během měření variabilní aplikace se požadovaná dávka pohybovala pro amofos v rozmezí 53,2–158,4 kg/ha a pro draselnou sůl v rozmezí 0–336,3 kg/ha. Při hodnocení variabilní aplikace jsme sledovali, zda jsou odchylky od požadované dávky jednotlivých hnojiv závislé na pracovní rychlosti rozmetadla nebo na velikosti požadované dávky. Naměřené hodnoty byly vyneseny do grafů (obr. 3–6) a statisticky zpracovány pomocí lineární regrese. Posouzení, zda naměřené odchylky v dávce hnojiva závisejí na pracovní rychlosti nebo na požadované dávce, bylo provedeno testem lineární nezávislosti, tj. testem nulovosti korelačního koeficientu. Před provedením testu byla ověřena normalita empirických hodnot pomocí Kolmogorova-Smirnovova testu dobré shody. Ve všech případech byla u naměřených hodnot prokázána dobrá shoda s normálním rozdělením na hladině významnosti vyšší než $\alpha = 0,05$. Rovnice vypočtených regresních přímek spolu s 95% pásem spolehlivosti kolem regresní funkce, koeficienty korelace a výsledky testu nulovosti korelačního koeficientu jsou uvedeny v tab. 1. Naměřené absolutní odchylky od požadované dávky u obou současně aplikovaných hnojiv nepřesáhly 4,6 %. Výsledky testu (tab. 1) v obou případech prokázaly, že na hladině významnosti $\alpha = 0,01$ nelze zamítnout nulovou hypotézu, tzn. že odchylky v dávce nezávisejí na pojezdové rychlosti měřeného rozmetadla ani na velikosti dávky hnojiva. Na základě uvedených výsledků měření je možné konstatovat, že sledovaný stroj dodržuje požadovanou dávku s vysokou přesností.

Klíčová slova: precizní zemědělství; rozmetadlo; variabilní dávkování hnojiv; přesnost aplikace

Corresponding author:

Ing. PAVEL SEDLÁK, CSc., Mendelova zemědělská a lesnická univerzita, Ústav zemědělské techniky, Zemědělská 1, 613 00 Brno, Česká republika, tel.: + 420 5 45 13 20 98, fax: + 420 5 45 13 20 93, e-mail: sedlakp@mendelu.cz

Transverse spreading non-uniformity of solid industrial fertilizers on the slope

J. Paulen [1], **J. Poničan**

Slovak University of Agriculture, Nitra, Slovak Republic

ABSTRACT: This work contains characteristics of transverse distribution patterns and possible effective working widths worked out through experiments in laboratories as well as in field terms. These experiments provided us with evidence, that the transverse inclination of dry fertilizers centrifugal spreaders has serious impact on symmetry of their distribution patterns and thus also on their effective working width up from 8 degrees of the slope. We figured out during laboratory tests, that while effective working width was 2.7 m at 0° slope, at 8° it was just 1.35m. In field tests effective working width fell from 10.25m (0°) down to 9.0m (8°) (Fig. 4). Further reductions of effective working width were not that important, but there remains a gradual tendency of slight reductions, especially in field terms (Fig. 4) at slopes from 8° to 16°. A detailed evaluation of test results allows us to state, that calculations of effective working width on transverse slopes over 8° are necessary to be done through consideration of plot style movement (left half of the distribution pattern is covered by the right half on the way back) regardless of the real movement of spreaders on the slope.

Keywords: solid industrial fertilizers; centrifugal spreader; transverse spreading non-uniformity; effective working width; movement of machine at contour line

Fertilizing of hilly lands is in current days necessary especially for permanent grass vestures. Although for fertilizing of such hilly lands by solid fertilizers are needed centrifugal spreaders, for their users it is almost impossible to get reliable information from their manufacturers how spreading devices work while moving on the slopes following contour lines. This kind of movement is often, considering a plot shape or layout of the land, the only one possible.

It is natural for centrifugal spreaders, movement on slopes effects both their inside functioning and spreading efficiency. There is lack of theoretical information in this area. But existing theoretical sources support the statement, that a 10° transvense slope has an unfavourable impact on keeping proper amount of fertilizers per given plot at some types of spreaders (Explanatory 1964). But there was not figured out any transverse spreading non-uniformity and thus gained results can not be used for supporting commonly known conclusions about impact of plot slopes on non-uniformity of fertilizers application by centrifugal spreaders.

According to SZIRMAI (1987), a 8° slope reduces the efficiency of a centrifugal spreader by 0.8–1.1m as compared to a 0° slope. There is an interesting conclusion of GUBAREV (1985), which states that using of spinning disc spreaders helps to minimize negative impact of 15° slope under 2% (most likely Gubarev meant tributary movement). KOHOUTEK (1988) had examined the efficiency of RCW-3g centrifugal spreader on the

17° slope (moving on contour lines). By using plot style movement he reached a variation coefficient of transverse inequality of only 26.6%, which was not, considering the transverse distribution of fertilizers, sufficient. According to SPEELMANN (1979) the effective working width of any spreading device is necessary to be examined in relation to the specific amount of fertilizers per hectare, because he had found, during his tests of a reciprocating spout spreader, either maximal or effective relation between the amount of fertilizers and the working width. Obligatory tests of efficiency of solid fertilizer spreaders on slope plots are given by ISO 5690/1 standard of transverse non-uniformity spreading (the evenness transverse distribution) of both trailers and carried spreaders. Tested devices have to be inclined transversely by 7% (ca. 4°). The longitudinal spreading non-uniformity of spreading trailers has to be figured out only by getting one side of spreader on a barrier 80mm tall. The same standard suggests to test these spreaders also in real conditions on slope plots by riding on contour lines as well as on tributary lines with slope at least 15% (ca. 8.5°), but it is not obligatory.

Existing theoretical sources as well as wide experience support the statement, that solid industrial fertilizers spreading by centrifugal spreaders is a topic that should be examined more from both researchers as well as manufacturers points of view. Unfortunately, even best international centrifugal spreader producers do not provide users with any advice or information the impact of transverse slopes on efficiency of their products.

MATERIAL AND METHODS

The goal of this paper was given as definition of transverse spreading non-uniformity of spreaders working on slopes. Transverse spreading non-uniformity and given effective working width were analyzed for both shuttle as well as plot kind of movement of spreaders. Tests took first part in laboratory using a Vicon reciprocating spout spreader. It was carried spreader with reciprocating spout 14 cm long only. The spreader was gradually inclined at 0°, 5°, 8°, 10°, 13° and 16°. Transverse distribution patterns were examined without any movement of the spreader towards or backwards at given spreading width 3.9m and flow weight from 0.0230 up to 0.0287 kg/s (one position of the dosage). The recording time was 60s and it was repeated three times. Fertilizer was later replaced by plastic balls with diameter 2–3.5mm and bulk density of 542 kg/m. There were used non-standard fertilizer collectors 0.15m wide and 1m long produced of tin-plate. The entire collecting table was 3.9m wide and its both sides as well as the back side were covered by tarpaulin blanket. Top side of the collecting table was covered by translucent plastic glass. There was proved impact of the collecting table covers on non-uniform spreading. It was an imperfection which appeared at all variants of laboratory tests. The collecting table was leaned together with the spreading device.

There were done also tests in field conditions testing a spinning twin-disc spreader. Examination of transverse distribution patterns took place on a permanent grass vesture plot. The spreader was following contour-lines with slopes 0°, 8° and 16°. There was permanently set a constant amount of spread fertilizers, the weight flow was from 1.83 up to 2.13 kg/s at a speed of 2.83 m/s and spreading width 11m. There was used granular NPK fertilizer whose granular structure was as followed:

particles smaller than $\varnothing$ 1 mm — 0.5%,
particles from $\varnothing$ 1.0 mm up to 2.0 mm — 22.5%,
particles from $\varnothing$ 2.0 mm up to 4.0 mm — 73.2%,
particles over $\varnothing$ 4.0 mm — 3.8%.

Percentage of these various pieces is given by a weight structure of fertilizer sample. Transverse distribution patterns research procedure, calculation of variation coefficients as well as definition of spreader efficiencies were done according to following Standards CSN 47 0127, STN 47 0127 part 1 as well as ISO 5690/1. Every repetition of transverse spreading non-uniformity test requires to be done always in the same direction as a previous test. This rule is valid also for flat plots but for slope slots it is a necessity. Shuttle spreading variance coefficient was calculated by authors of this papers using PC software. Plot spreading variance coefficient was calculated by standard paper method. Effective working width of a device is such a working width, where the variance coefficient is equal to non-uniformity ≤ 20% – CSN 47 0127.

The calculation of transverse non-uniformity variation coefficient was performed with consideration of over-covering of left and right parts of original distribution patterns concerning remarkable movement of a spread fertilizers to a lower parts of transverse distribution patterns at slopes over 5°. It is typical for a plot style of movement.

There were calculated certain results for cases of 0° or lower slopes. The results also comprise a comparison of effective working width derived from calculation of transverse spreading non-uniformity at a shuttle style of movement, when the left part is over-covered by the left part of next-coming working ride and the right part by another right part.

RESULTS AND DISCUSSION

LABORATORY EXPERIMENTS

Transverse distribution patterns as means of dependency of spreaded amount of fertilizers within certain time at a spreading width for transverse slopes from 0° and 5° are shown in Fig. 1 and for transverse slope of 8°, 10°, 13° and 16° degrees are shown in Fig. 2.
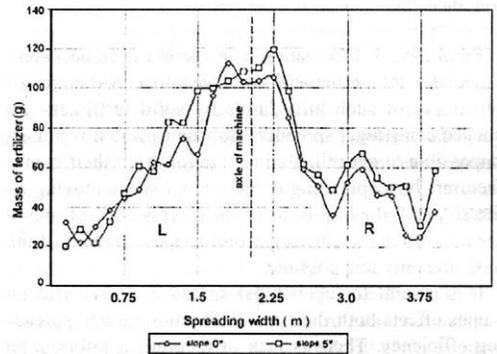

Fig. 1. Transverse distribution patterns measured at transverse slope 0° and 5° of spreader. L – left part of pattern, R – right part of pattern

Distribution pattern at the slope of 0° (Fig. 1) can be seen as a triangle one-peak pattern although a sign of the second peak is at its right part in the width interval 3.0–3.75 m. This imperfection might be caused either by the spreading device or by higher rebound of fertilizer particles from side cover plate of the collector on its both sides, left and right. The pattern can be seen as quite balanced because distinction between the variance coefficient of the left and right half was only 0.71% (the higher one was recorded for the left part) and the distinction of average amount of collected fertilizers was only 4.61g (higher average amount recorded for the left part of the collector).Transverse distribution of fertilizer distribution at the slope of 5°

(Fig. 1) starts to prove that a movement begins of fertilizer parts to the right side. The right side is at this experiment a lower one comparing to the left side. Distinction of the transverse distribution variance coefficient division increased up to 10.98% (higher number recorded for the left part) and average amount of fertil-
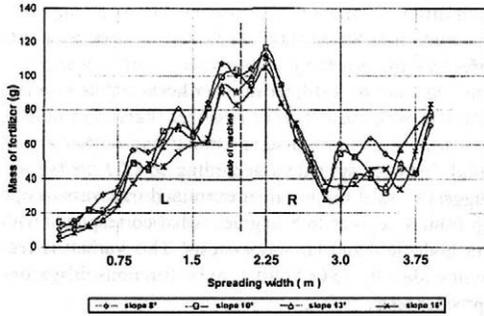

Fig. 2. Transverse distribution patterns measured at transverse slopes 8°, 10°, 13°and 16° of speader. L, R like in Fig. 1

izer in one collector was higher by 1.89g on the right part (lower one comparing to the left part).

Gradually also shapes of transverse distribution patterns at 8°, 10°, 13° and 16° slopes (Fig. 2) can be seen as one peak triangles with more intensive movements of fertilizer towards the right parts of patterns. We can find proof of this statement in statistics calculated of amounts of fertilizer recorded in individual collectors for right and left parts of transverse distribution patterns. The average fertilizer masses for one collector on the right side were at transverse slope of 8° higher by 9.61g (Fig. 2), at 10° higher by 9.15g, at 13° higher by 14.31g and at 16° higher by 17.42g. Last number presents 33.84% of average fertilizer amount collected in one collector for this variant of distribution pattern.

Having evaluated shapes of distribution patterns examined in laboratory at individual transverse slopes of a spreader the finding can be generalized, that the shape of transverse distribution patterns gets noticeably changed from transverse slope of 8° (or slope close to this one). Transverse distribution of fertilizers is more intensive on the lower side of the spreader what is related to centrifugal principle of the spreader but such shape of the pattern has to be seen as purely asymmetric transverse distribution pattern with all implications of less effective working width with minimal range of over-cover. It is necessary to comment, that machine transverse inclination simulation in laboratory at spreading width of 3.9m may lead to various errors and imperfections, which do not arise in field conditions.

To the effective 2.7 m working width at slope of 0° a variance coefficient relates of 19.75%, to the 2.55m width the 17.75% coefficient and then gradually 1.35m – 18.51%, 1.2 m – 11.31%, 1.05 m – 9.03% at 13°

slope and 1.05m – 12.24% at 16° slope. Lower values of transverse non-uniformity at transverse slopes of 10°, 13° and 16° are always first under tolerable level of 20%, which were recorded by gradual over-cover of distribution patterns. Because of high degree of random distribution of individual fertilizer particles at higher slopes it can occur (and it actually occured several times) that at transverse slope of 16° effective working width can even increase.

The reason for such a development can be both the random distribution of fertilizers parts as well as fact that some parts were over-covered four times. To compare results for all recorded combinations the effective working widths were calculated. But these calculations are reasonable only until transverse slope is not so high that fertilizer parts would move towards one side of spreader and this way worsen the symmetry of a profile pattern. According to the performed calculations we can rely only on combinations of 0° and 5° transverse slopes.

FIELD TEST

Distribution patterns recorded in field conditions at transverse slope of a spreader at 0°, 8° and 16° are shown in Fig. 3. Profile of fertilizer distribution at 0° transverse slope can be seen as trapezium with rather steep sides. Such shape of pattern requires keeping of
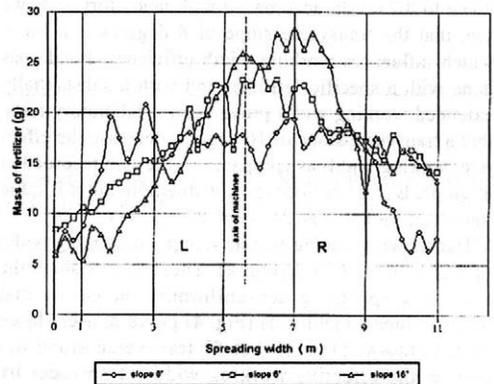

Fig. 3. Transverse distribution patterns measured at transverse slope 0°, 8° and 16° in field conditions of spreader. L, R like in Fig. 1

exact working width, because, at sufficient uniformity, it requires only minimal over-covering and the working width then is very similar to the spreading width. This basic profile pattern is quite balanced and symmetric, because distinction between variance coefficients of its left and right parts is only 4.83% (higher one for the left part) and the difference of average amount of fertilizer collected is 0.81g (higher one for the left part). Shapes of distribution patterns at 8° and 16° slopes become to look as one-peak triangles having peak on the

right side. Similarly as in laboratory tests, the fertilizer moves towards the right side was noticed what made patterns asymmetric in relation to the machine direction.

We can find proof of this in statistics. The distinction of variation coefficient of the left and right part of a pattern at transverse slope of 8 degrees is 13.25% (higher number for the left part) and distinction of average amount of fertilizer in one collector is 3.58g (higher average weight in the right collector). These distinctions are even more noticeable for distribution patterns of spreaders at slopes of 16 degrees, variation coefficient 20.8% (higher number for left part) and average weight in one collector 7.27g (higher number for the right part of the profile).

Recorded numbers of effective working width of spreader plot movement are on Fig. 4. The uniform trapezium shape of pattern at 0° slope caused that effective working width 10.25m is only slightly different from 11m width at the variation coefficient of spreading transverse non-uniformity 19.82%. Transverse slope of 8 degrees decreased the effective working width 9.0m at variation coefficient of 19.56%. But it is not such noticeable decrease as in laboratory conditions but at a working width of 11.0 m the decrease of effective working width 1.25m is confirmative. The highest transverse slope of 16% cause a further, although nor very noticeable, decrease of effective working width down to 8.25m. In accordance with laboratory tests we see, that the transverse slope of 8 degrees is a limit, which influences working width efficiency. Field tests done with a specific fertilizer and with a substantially extended working width prove against laboratory tests, that a transverse slope of 16 degrees decrease the effective working width as compared to the one recorded at 8° slope. It is a less noticeable distinction, but it is quite important for application of solid fertilizers.

Transverse spreading non-uniformity at working width of 8.25m was 18.79% (Fig. 4). These results show the transverse spreading non-uniformity increasing that over 8° slopes. Field tests (Fig. 4) prove in accordance with SZIRMAI (1987), that 8° transverse slope decreases 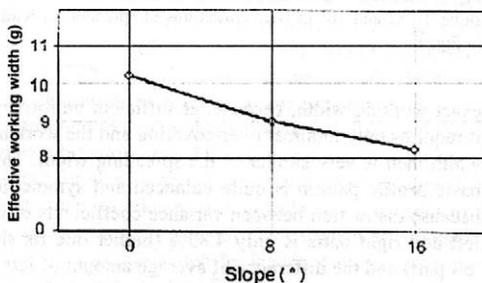the effective working width of spreader by 0.8m to 1.1m as comparing with the 0° slope. But this fact depends also, among other, on the efficient working width of the tested spreader. Our tests resulted in a difference of 1.25m at the 11m working width.

Presented results show higher working quality than KOHOUTEK (1988) proved with a similar spreader at 17° transverse slope. Many repeated field tests, the results of which we had to exclude of our calculations, with different amounts of fertilizer rationing supported the opinion of SPEELMAN (1979) on the need to define effective the working width in relation to a specific (one) amount of fertilizer rate per hectare thus to relate it to the same mass flow of fertilizer (kg/s). For obligatory testing of transverse spreading non-uniformity of solid fertilizer spreaders according to ISO 5690/1 we suggest to shift the minimal examined transverse slope up from 4 degrees to 8 degrees, what corresponds with our both field and laboratory tests. This variant is recommended by ISO 5690/1 only for non-obligatory spreader tests.

As a conclusion of the entire evaluation of recorded a recommendation results for users of spreading devices to test their spreaders at 8° transverse slopes with certain amount of fertilizer on one hectar and then to define by calculation the exact amount of applied fertilizer and efficient working width. In such conditions the spreading charts given by producers of spreaders are not usable. It is important to co-ordinate fertilizer distribution with the working speed of spreaders to keep the calculated amount of fertilizer per hectar and given effective working width. Spreader producers should extend the information for spreader users of by methodical hints of how to set up the fertilizer rates for spreading on transverse plots.

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Fig. 4. Effective working widths obtained in case of plot style of movement in field conditions

Priečna nerovnomernosť rozhadzovania tuhých priemyselných hnojív na svahu

ABSTRAKT: Práca hodnotí možnosti kvality práce rozhadzovania tuhých priemyselných hnojív odstredivým rozhadzovačom pri práci na svahu s pohybom súpravy po vrstevnici. Kvalita práce je posudzovaná tvarom priečnych profilových obrazcov a výpočtom efektívneho pracovného záberu pri požadovanej priečnej nerovnomernosti rozhadzovania ≤ 20 %. V laboratórnych podmienkach bolo modelované priečne naklonenie odstredivého rozhadzovača s kývavou rúrou pri sklonoch 0°, 5°, 8°, 10°, 13°, 16° a v poľných podmienkach sa uskutočnili experimenty dvojkotúčovým odstredivým rozhadzovačom pri uhloch priečneho sklonu stroja 0°, 8° a 16°. Ako materiál boli v laboratóriu rozhadzované plastové guľôčky s priemerom 2–3,5 mm a v poľných podmienkach granulované hnojivo NPK. Zhodnotenie laboratórnych experimentov ukázalo, že profilové obrazce sú v rozsahu priečnych sklonov 8–16° výrazne deformované a nesymetrické voči osi stroja (obr. 2). Z toho dôvodu dochádza pri sklone 8° k preukaznému zníženiu efektívneho pracovného záberu na 1,35 m oproti záberu 2,7 m pri uhle svahu 0°. Ďalšie znižovanie možného efektívneho záberu medzi priečnym sklonom stroja 8–16° už nie je tak výrazné, avšak pokračuje tendencia jeho mierneho zmenšovania až na 1,05 m pri sklone 16°. Výsledky poľných meraní potvrdili poznatky získané v laboratóriu v tom, že profilové obrazce pri priečnom sklone 8° i 16° sú deformované a nesymetrické, vyššia hustota hnojiva je na nižšie položenej polovine obrazca (obr. 3). Pri šírke rozhadzovania 11 m bol efektívny pracovný záber 10,25 m, pri priečnom sklone 0° znížený na 9 m pri sklone stroja 8° a na hodnotu 8,25 m pri uhle sklonu 16° (obr. 4). Ako laboratórne, tak aj poľné experimenty dovoľujú vysloviť poznatok, že od uhla sklonu stroja 8° je priečne rozdelenie hnojiva zhustené vždy na nižšie položenej polovine obrazca (v našom prípade v pravej polovine), a preto od tohto uhla svahovitosti je reálne počítať hodnoty efektívneho pracovného záberu iba s uvažovaním záhonového spôsobu pohybu (ľavá polovica obrazca sa prekrýva s pravou polovinou pri spiatočnej jazde súpravy a naopak). Tento stav vždy platí aj pre článkový spôsob pohybu stroja, nakoľko zmenou smeru jazdy sa nemení tvar obrazca, ale iba sa navzájom vymenia ich pravé a ľavé poloviny, čo je dôvodom k tomu, aby bol efektívny pracovný záber vypočítaný rovnakým postupom ako pre záhonový spôsob jazdy.

Kľúčové slová: tuhé priemyselné hnojivá; odstredivý rozhadzovač; priečna nerovnomernosť rozhadzovania; efektívny pracovný záber; pohyb stroja po vrstevnici

Corresponding author:

Doc. Ing. JURAJ PONIČAN, PhD., Slovenská poľnohospodárska univerzita, Mechanizačná fakulta, Katedra strojov a výrobných systémov, Trieda A. Hlinku 2, 949 76 Nitra, Slovenská republika, tel.: + 421 87 650 83 51, fax: + 421 87 741 70 03, e-mail: Juraj.Ponican@uniag.sk

The comparison of different small mowing machines under practical working conditions

F. Kumhála[1], I. Celjak[2], V. Vávra[2]

[1]Czech University of Agriculture, Technical Faculty, Prague, Czech Republic
[2]University of South Bohemia, Faculty of Agriculture, České Budějovice, Czech Republic

ABSTRACT: Mowing machines used under small-scale farming conditions become very popular in Czech Republic. New types of the machines with different work principles have been appearing on a market. The main subject of our article is to describe an evaluation of different types of mowing machines frequently used under small-scale farming conditions. Three types of mowing machines were researched: cutter bar mower, drum mower with two drums and drum mower with one drum. Technical characterizations of measured machines are shown in Table 1. The fuel consumption range was from 4.5 to 13.5 l/ha and it was always higher for drum mowers (see Fig. 4). The working capacity varied from 0.146 to 0.26 ha/h and it was always best for the cutter bar mower (see Fig. 2). Cutter bar mower work quality depends on weather and crop conditions more significantly than work quality of drum mowers. From that reason the stubble length varied from 3.5 to 4.1 cm for machines with rotary drum and from 3.4 to 5.6 cm for machine with cutter bar (Fig. 1).

Keywords: agricultural engineering; small scale farming; mowing machines; comparison

Nowadays, machines used for small-scale farming become very popular also under Czech Republic conditions. The new type machines using different work principles have been appearing on the market. Some measurements on several types of these machines were performed for this reason. These measurements were carried out within two years (1996 and 1997) on two working places independently. The first working place was Czech University of Agriculture (CUA) in Prague and the second one was University of South Bohemia (USB) in České Budějovice. This paper presents the comparison of results obtained from those measurements.

CHOOSING OF MEASURED MACHINES AND THEIR DESCRIPTION

The VARI system of small scale farming mechanization, produced by MEPOL Libice company, was used for our measurements. This system consists of several parts: engine unit (JM4-003), gear box driving wheels (DSK-315), cutter bar mower for middle cut (AZS-345), cutting adapter using two drums (BDR-700), cutting adapter using one drum (RZS-69) and others. Three machines, consisting of the above listed components, were compared. The first one mowing machine consists of engine unit, gearbox and cutter bar mower (AZS-345). The second one mowing machine consists of a similar engine unit and cutting adapter using two drums (BDR-700). Both machines were compared in CUA in Prague and in USB in České Budějovice as well. The third one mowing machine consisting of

similar engine unit combined with one drum cutting adapter (RZS-69), was compared with AZS-345 in CUA in Prague only. The main technical characteristics for all the three machines are given in Table 1.

EQUIPMENT AND EXPERIMENTAL METHOD

The following parameters were compared for all measured machines:
a) crop parameters: density, height, moisture content (CMC), diameter of stems;
b) work quality parameters: stubble length, work period, visual control of the stubble;
c) efficiency parameters: energy consumption, work capacity.

Since energy consumption was one of the aims of our work there was necessary to prepare the engine unit. The preparation was made by replacement of the original petrol tank used by manufacturer with a new calibrated petrol tank. This configuration enabled to find out the fuel consumption of each of the three machines. The engine unit was partly new and it was adjusted according to manufacturer's recommendation. New sharp knives were used for all types of machines.

All experiments were carried out in following procedures:
1. The stubble length was set up to 28 mm for all three machines under laboratory conditions.
2. The length of trial course was set up to 60 m.
3. The petrol level in tank was provided.

Table 1. The technical characteristics of measured machines

Type of the machine	Cutter bar mower AZS-345	Drum mower BDR-700	Drum mower RZS-69
Engine	Type: JM4-003 Volume: 133 cm³ Power: 3.75 kW Max. speed: 4,700 rpm	Similar	Similar
Working width (m)	0.92	0.715	0.68
Number of knives	12	6 (3 per drum)	3
Number of fingers	17	–	–
Number of drums	–	2	1
Drum diameter incl. knives (m)	–	0.38	0.68
Forward speed at 4,700 rpm (m/s)	0.875	0.847	0.91
Set cutting high (mm)	28	28.5	28
Cutting speed at 4,700 rpm (m/s)	2.17 (average)	91.1 (max.)	50.7 (max.)

4. The machine was positioned 5 m in front of the measured course.
5. The time necessary for the passing the trial course was measured.
6. The engine was switched off just after passing the trial course and the new petrol level was measured.
7. After each trial course five samples of stubble were picked up from area of 10 × 10 cm. Stubble length and density were obtained from these samples for each passage of the machine.

The measurements were carried out within two years, 1996 and 1997. The machines AZS-345 and BDR-700 were compared and evaluated in 1996. The AZS-345 (the same machine like in 1996) and RZS-69 were compared and evaluated next year.

RESULTS

CHARACTERISTIC OF THE MEASURED FIELDS

The machine comparisons require knowledge of crop characterizing values (crop density, type of crop, crop height, and crop MC) and their similarity on all the measured fields. The fields were chosen very carefully to ensure similar work conditions for all measured machines. Unfortunately field conditions of the year 1996 were different from the year 1997 and also, field conditions in Prague were different from those in České Budějovice. It was caused by different weather conditions in those two years and in those two regions. Anyway the weather conditions were better for grass growth (frequent rain in spring) in 1996 and the crop yield was higher than in 1997. The meadow grass with an average height of 0.38 m and MC of approximately 85% was on every fields of CUA in Prague. On the other hand field measurement carried out in České Budějovice showed the average height of grass 0.68 m. It is evident that the differences between fields from year to year and from working place to working place

were unfortunately important. The average of stubble diameter on cutting place was 1.8 mm under every measurement. To minimize the influence of field conditions the cutter bar mower AZS-345 was used like test gauge machine in all cases.

WORKING QUALITY

The most important work quality value was the stubble length. In Prague, the average stubble length was calculated from five samples obtained after trial courses by machine. The stubble length was calculated from 10 measurements of stubble profile in each passing by of the machine in České Budějovice. The quality of work was proved also by visual control of the stubble for all machines investigated. The stubble length was larger in any case that the one set up under laboratory conditions. The average stubble length for all measured machines is given in Fig. 1. It is evident from Prague measurements that the stubble length was adequate for all measured machines. The difference between stubble length for machines measured in 1996 from those in 1997 can be explained using the stubble density. The stubble density of grass in 1996 was higher; the stubble length was also higher for both measured machines in this year. But it is necessary to
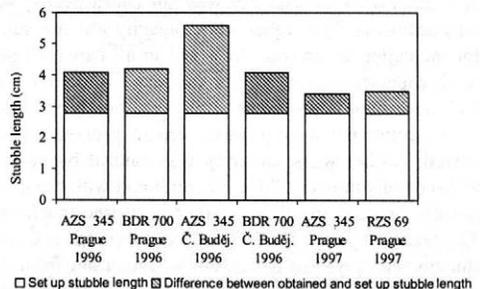

Fig. 1. Stubble length for the measured machines

remark that all the measured machines in Prague have been operating under optimal work conditions.

On the other hand, the stubble length was a very important factor for measurements carried out in České Budějovice. The highest stubble length was measured for the cutting adapter AZS-345. It was very probably caused by field conditions. The harvested grass in České Budějovice was nearly two times higher that than one harvested in Prague and their stubble density was higher as well. Weather conditions were not ideal for the function of cutter bar mower. Higher humidity (95%) and rain day before measurements caused problems. The result was that the work quality of cutting adapter AZS-345 was not sufficient in some cases.

OPERATOR'S POINT OF VIEW

On the other hand the main disadvantage of two-drum mower BDR-700 consisted in small pieces of grass flying around the mowing mechanism during cutting. Those small pieces were found on both working places. Worse field tracking was main disadvantage of one drum machine (RZS-69) and vibrations on handrails were the disadvantage of cycle bar mower (AZS-345).

The noise rate of the machines is another important attribute from the operator's point of view. The measurements of maximum acoustic pressure were carried out in České Budějovice only. These measurements were made under procedure described in Standard CSN 47 0180. The maximum acoustic pressure was measured 83 dBa for AZS-345 and 82 dBa for BDR-700. It is possible to say that there is no difference between these two machines. The probable reasons are following. First, the main source of noise is the engine unit for these types of machines. Secondly, similar engine unit was used for both measured machines.

WORKING CAPACITY

It is commonly known (PERSSON 1987), than the mowers employing the impact cutting principle (i.e. rotary drum and disc mowers, flail mowers) have about two times higher work capacity than the mowers using the shear cutting principle (i.e. cutter bar mowers). This prediction of work capacity was not confirmed by our measurements. The higher work capacity was measured for the cutter bar mower AZS-345 in all cases. Higher work capacity was measured in České Budějovice as well nevertheless problems with occasionally jamming of the cutter bar during measurement procedures occurred. Higher work capacity was caused by cutting width of this mower (Table 1) combined with the comparable forward speed with other measured machines. The technological idle times were observed in České Budějovice only. But it was not so important from the point of view of work capacity. For this reason, the larger cutting width with comparable forward speed for

the AZS-345 must result in the higher working capacity. The comparison of the working capacity of all the machines is presented in Fig. 2.
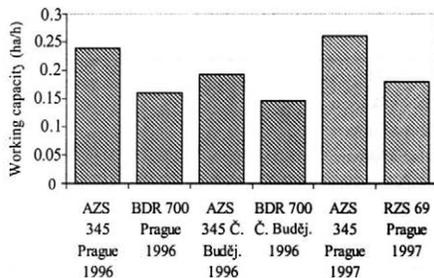

Fig. 2. Working capacity of the measured machines

It is clear from this figure, than the machine AZS-345 has a higher working capacity (discussed above). The smallest working capacity was found out at the two-drum mower BDR-700. The one drum mower RZS-69 had a smaller working width but was used with the higher forward speed. The result of comparison is second position from the point of view of working capacity from all machines.

ENERGY CONSUMPTION

According to measurements of many authors (O'DOGHERTY, GALE 1986, 1991; PERSSON 1987; TUCK et al. 1991) mowers using the impact cutting principle have relatively high power requirements (10–12 kW/m) in comparison with the mowers employing the shear cutting principle (1–4 kW/m). This prediction of energy consumption was also confirmed by our measurements. The rotary drum mowers (BDR-700 and RZS-69) had always higher fuel consumption in equal work conditions. It is evident from the values obtained. It is possible to declare that one litre of the fuel can be used for cutting about 0.15–0.21 ha by cutter bar mower AZS-345, about 0.11 ha with RZS-69 and about 0.074–0.086 ha using BDR-700 only (Fig. 3). It is
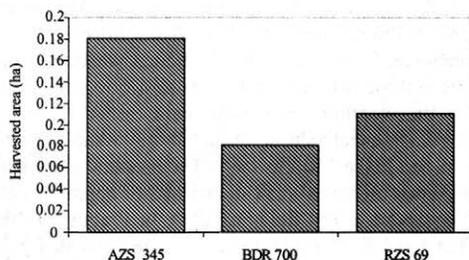

Fig. 3. Average area which is possible to harvest using one litre of fuel

nearly a two times lower value for rotary mowers. This difference is very important and it confirms prediction. From this point of view, the cutter bar mower is definitely better solution. The fuel consumption for one hectare of cutting area is seen in Fig. 4 for all the machines measured.
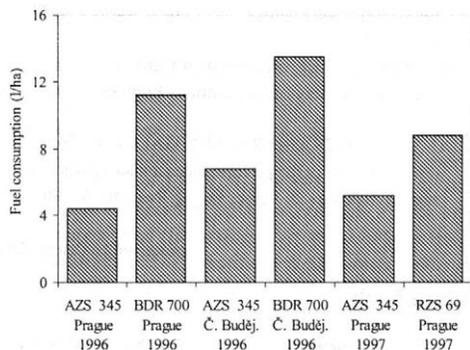

Fig. 4. Fuel consumption of the measured machines

DISCUSSION

The principal objective of the work described in this paper was to examine the behaviour of different types of mowing machines used for small scale farming mechanization. This work is comparison of measurement results carried out in two measured regions (Prague, České Budějovice) independently.

A high attention was devoted to selection of fields used for the measurement. We wanted to minimize the differences among fields by managing similar working conditions for all machines. This intention was possible to accomplish in the same year and same place only. Since the experiments were completed during two years and into two regions, the machine AZS-345 was used like standard scale measure in all cases. The results from all measurements can therefore be comparable.

From the point of work quality is possible to say, that the quality was good for all measured machines compared in Prague. This is maybe also due to using of new sharp knives and operation under optimal conditions in all cases. It is necessary to remark, that the machines using rotary drums (BDR-700 and RZS-69) have better preconditions to work under worst working conditions (older high and thick grass) than the cutter bar mower (AZS-345). It was confirmed by measurements carried out in České Budějovice. The quality of work of AZS-345 was not ideal here. It was caused by not optimal weather conditions (high MC of harvested grass after rain) and higher crop density and height.

Small pieces of grass flying away around the mowing mechanism during cutting of the rotary drum mowers

are unpleasant for machine operators. This happens, first of all, at two drum mower (BDR-700). Vibrations on hand rails of the machine equipped with cutter bar mower adapter (AZS-345) are unpleasant for machine operators as well. The field tracking was good for the machines AZS-345 and BDR-700; it was worst for the machine using one drum (RZS-69). This is probably due to worst field tracking by only one drum and also to the design of the machine. The wheels are in back of the machine and for this reason the drum cannot react immediately to small unevenenesses of the ground during cutting. It was no difference between these machines from the point of view of noise level.

The working capacity was best for cutter bar mower (AZS-345) due to its higher working width and comparable forward speed with other tested machines. The technological idle times observed in České Budějovice were not so important from the point of view of work capacity. The smaller working capacity was found out at the two drum rotary mower (BDR-700). This was due to the smallest forward speed from the tested machines (Table 1). The rotary mower using one drum (RZS-69) has the smallest working width, but a higher forward speed. Their working capacity was better then BDR-700 but lower then AZS-345.

The energy consumption was (it confirms prediction very well) about two times higher for the mowing machines using rotary drums. According to many authors, this is due to the principle of work of these machines (impact cutting principle). Higher energy consumption for machines using rotary drums was expected for that reason. But so high difference between fuel consumption of the machines using rotary drums and the machine using cutter bar was striking in both working places. The high fuel consumption is the main disadvantage of these machines. The high fuel consumption probably has relationship with lesser work rates of these machines in comparison with cutter bar mower. If the engine power output is available for the adapter cutter bar mower AZS-345, for these rotary adapters there can be better to use the engine with higher power output. If the engine with small power output is used, the main part of the power output is to consume for the no load power input of rotary cutting mechanism and here is no reserve of power input. The working capacity is smaller in this case, the fuel consumption higher and finally, the operation of machine is more expensive. It is necessary to take in account, than the easier driving machine for operator is paid by more expensive operation of the machines using rotary drums.

CONCLUSIONS

The main work subject, described in this paper was to evaluate different types of mowing machines used under small-scale farming conditions very often. This work is comparison of measurement results carried out

in two measured regions (Prague, České Budějovice) independently. Three types of mowing machines were tested: cutter bar mower, drum mower with two drums and drum mower with one drum. The energy consumption was higher for the drum mowers, the working capacity was best for the cutter bar mower. Quality of work for cutter bar mower depends on weather and crop conditions more significantly, like the quality of work of drum mowers.

One fact is evident according to the results. It is very difficult to design an optimal machine with so different types of mowers and equipped with the same engine unit. The designers would like to create a new machine. This should be simpler and cheaper but many compromises are implied.

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Porovnání různých žacích strojů v provozních podmínkách

ABSTRAKT: V současné době se u tzv. malé nebo zahradní mechanizace můžeme setkat s různými technickými řešeními žacích strojů, určených pro sečení vysoké trávy. Jedná se především o klasické prstové žací lišty, žací stroje rotační s dvojbubnovým žacím ústrojím a žací stroje rotační s jednobubnovým žacím ústrojím. Zástupce všech těchto strojů lze najít u systému malé zahradní mechanizace VARI od výrobce MEPOL Libice nad Cidlinou. Právě na těchto strojích byla v letech 1996 a 1997 uskutečněna provozní měření. Nezávisle na sobě tato měření prováděli odborníci na dvou pracovištích – na České zemědělské univerzitě v Praze a na Jihočeské univerzitě v Českých Budějovicích. Tato měření mohou sloužit pro porovnání jednotlivých strojů mezi sebou. Měřenými stroji byly žací adaptér AZS-345 (žací lišta prstová polohustá), žací adaptér BDR-700 (rotační žací stroj bubnový se dvěma bubny) a žací adaptér DAKR RZS-69 (rotační žací stroj s jedním bubnem). Objektivní porovnání všech strojů bylo zajištěno tak, že adaptér AZS-345 ve všech případech sloužil jako srovnávací stroj. Toto řešení bylo nutné vzhledem k rozdílným podmínkám měření v letech 1996 a 1997 i k různým podmínkám měření v Praze a v Českých Budějovicích. Mezi základní sledované parametry patřila kvalita práce, která se hodnotila objektivně pomocí výšky strniště a subjektivně obsluhou během provozu strojů. Dále se sledovala výkonnost jednotlivých strojů a jejich energetická náročnost měřením spotřeby paliva. Všechny zkoušky probíhaly podle stanoveného zkušebního postupu. Jednotlivé stroje byly mezi sebou porovnány na základě sledovaných parametrů. Z hlediska kvality práce vykazoval její zhoršenou kvalitu pouze žací adaptér AZS-345 při zkouškách, které se uskutečnily v Českých Budějovicích. Příčinou byla patrně mj. vyšší vlhkost porostu po dešti z předchozího dne, vyšší hustota a větší výška zkušebního porostu. Výška strniště u tohoto stroje se na zkušebním pozemku ČZU v Praze pohybovala od 3,4 do 4,1 cm, v Českých Budějovicích ale byla až 5,6 cm a stroj se občas ucpával. U rotačních žacích strojů se výška strniště pohybovala v rozmezí 3,5–4,1 cm, což bylo vždy v normě. Porovnání naměřené výšky strniště je na obr. 1, na obr. 2 se porovnává výkonnost. Proti všem předpokladům měly rotační žací stroje vždy menší výkonnost než prstová žací lišta polohustá. Bylo to způsobeno jejím větším záběrem a vyšší pojezdovou rychlostí. Rotační žací stroje byly také energeticky mnohem náročnější (obr. 3, 4), což je naopak v dobrém souladu s předchozími měřeními podobného druhu. Oba měřicí týmy s překvapením konstatovaly téměř dvojnásobnou spotřebu paliva u rotačních žacích strojů. Předpoklad spotřeby byl pouze o třetinu až polovinu vyšší než u žacího stroje prstového. Nevýhody rotačních žacích strojů jsou pravděpodobně způsobeny také tím, že instalovaný výkon motorové jednotky nebyl pro stroje pracující na tomto principu práce dostačující. Touto domněnkou by se vysvětlila především jejich menší výkonnost. Z hlediska obsluhy je možné konstatovat, že u prstového žacího stroje jsou nepříjemné jeho vibrace a zastávky nutné v některých případech k vyčištění žací lišty. U rotačních žacích strojů jsou naopak nepříjemné drobné částečky posečené píce poletující během práce okolo stroje. Jinak se rotační žací stroje lépe ovládají a pracují bez vibrací. V Českých Budějovicích byla měřena také hladina hluku, která byla téměř srovnatelná pro oba stroje a jejíž maximum se pohybovalo v rozmezí 82–83 dBa. Z výsledků je patrné, že s jedním typem pohonné jednotky lze vytvořit optimální sestavu se všemi uvedenými druhy žacích adaptérů jen za cenu kompromisu.

Klíčová slova: maloplošné hospodářství; malé farmy; žací stroje; srovnání

Corresponding author:

Ing. Dr. FRANTIŠEK KUMHÁLA, Česká zemědělská univerzita, Technická fakulta, 165 21 Praha 6-Suchdol, Česká republika, tel.: + 420 2 24 38 31 35, fax: + 420 2 20 92 13 61, e-mail: kumhala@tf.czu.cz

Grassland renovation techniques at the areas of protected landscape in Slovakia

Ľ. GONDA[1], D. RATAJ[2]

[1]Grassland and Mountain Agriculture Research Institute, Banská Bystrica, Slovak Republic
[2]Grassland and Mountain Agriculture Research Institute, Poprad, Slovak Republic

ABSTRACT: From 1995 onwards, control of sward infestation with tufted hair grass (Deschampsia caespitosa [L.] P. Beauv.) by mechanical treatment has been studied. A research was conducted in a mountain region within the area of the Nízke Tatry Mts. National Park (NAPANT) at Liptovská Teplička site (altitude 1,300 m, mean annual rainfall 1,100 mm, mean annual temperature 2.5°C, soil pH 3.8, humus 74 g/kg). Mechanical control in combination with oversowing or direct drilling a grass/clover mixture were the only treatments applied to the sward. Preliminary results showed rather a good control of this weed. The optimum combination appeared to be the autumn surface sward treatment (mulcher FM-180), the old sward cultivated in the autumn and in the spring (spike rotavator VUTA 01 and HORSCH SE-3) with direct drilling of the ecologically suitable grass/clover mixture in the early summer (HORSCH SE-3 or SE 2-024). The proportion of D. caespitosa was markedly reduced in the sward at the research site, mean efficacy of this procedure was 80%.

Keywords: Deschampsia caespitosa (L.) P. Beauv.; grass/clover mixture; mechanical sward treatment; weed control

Deschampsia caespitosa (L.) P. Beauv. can be counted among weeds causing a number of problems in grassland at upland and mountain regions of Slovakia. Swards are often infested because of violated agronomical practices and the weed control is labour-demanding and costly. The management of grassland should be in agreement with ecological principles at minimum or zero utilization of classic agronomical practices. Application of herbicides is rather a quick and successful method to control D. caespitosa in grassland. Good results were reported both abroad (BOZZO, PARENTE 1991; FATYGA 1991; OBERS-RIEBNIG et al. 1991) and in Slovakia (RATAJ 1996, unpublished data) at application of Roundup herbicide in combination with mechanical sward treatment followed by oversowing or direct drilling grass/clover mixture. If herbicides are not allowed, only mechanical methods can be used, i.e. at the protected areas. Therefore special attention was paid to the choice of optimum ma-

chinery with the objective of minimizing the presence of D. caespitosa in the existing sward or for establishment of a new one. Results of an earlier research testing the surface trimmer-crusher PB 2-077 were also considered (GONDA, KUNSKÝ 1991).

Non-traditional techniques were used to improve grassland for agricultural purposes within the area of protected landscape (NAPANT) at Liptovská Teplička site in the mountain region of Slovakia.

The site characteristics is as follows: altitude 1,300 m, mean annual rainfall 1,100 mm, mean annual temperature 2.5°C, soil pH 3.8, humus 74 g/kg. The research has been carried out from 1995 onwards.

Botanical composition of the investigated sward was as follows: grasses 65% (dominated by D. caespitosa) and herbs 35% (Alchemilla vulgaris L. 10%, Achillea millefolium L. 8% and other).

Any application of chemicals was excluded and only mechanical means were used. Treatments were carried

Table 1. The research treatments

Treatment No.	Sward treatment and management machinery/dates		Oversowing /Direct drilling machinery/dates	
1	VUTA-01	autumn 1995 spring 1996	SE 2-024	summer 1996
2	VUTA-01 PB 2-077	autumn 1995 spring 1996	HORSCH SE-3	summer 1996
3	HORSCH SE-3	spring 1996	SE 2-024 (adapted)	summer 1996
4	HORSCH SE-3	summer 1997	HORSCH SE-3	summer 1997
5	FM-180 + BDT-2.5+ HORSCH SE-3	autumn 1997	–	–

Table 2. Machinery data

Machinery	Weight (kg)	Minimum power input (kW)	Working efficiency (ha/h)	Working span width (mm)	Fuel consumption (l/ha)
Spike rotavator VUTA-01	850	40	0.18	1,800	31.37
Surface trimmer-crusher PB 2-077	732	50	0.46	1,624	28.80
Mulcher FM-180	760	36	0.92	1,800	10.50
Precision seeder HORSCH SE-3	1,700	74	1.54	3,100	23.46
No-tillage strip seeder SE 2-024	670	50	0.50	1,650	18.60

out by machinery with active working tools providing strong or aggressive impact on sward. The working operations were performed either once only or repeatedly in different growing seasons. The objective was to find the most optimum and efficient machinery, techniques and timing.

The control of *D. caespitosa* by mechanical means was divided into two stages:
a) mechanical treatment of sward by machines,
b) grass/clover mixture sowing/direct drilling.

The research treatments are given in Table 1 and the machinery data are presented in Table 2.

The grass – clover mixture (GCM) consisting of *Phleum pratense* L., *Trisetum flavescens* L. (P. Beauv.), *Poa pratensis* L., *Agrostis stolonifera* L., *Festuca rubra* L., *Lolium perene* L., *Trifolium pratense* L. and *Trifolium repens* L. was sown at seed rate of 50 kg/ha. Fertilizers were applied at the rates of N_{60}, P_{30}, K_{80} before sowing.

RESULTS

Sward surface treatment by mulcher FM 180 provided some control of *D. caespitosa*. By mulching, the above-ground plant parts were removed up to the height of 40 mm but roots were not affected. The single technique of mulching might prove useful for extensive system (possibly in combination with cattle or horse grazing) to reduce a proportion of the weed in grassland.

Only total cultivation of the infested sward with a spike rotavator VUTA 01 proved to be fully effective. Two treatments by the machine (autumn–spring) totally destructed tufts of *D. caespitosa*. However, a disadvantage of this technique is low working efficiency and high fuel consumption of the rotavator (Table 2). Mechanical treatment by the precision seeder HORSCH SE-3 supported by a horizontal rotavator with flat blades gave a nearly complete destruction of *D. caespitosa*. However, neglected swards with large amount of organic matter required to treat their surface by the mulcher FM-180 followed by disking (BDT-2.5). The treatment repeated twice, i.e. in the autumn and in the spring, was better for processing the sward, surface levelling and distribution of organic matter and provided better conditions for grass/clover mixture drilling. The precision seeder proved to be very good for

sowing but strip seeding using the passive system (disks) was not so successful as the active one using a rotavator and sowing into tilled belts. A comparison showed that the system with HORSCH SE-3 was more efficient than sward treatment plus oversowing and reduced the initial 50% proportion of *D. caespitosa* to 7%, that is 86% efficiency of combined intervention (machinery plus grass/clover mixture reseeding). The intervention was 10% more successful when combined with grass/clover mixture over-drilling and botanical composition of the sward was also improved (Table 3).

Table 3. Sward botanical composition

	HORSCH system	Oversowing
Grasses	65	65
Herbs	15	15
Legumes	20	20
Phleum pratense	17	15
Poa sp.	18	13
Trisetum flavescens	5	7
Deschampsia caespitosa and other	7	12
Trifolium repens	15	12
Trifolium pratense and other	5	7
Alchemilla vulgaris	3	3
Ranunculus sp. and other	3	4

DISCUSSION

Two options to kill *D. caespitosa* in swards have been indicated by the research data:
a) the extensive long-term one (sward surface treatment with a possibility to include grazing of cattle, goats or horses),
b) the intensive and radical one (tilling all the area followed by establishment of the new sward).

The extensive alternative is friendly to the environment and consumes less energy and cost. Nevertheless, it neither provides a solution to the current alarming grassland infestation with *D. caespitosa* nor prevents its possible expansion to more areas. Therefore, it was concluded that the radical weed control was supported and an optimum technique was as follows: sward surface treatment by the mulcher (FM-180) + management of the sward two times, i.e. in the autumn and in the spring (VUTA 01 or HORSCH SE-3) + sowing in the early summer (HORSCH SE-3).

FATYGA (1991) as well as BOZZO and PARENTE (1991) stressed repeated mechanical treatment of sward. The latter authors considered two rotavator treatments of the infested areas repeated after 6 months nearly as efficient as the combination of herbicide application and one mechanical intervention.

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Obnova trávnych porastov v chránených krajinných oblastiach Slovenska

ABSTRAKT: Od roku 1995 sa v horskej oblasti NAPANT v lokalite Liptovská Teplička (nadmorská výška 1 300 m, ročné zrážky 1 100 mm, priemerná ročná teplota vzduchu 2,5 °C, pH pôdy 3,8, humus 74 g/kg) sledujú efekty potlačovania metlice trsnatej (*Deschampsia caespitosa* [L.] P. Beauv.) v poraste. Plošné zastúpenie tejto trávy predstavovalo 50 %. Variantné riešenia tohto stavu zahŕňali len použitie mechanizačných prostriedkov v kombinácii s prísevom/výsevom ďatelinotrávnej miešanky. Predbežné výsledky poukazujú na relatívne vysokú účinnosť intenzívneho, radikálneho systému boja proti burine. Optimálna je kombinácia jesenného ošetrenia povrchu (mulčovač FM-180), celoprofilového spracovania mačiny (zemná fréza VUTA 01, resp. HORSCH na jeseň a jar) a skorého letného výsevu ekologicky vhodnej ďatelinotrávnej miešanky (HORSCH SE-3). Pri kombinácii dvojnásobného mechanizačného zásahu (jeseň, jar) a výsevu miešanky (SE-3 HORSCH, resp. SE 2-024) došlo k výraznému ústupu metlice na danom stanovišti. Účinnosť tohto kombinovaného postupu bola v priemere 80%.

Kľúčové slová: *Deschampsia caespitosa* (L.) P. Beauv.; ďatelinotrávne miešanky; mechanické ošetrenie porastu; zaburinenie

Corresponding author:

Ing. ĽUBOMÍR GONDA, CSc., Výskumný ústav trávnych porastov a horského poľnohospodárstva, Mládežnícka 36, 974 21 Banská Bystrica, Slovenská republika, tel.: + 421 88 413 25 41, fax: + 421 88 413 25 44, e-mail: gonda@vutphp.sk

Dry pumping systems for milking devices

M. LIBRA[1], J. NAVRÁTIL[2]

[1]Czech University of Agriculture, Technical Faculty, Czech Republic
[2]Czech University of Agriculture, Faculty of Agronomy, Czech Republic

ABSTRACT: Milking is, next to technique and technology of feeding and stabling, the most important process in breeding of dairy-cattle. Existing milking devices are mostly pumped by the rotary vane pumps or by water jet pumps. In this article we discuss the advantages and disadvantages of the new dry pumping systems and the possibilities to use this dry pumps in the milking devices.

Keywords: milking; vacuum; pump

The first piston vacuum pump with wood piston was constructed in 1672 by Guericke who demonstrated the force that was keeping "Magdeburg hemispheres" together. Vacuum was just a curiosity at that time and people could not believe that few pairs of horses almost were not able to tear the hemispheres apart.

The pumping methods, vacuum measuring methods, and leak detection methods went through substantial development since that time (GROSZKOWSKI 1981). Further yet, evolving physical theories of leaks, hydromechanics, behavior of gases on the boundary of vacuum and chamber wall, and theory of walls sorption and desorption were developed. Modern industrial technologies need top quality vacuum systems giving ultra high vacuum in the pressure range $p \approx 10^{-4} \div 10^{-6}$ Pa (for example in semiconductor industry). In agriculture, the most important application of vacuum systems is in milking devices. The requirements to achieve pressure- and leak-proof pumping systems are less strict. In order to avoid hurting the animals, the milking device pressure should not be below $p \approx 5.10^4$ Pa that corresponds approximately to the half of the atmospheric pressure. The air flow must be passing through the regulating valve into the pumped space to keep the pressure in the milking device on this value, which is extremely high from the vacuum technology point of view. The main vacuum pump requirement therefore is the possibility to pump at this high input pressure.

MILKING TECHNOLOGY

Milking is, next to technique and technology of feeding and stabling, the most important process in breeding of dairy-cattle. Any defficiences in these areas will immediatelly show up by an abrupt fall of production (respectively its complete loss). In spite of a quick removal of the problem, return to a normal production level always takes longer, and if the problem concerns the very milking process, it is furthermore accompanied by health problems such as inflammations and trauma of udder, etc. (NAVRÁTIL 1985).

Basically there are two types of milking technologies used according to a capacity of stable and size of a farm. In case of tie-up cowshed with a low number of cows (this type is very rare at present) milking to cans or pipeline is still usuall. Disadvantage of this type is a considerably higher risk of milk contamination, higher labor and lower efficiency.

In case of larger dairy-cattle herds with higher productivity it is advisible to apply open-shed stabling and milking in separate milking room. Advantages of milking parlors are more effective and productive milk-yielding, better hygiene, better working conditions for people, more effective preparation of cow and control of udder, harmless and continuous milking and consequent improvement of health of cattle.

Professional dairy-stock breeders mostly employ herring-bone, autotandem or paralel milking-parlors according to an actual productivity of cows. Since the end of eighties milking robots have been tested with various results. Their main advantage is a complete substitution of human work that is positive from economical as well as social point of view.

Main technical demand for the systems described above, with respect to the cow's well-being, is to maintain parameters of underpressure, pulsation and stability of their values during the milking. Fluctuation of underpressure (generally due to low efficiency of the valve towards the lenght and widht of pipeline) is the main source of udder damage that ensues in its alteration, increase of somatic cells in milk and quality deterioration. Problems with underpressure fluctuation led to a replacement of standard vacuum pumps by much more reliable electromagnetic pumps. At the same time we must not forget to keep the human factor

in mind as for strict following of technological process as it has a direct influence on milk-production a health of udder.

Last but not least in the process of care is an effective and quick cooling of the milk down to 4–6°C and its storing untill further transport.

CLASSICAL SOLUTION OF THE UNDERPRESSURE IN THE MILKING DEVICE

Rotary vane pumps are standardly used in current milking devices in large milking rooms. Water jet pumps are employed if milking of only a few cows is performed. The scheme of a rotary vane pump is on Fig. 1, the scheme of a water jet pump is on Fig. 2.
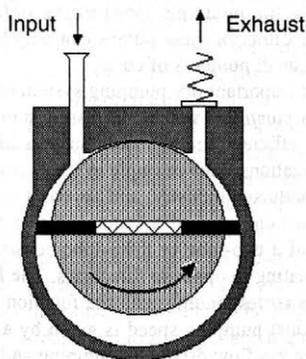
Fig. 1. Scheme of the rotary vane pump
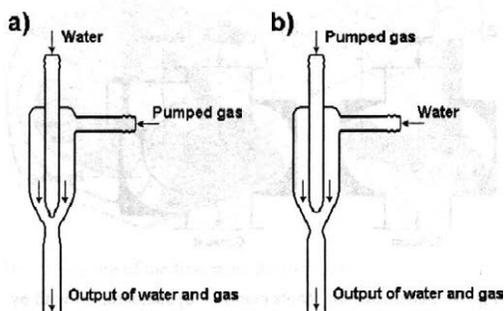
Fig. 2. Scheme of the water jet pump

We consider *water jet pumps* as a suitable solution, they are simple and ecological. Small water jet pumps have a pumping speed of about 3 m³/h and their ultimate pressure is about $p \approx 1,000$ Pa. They are suitable for milking of one or two cows. They are working on the principle of the Bernoulli equation. It is possible to

connect them either to the common water piping or to the water piping with a closed circle driven by the pump. In the case of connection to the common water piping, the used water can for example provide drink for the cows. Large water jet pumps have a pumping speed of about 60 m³/h and the ultimate pressure of about $p \approx 1,000$ Pa. They are suitable for milking of up to twelve cows and they are typically connected to the water piping with a closed circle driven by the pump.

Rotary vane pumps are primarily used in the large milking rooms. However, they have some disadvantages in addition to their indisputable advantages. The advantages are as follows. Many such pumps are currently in use and their pumping speeds range from single units to hundreds of m³/h. Large milking rooms have about 20 ÷ 24 stalls and they need the vacuum pumps with the pumping speeds of about 120 ÷ 150 m³/h. The ultimate pressure of even the most simple single stage rotary vane pumps exceeds the above-stated requirements (GROSZKOWSKI 1981). As explained earlier, the air flow is flowing into the pumped space through the regulating valve to hold the pressure of about 5.10^4 Pa. The price is another indisputable advantage since all the solutions discussed below are more expensive.

The presence of oil in the pumping system is the main disadvantage since the back-diffused oil vapour contaminates the milk. The oil flows out from the vacuum pump as a liquid and also escapes in the form of oil vapour. This process is caused by the rotary vane pump not working in the optimal mode since it is permanently pumping at a high input pressure of about a half of the atmospheric pressure. The substantial amount of 0.1 l of oil is lost daily and must be refilled. In addition, the entire oil content must be changed approximately once a year.

This is the main reason why *special rotary vane pumps* are used for higher simplicity and higher resistance and reliability at penetration of humidity and tiny impurity. Their oiling is resolved by an oil dripping mechanism directly from a dosing device into the input of the vacuum pump. Unfortunately, the oil consumption is much higher in this case.

A relatively high input power is another disadvantage of this system. The input power of the rotary vane pump is maximal just at the input pressure range $p = (3 \div 5).10^4$ Pa. The input power comes to a local minimum, when the input pressure is about equal to the atmospheric pressure, because the compression ratio is small. When the input pressure decreases to the half of the atmospheric pressure, the input power increases up to three times. Further decreasing of the input pressure causes decreasing of the input power because the amount of the compressed gas is very small. The necessity to take the exhaust with oil vapour away from the room by a pipeline is a disadvantage as well. The oil must be separated and the oil leakage is dangerous. Beside the ecological aspects, the noise of the rotary vane pumps troubles the operator and staff of the farm.

NEW POSSIBILITIES FOR SOLUTION OF THE UNDERPRESSURE IN THE MILKING DEVICE

For a long time, the designers made an effort to construct dry vacuum pumps with liquid free pumping systems and with possible output pressure as high as the atmospheric pressure. But all previously developed devices had low efficiency and effectivity. That is the reason why rotary vane pumps formed the basis of the transport pumping systems for a long time. Patience and effort of the vacuum technology producers and many years of experience of their designers recently opened new possibilities in the field of vacuum technology (LIBRA et al. 1998). Dry pumping systems are much more complicated from the point of view of construction and production and therefore they are more expensive. That is the reason why cheaper oil vacuum pumps are used in the majority of applications, if the dry vacuum is not necessary. Nevertheless, dry vacuum pumps quickly increase their importance and we hope that the future of the vacuum technology is just in dry vacuum systems. The concept "dry vacuum pump" means that the pumping system is dry, but the bearings and gear box are lubricated by oil or by grease.

Screw vacuum pumps are based on the following principle. Two screws with opposite threads are rotating one next to the second in opposite directions. The gas is driven in the spiral flutes. Rotating screw principle was originally developed as the compressor for air, ice refrigerators, natural gas and so on. The acquired experience with screw compression was later applied to vacuum pumps. But this problem is much more complicated and that is why it was successfully resolved much later.

Screw vacuum pumps have a stator and two of the above mentioned screw rotors inside. The pumped low pressure gas is driven along the rotors axle and then it is caught in the cavity of the stator. Rotors are working, their moving lobes periodically reduce the cavities capacity and increase the pressure of the caught gas. The gas is then ejected through the exhaust valve. The function of the lobes is corresponding with the function of the pistons. The modern pumps have a rotating frequency up to $f = 15,000$ rpm. The fine mechanics is necessary, the rotors must not touch each other but distances are less than $d = 0.1$ mm. The final pumping speed is given by the difference between the gas flow driven by pumping and the back flow through the leaks between the rotors and the stator. The best single stage screw vacuum pumps have ultimate pressure in the order of $p \approx 1$ Pa and the atmospheric exhaust pressure.

Membrane vacuum pumps are based on the same principle as the membrane water pumps. The working space is closed by a metal or rubber membrane which is alternately deflected by a cam or by an electromagnet. The function of the deflecting membrane is corresponding with the function of the piston, it is changing the capacity of the working space and alternately is

sucking and ejecting the pumped gas through the valves. The scheme of a membrane vacuum pump is on Fig. 3.
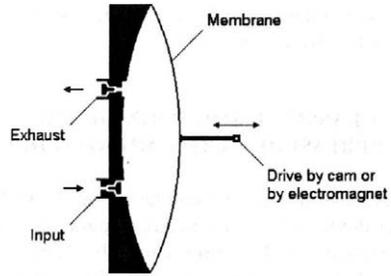

Fig. 3. Scheme of the membrane vacuum pump

Neither screw vacuum pumps nor membrane vacuum pumps have the pumping speed in the order of hundreds m³/h. Either of these pumps can only be used for milking of small numbers of cows.

The most important dry pumping system is the multistage *Roots pump* that will be discussed in this paper. It is reliable, efficient and has been successfully used in many applications – for example in the chemical industry, semiconductor industry, and so on. The corpus of the pump is composed of a stator and two rotors. The rotors are of a two-lobe or three-lobe construction and they are rotating in opposite directions. The function of the lobes is corresponding with the function of the pistons. The final pumping speed is given by a difference between the gas flow driven by pumping and back flow through the leaks between the rotors and the stator. The fine mechanics is necessary in this case as well, the rotors must not touch each other but distances are lower than $d = 0.1$ mm. The rotating speed is up to 4,000 rpm. The scheme of a Roots pump is on Fig. 4.
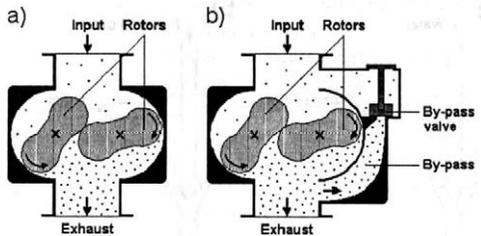

Fig. 4. Scheme of the Roots pump – a) standard, b) with by-pass

The pumping speed of a Roots pumps depends on some construction factors (GROSZKOWSKI 1981). The flow in the pumping direction can be expressed by equation

$$I_+ = S_g p$$

where: S_g – the pumping speed depending on the capacity between the stator and the rotors and on the rotating speed.

The back flow through leaks between the stator and the rotors can be expressed by equation

$$I_- = G_n(p_o - p)$$

where: G_n – conductivity of the leaks,
p – the input pressure,
p_o – the exhaust pressure.

The final flow is the difference between both flows

$$I = I_+ - I_- = S_g p - G_n(p_o - p)$$

The pumping speed is equal to

$$S = \frac{I}{p} = S_g - G_n(\frac{p_o}{p} - 1) = S_g[1 - \frac{G_n}{S_g}(\frac{p_o}{p} - 1)]$$

It can be seen, that the higher is the pumping speed, the lower must be the ratio G_n/S_g. This can be achieved by decreasing of the distance between the stator and the rotors, by increasing the capacity between the stator and the rotors and by increasing of the rotating speed. Ultimate pressure can be calculated from the condition $S = 0$, but it is not important in this context.

Multistage Roots pumps were developed especially for reliable pumping in the semiconductor industry. For example the company Alcatel CIT has been producing them since 1985 (Catalogue Alcatel CIT 1999). The vacuum pumps are mostly constructed with five stages, the stages are constructed serially on the common shaft. The standard scheme is on Fig. 5. The pumping unit is compact and the noise is minimal. The ultimate pressure is in the order of up to $p = 1$ Pa and highly exceeds the requirements for milking devices.
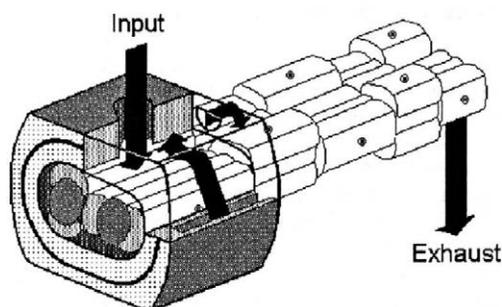

Fig. 5. Scheme of the five stage Roots pump

The vacuum pump can be located outside of the milking room and the pumping can be conducted by a pipeline. The service life of the pumping systems Alcatel series ADP/ADS and ACP is more than 50,000 hours and the maintenance is minimal. Important technical parameters of some dry pumping systems are given in Table 1 (Catalogue Busch 1999; Catalogue Alcatel CIT 1999).

Table 1. Important technical parameters of some dry pumping systems

Type	ADP 122 (Alcatel CIT)	ACP 20 (Alcatel CIT)	MI 1122 (Busch)
Maximum pumping speed for N_2 (m³/h)	112	20	165
Ultimate pressure (Pa)	0.6	6	10,000
Input power at ultimate pressure (kW)	1.5	1.5	3
Weight (kg)	250	39	115

CONCLUSION

In this paper, we discussed main advantages and disadvantages of the rotary vane pumps and new dry vacuum pumps for applications in milking devices. In the school farm of the Czech University of Agriculture in Ruda (Rakovník District), 400 Holstein-friesian cows with high efficiency are bred. There are 22 stalls in the milking room (milking device 2 × 11 Alfa Laval). A rotary vane pump Alfa Laval is used and the underpressure is regulated by a regulating valve. The pumping speed is 150 m³/h and the input power is 7.5 kW. The oil consumption is approximately 11 g/h. By installing the dry vacuum pump as an alternative to the rotary vane pump, the positive influence on the energy consumption and on milk quality can be studied. The problem of the oil liquidation would disappear. There would be 100% reserve and thus it would be possible to use the second pumping system when the first one is out of order or in maintenance. Authors sent a grant application to the Grant Agency of the Ministry of Agriculture of the Czech Republic. If they will obtain financial resources, they will install the dry vacuum pump in the school farm and they will investigate the above mentioned influence on the milk quality.

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Suché čerpací systémy pro dojicí zařízení

ABSTRAKT: Dojení je spolu s technikou a technologií krmení a ustájení nejdůležitějším procesem v chovu mléčných krav. Stávající dojicí zařízení jsou nejčastěji čerpána rotačními olejovými vývěvami nebo vodními vývěvami. V článku diskutujeme výhody a nevýhody nových suchých čerpacích systémů a možnosti použití těchto suchých vývěv v dojicích zařízeních.

Klíčová slova: dojení; vakuum; vývěva

Corresponding author:

Ing. MARTIN LIBRA, Česká zemědělská univerzita, Technická fakulta, 165 21 Praha 6-Suchdol, Česká republika, tel.: + 420 2 24 38 32 84, fax: + 420 2 20 92 22 54, e-mail: libra@tf.czu.cz

Finite element modelling of the frequence response of apples

M. Fraňo, D. Brozman

Slovak University of Agriculture, Nitra, Slovak Republic

ABSTRACT: The three dimensional finite element models of apples were constructed with linear, homogeneous and elastic material properties. Each model had assigned different geometric and material properties. Torsional and longitudinal mode shapes were extracted and analyzed. The occurrence of these modes is correlated with a range from 369.198 Hz to 742.316 Hz and from 412.177 Hz to 901.179 Hz for the torsional resonant frequency and the longitudinal resonant frequency respectively. In the case of the constant Young's modulus of elasticity of apple flesh, the torsional resonant frequency remained at the constant value of 524 Hz for each geometric shape. The modelling approaches considering simultaneous change of material properties of the core and the flesh and assuming constant Young's modulus of the core are almost identical. The sensitivity number was determined for each modelling approach. Based on the results of laser Doppler vibrometry, the ripeness curve for variety GALA was constructed.

Keywords: apples; firmness; finite element method

Vibrational mode shapes of fruits have been studied for mechanical properties determination by several authors (ABBOTT et al. 1968; KIMMEL et al. 1992; HUARNG et al. 1993). The techniques were based on the resonant frequency measurements during which the fruit was mechanically vibrated by an exciter or the fruit was suspended by its own stem. The resonant vibration of apples shows unique mode shapes corresponding with unique resonant frequencies. ABBOTT et al. (1968) reported for apples, that the longitudinal mode refers to the first resonant frequency and the torsional mode corresponds with the second resonant frequency. Based on the spherical and earthquake theorem, a relationship between the mass of the fruit and the second resonant frequency was proposed for the firmness evaluation in the term of the firmness index (COOKE, RAND 1973). Another approach suggested using for the apples firmness evaluation the lowest spherical resonant frequency (FINNEY 1970). Nowadays numerical simulation has been widely used for mode shape determination of an agricultural products. This approach allows to predict different physical, chemical and biological nature of the different problems in agricultural engineering (dynamics, thermodynamics etc.). Theoretical estimation or application of the numerical methods leads to the simulation of different conditions and helps to interpret an experimental results. ROSENFELD et al. (1992) used the boundary element method for the frequency response determination of an ellipsoidal model of the fruit. An application of the finite element method (FEM) in the field of material properties determination of the agricultural products has been aimed at mode shape extraction and natural frequency determination by several researchers like CHEN and DE BEARDEMAEKER (1993), LU and ABBOTT (1996).

Specific objectives of this study are:
- to determinate changes in the frequency spectrum during storage period,
- to verify the results of FEM and laser Doppler vibrometry,
- to determinate basic modal shapes in the frequency spectrum,
- to construct the ripeness curve to predict changes in material properties of GALA apples,
- to determinate sensitivity of the finite element model to variation in material properties.

MATERIAL AND METHODS

MATERIAL

Four apples of variety GALA were measured for the resonant frequencies during the five months regularly each three weeks. Each apple was stored in controlled

atmosphere (N_2 78– 96%, CO_2 3%, O_2 1%) at 0°C. Humidity ranged between 90–95%. Harvested apples were taken from the same part of a tree, they were selected according their size and shape for resonant frequency measurement.

LASER DOPPLER INTERFEROMETRY – VERIFICATION EXPERIMENT

Laser Doppler vibrometry was used for the frequency spectrum determination (POLYTEC 1998). This non destructive technique determinates velocity and absolute displacement at one point of a vibrating structure. Laser beam focused at measured surface induces Doppler frequency shift which is proportional to velocity of the vibrating structure in the direction of focused laser beam. This frequency difference between an object beam and a reference beam causes light intensity modulation which refers to velocity of the vibrating object. Tested fruits were suspended by their own stem, they were subjected to sonic vibration ranging between 200 Hz and 2,000 Hz (BROZMAN, KUBÍK 2000). Laser beam was focused at the upper part of the tested apple considering relatively uniform mechanical properties around circumference (ABBOTT, LU 1996). Temperature varied from 18°C to 22°C during measurements.

THE FINITE ELEMENT MODELLING – VIRTUAL EXPERIMENT

The finite element software LUSAS ver. 13.1-2 (FEA Ltd., Forge House, 66 High Street, Kingston Upon Thames, Surrey, KT 1 1HN, United Kingdom) was used for the resonant frequency and mode shape extraction. Four three dimensional models of apples were created for virtual experiment. Each model had assigned an unique H/D ratio. H and D represent the mean values of the shoulder height and the equator diameter of apple respectively. The ratio H/D determinates a divergence of the finite element model from a sphere. H/D ratio was changed in the range from 0.80 to 0.95 with 0.05 increment during the simulation. The core and the flesh of apple model had assigned elastic, linear and homogeneous material properties. Viscoelastic approach has been neglected. These simplifications are conditional to the lack of detailed knowledge of material properties. Both fundamental parts of apple model together consisted from 1536 HX20 elements (FEA Ltd. 1999). Each three dimensional element has three degrees of freedom per node. An assigned value of the density and Poisson ratio was of 880 kg/m³ and 0.3 respectively for each virtual experiment. The basic geometric dimensions of models were taken from real fruits. An influence of apple core and apple flesh on the resonant frequencies and theirs corresponding modal shapes was investigated for each H/D ratio. Numerical simulation considered following modifications in performed modal analysis:

A: the core had assigned estimated value of Young's modulus of 8 MPa (E_c = constant), Young's modulus of the flesh (E_f) changed from 2 MPa to 7 MPa with increment of 1 MPa.

B: the core and the flesh had the same elastic properties, the Young's modulus ranged from 2 MPa to 8 MPa with increment of 1 MPa ($E_c = E_f$).

C: the flesh had assigned estimated value of Young's modulus of 4 MPa (E_f = constant). Young's modulus of the core (E_c) ranged from 4 MPa to 9 MPa with increment of 1 MPa.
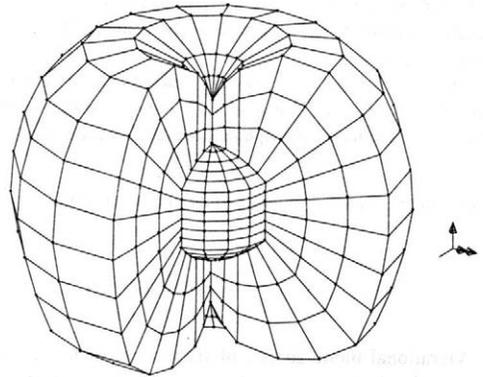

Fig. 1. Three-dimensional finite element model of apple

Given values intended as input for virtual experiment represents large variations in mechanical properties from the inner to the outer part of apple. Support conditions were assigned according to previous verification experiment of laser Doppler vibrometry.

The basic equation of motion used in this undamped analysis is given by:

$$[M]\{\ddot{u}\} + [K]\{u\} = 0 \qquad (1)$$

where: $[M]$ – mass matrix,
$[K]$ – stiffness matrix,
$\{u\}$ – displacement vector.

Each nodal point connecting an adjacent elements is assumed to vibrate in phase with others nodal points. In this term, displacement of nodal points can be written:

$$\{u\} = \{\phi_i\}\sin(\omega_i t) \qquad (2)$$

where: $\{\phi_i\}$ – i-th modal shape or amplitude,
ω_i – i-th natural frequency.

Substituting (2) in (3), eliminating $\sin(\omega_i t)$ using $\lambda_i = \omega_i^2$, we get eigenproblem formulation as follows:

$$([K] - \lambda_i [M])\{u\} = \{0\} \qquad (3)$$

where: λ_i – i-th eigenvalue.

Equation (3) is equivalent to:

$$[K][\Phi] = [\Lambda][M][\Phi] \qquad (4)$$

where: $[\Lambda]$ – diagonal matrix of eigenvalues λ_i,

$[\Phi]$ – matrix of eigenvectors $\{\phi_i\}$.

The objective of performed modal analysis is calculate λ and corresponding u.

LUSAS offers the following methods for eigenvalue extraction: Guyan reduction, Lanzos method, reduced iteration method with shifts and subspace iteration (FEA Ltd. 1999). Each technique has the specific attributes which define its application. An appropriate selection of algorithm with respect to ratio time versus accuracy is needed. Subspace iteration is used in this study. Subspace iteration technique is more effective than Guyan reduction since error in initial master degree of freedom determination may only affects number of iteration to converge in subspace iteration, whereas it would affect directly the accuracy in Guyan reduction. In addition, subspace iteration is more accurate than the Householder – bisection – inverse reduction method because subspace iteration method uses full matrices of mass and stiffness. Beside subspace, Householder – bisection – inverse reduction method uses approximated mass matrix. Lanzos method is assigned for a large problems of eigenvalue extraction.

Since the used algorithm is supposed to converge for accurate solution, convergence is given by (FEA Ltd. 1999):

$$\frac{|\lambda_i^{k+1} - \lambda_i^{k}|}{\lambda_i^{k}} \leq tolerance \tag{5}$$

where: λ_i^{k+1} – current eigenvalue calculated during the iteration process,

λ_i^{k} – previous eigenvalue calculated during the iteration process.

Value of tolerance is set on 10^{-6}. A control of numerical simulation was completed by a sturm sequence which corrects gained eigenvectors. This additional procedure was used since the natural frequencies of the studied objects are closely spaced. Determination of the computed resonant frequencies was given by detection of the unique modal shapes as output from virtual experiment considering the fact that each modal shape corresponds with the equivalent resonant frequencies. The eigenvalues and eigenvectors described in equation (4) identify directly the resonant vibrational frequencies and corresponding mode shapes of the finite element model respectively.

Firmness is a physical property that is commonly used for evaluating the quality and the state of maturity of the fruits. Firmness could also be used as a criterion for sorting. According to mathematical model for an interpretation of the vibrational behaviour of an intact fruit, firmness can be estimated by the firmness index FI (COOKE, RAND 1973):

$$FI = f_2^{2} m^{2/3} \tag{6}$$

where: f_2 – the second resonant frequency,

m – mass of the fruit.

In order to determinate the firmness index, the lowest flexural resonant frequency and the lowest longitudinal resonant frequency were extracted from modal analysis of the vibrating model. This assumption is based on previous studies (CHEN, DE BAERDEMAEKER 1993). Mass of the fruit is assumed to be constant (180 g) during the firmness index determination. This assumption is based on the fact that the weight loss is about 1.8% during storage in controlled atmosphere (HUNG et al. 1994).

RESULTS AND DISCUSSION

RESULTS OF VERIFICATION EXPERIMENT

The measured values of the resonant frequency using laser Doppler vibrometry are shown in Fig. 2. During the storage period, as apple becomes riper and softer, the resonance frequency gradually decreased. The values of standard deviation for each measurement in the
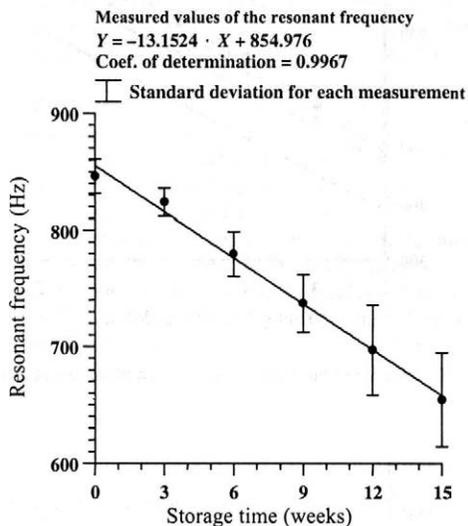

Fig. 2. The frequency response of the GALA apples during the storage

specific time increase. As it is shown in the figure, a development of the resonant frequency strongly depends on the storage period with a correlation coefficient $R = 0.9968$.

RESULTS OF THE FINITE ELEMENT MODELLING

The lowest 30 modes shapes were extracted and examined during the finite element simulation. Mode shapes emerged in the low frequency range behaved as
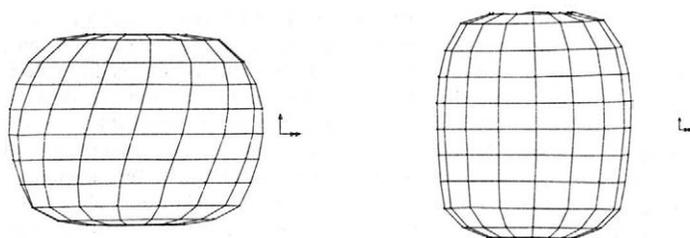
Fig. 3. The torsional and the first type longitudinal mode shape respectively

a rigid body modes. This modes are not included in the result presentation because of their lack of testifying competence. In addition, these types of modal shapes are hard to detect. The priority interest was aimed at extraction of the torsional mode shapes and the lowest

first type longitudinal mode shapes in this study. These mode shapes are illustrated in the Fig. 3.

The torsional mode shape is characterized by tangential vibration around the y axis. In order to directly determine the torsional resonant frequency, the laser

Ec = 8 MPa

- ◆ H/D=0.80
- —— $Y = 63.2646 \cdot X + 344.569$, coef. of determination = 0.989681
- ● H/D=0.85
- - - - - $Y = 68.7667 \cdot X + 337.354$, coef. of determination = 0.988305
- ■ H/D=0.90
- — — — $Y = 70.5066 \cdot X + 350.918$, coef. of determination = 0.98845
- ▲ H/D=0.95
- — · — $Y = 72.1819 \cdot X + 360.395$, coef. of determination = 0.988548
- + The torsional resonant frequency for each H/D ratio
- —— $Y = 63.5823 \cdot X + 259.54$, coef. of determination = 0.992027
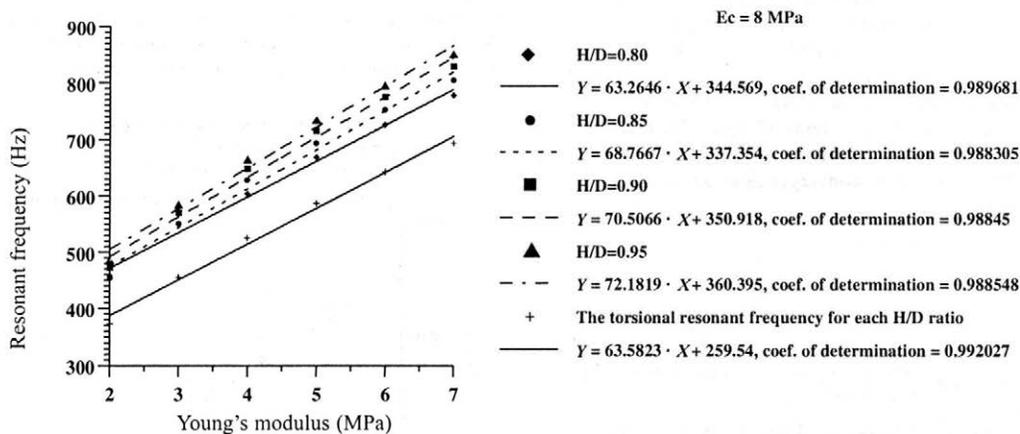
Fig. 4. Influence of the Young's modulus on the torsional and the first longitudinal resonant frequencies in modification A

Ec = Ef

- ◆ H/D=0.80
- —— $Y = 69.2427 \cdot X + 292.911$, coef. of determination = 0.993486
- ● H/D=0.85
- - - - - $Y = 70.1071 \cdot X + 308.267$, coef. of determination = 0.99076
- ■ H/D=0.90
- — — — $Y = 72.3581 \cdot X + 317.715$, coef. of determination = 0.990651
- ▲ H/D=0.95
- — · — $Y = 74.1864 \cdot X + 325.742$, coef. of determination = 0.990652
- + The torsional resonant frequency for each H/D ratio
- —— $Y = 60.9897 \cdot X + 267.616$, coef. of determination = 0.990717
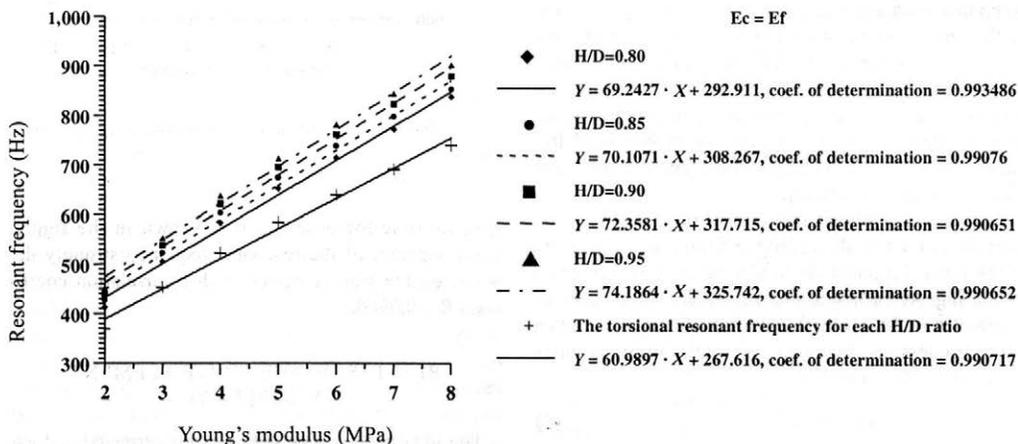
Fig. 5. Influence of the Young's modulus on the torsional and the first longitudinal resonant frequencies. Assigned values of Young's modulus of the core and the flesh are the same for each numerical simulation according to modification B
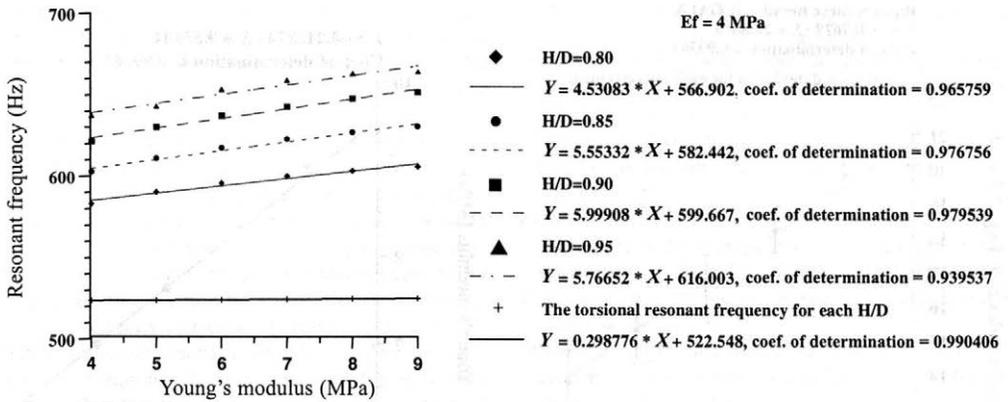
Fig. 6. Influence of the Young's modulus on the torsional and the first longitudinal resonant frequencies. Young's modulus of the flesh is the same

beam should be aimed at the lower or the upper part of the fruit. The area of the circumference should be avoided. The first longitudinal resonant frequency causes contraction and extension in transverse direction. This type of the resonance frequency is not dependent on the laser beam fixation. Each extracted mode shape was evaluated by the resonant frequency. Fig. 4 shows influence of the Young's modulus on the torsional and the first longitudinal resonant frequencies in numerical modification A. Young's modulus of the core remained the same during the simulation.

Values of the torsional resonant frequency are plotted by a curve which represents average for each H/D ratio. The curves of the first longitudinal resonant frequency gradually increase along with the curve of the torsional resonant frequency. The first longitudinal resonant frequency is more sensitive on H/D ratio change. In this case, higher values of the resonant frequency correspond with higher values of H/D ratio. The values of the torsional resonant frequency for each modelled H/D ratios remain closely related, they are almost identical. The similar results were obtained by the simulation where the Young's modulus of the core E_c and the flesh E_f varied simultaneously. This fact is described in the Fig. 5.

Both numerical approaches show similar ranges of the torsional resonant frequencies: from 370.299 Hz to 740.80 Hz ($E_c = 8$ MPa) and from 372.34 Hz to 693.06 Hz ($E_c = E_f$). Values of the first resonant frequency change rapidly in the case of $E_c = E_f$. Based on this results, for further determination of the firmness index, the case $E_c = E_f$ will be used. This approach allows to take into account Young's modulus variation in the whole continuum of apple. Another modelling approach (model C) considers constant value of the flesh of apple (Fig. 6).
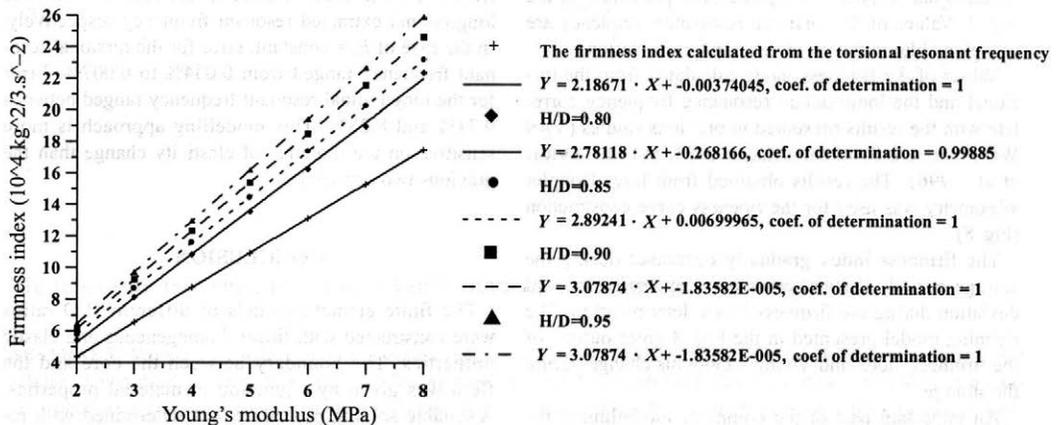

Fig. 7. The firmness index as a function of the torsional and the longitudinal resonance frequency. The data are based on results of models A, B, C
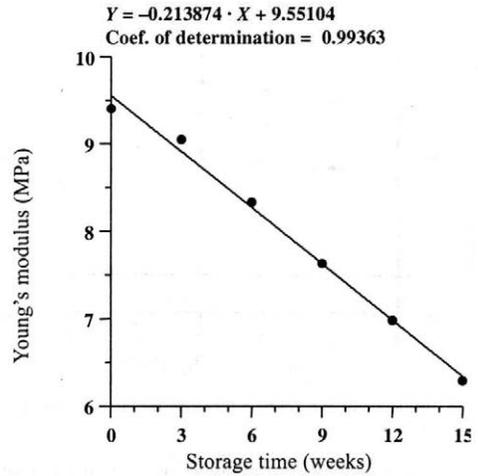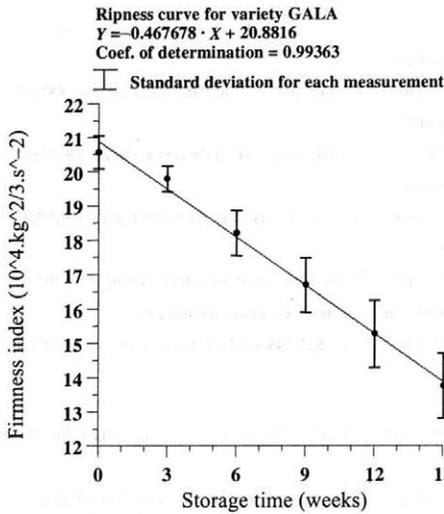
Fig. 8. The ripeness curve for variety GALA determinated by laser Doppler vibrometry and Young's modulus of tested fruits as the function of the storage time

The behaviour of the torsional resonant frequency was subjected to *t*-test, where a null hyphotesis $H_0 : M = M_0$ was tested against an alternative hyphotesis $H_1 : M \neq M_0$, M represents average value of the computed torsional resonant frequencies and M_0 represents constant value of 524 Hz. At the significance level of 0.01 the null hypothesis H_0 was not rejected. It can be stated that values of the torsional resonant frequency remain at constant value of 524 Hz. The obtained values of longitudinal resonant frequencies compared to previous modelling approaches A and B are slightly higher. Generally, model C is more rigid than the previous ones (model A and model B). The results of the firmness index for the torsional and the longitudinal resonance frequency are presented in the Fig. 7. Values of the torsional resonance frequency are processed like in the previous graph presentations.

Values of the firmness index calculated from the torsional and the longitudinal resonance frequency correlate with the results presented in previous studies (VAN WOENSEL, DE BAERDEMAEKER 1983; SCHMULEVICH et al. 1996). The results obtained from laser Doppler vibrometry was used for the ripeness curve construction (Fig. 8).

The firmness index gradually decreases during the storage period. Vertical error bars represent standard deviation during the firmness index determination. The ripening model presented in the Fig. 8 gives outline of the firmness index and Young's modulus change during the storage.

An important part of the computer modelling is the accuracy rating. This rating is given by a sensitivity of the computed resonant frequencies to variation of as-

signed material properties in this study. The sensitivity number is calculated from the following equation:

$$\mu = \frac{df_r x}{f_r dx} \tag{7}$$

where: f_r, x – resonant frequency and modulus of elasticity,

df_r, dx – resonant frequency and modulus of elasticity change.

Different values of the sensitivity number were detected during the simulation for each modelling approach. The sensitivity number for $E_c = E_f$ and for E_c = constant ranged from 0.628 to 0.666. In this case, 10% error in the assigned modulus of elasticity causes from 6.28% to 6.66 % error in the torsional and the longitudinal extracted resonant frequency respectively. In the case of E_f = constant, error for the torsional resonant frequency ranged from 0.034% to 0.007%. Error for the longitudinal resonant frequency ranged between 0.71% and 8.28%. This modelling approach is more sensitive on the modulus of elasticity change than previous two approaches.

CONCLUSION

The finite element models of different H/D ratios were constructed with linear, homogeneous and elastic properties. The boundary between the core and the flesh was given by a junction in material properties. A suitable solving procedure was determined with respect to the accuracy and the computational time. As evaluating tools for the resonant frequency extraction

the first type longitudinal and torsional mode shapes were used. H/D ratio varied in the range from 0.80 to 0.95. The effects of the change in Young's modulus for each H/D ratio with respect to three different modelling approaches were determinated. In the case of E_c = constant (model *A*) and $E_c = E_f$ (model *B*), the behaviour of the torsional and the longitudinal resonant frequency is almost identical. In the case of E_f = 4 MPa (model *C*), the value of the torsional resonance frequency remains at constant level of 524 Hz. Assuming this approach, the torsional resonant frequency remains constant for each H/D ratio. It could be stated that an increase in H/D ratio directly causes an increase in values of the first longitudinal resonant frequencies. The torsional resonant frequency is less sensitive for H/D ratio change. Thus this type of resonant frequency is almost independent on the shape of the fruit. Changes in values of core Young's modulus significantly affect values of the first resonant frequencies. Calculated values of the firmness index gradually decrease along with increment of the Young's modulus. The torsional resonant frequency from modelling approaches $E_c = E_f$ and E_c = constant could be used for the firmness index determination regardless the geometric shape of apple. The ripeness curve constructed from the results of laser Doppler vibrometry gradually decreases in the range of 15 weeks. A similar behaviour is depicted by dependance of Young's modulus and the storage time. These curves can be further used for quality evaluation of GALA apples. Linear equations of regression possess testifying competence in listed ranges of experiments with very high confidence and quite abbreviate this complex problem.

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Modelovanie frekvenčnej odozvy jablk pomocou metódy konečných prvkov

ABSTRAKT: V práci sú použité trojdimenzionálne počítačové modely jablk, ktorým boli priradené materiálové vlastnosti určujúce homogénne, lineárne kontinuum. Viskoelastické vlastnosti boli zanedbané. Použité počítačové modely sa navzájom odlišovali svojou geometriou a priradenými materiálovými vlastnosťami. Počas numerickej simulácie sa získavali torzné a pozdĺžne modálne tvary. Torzný mód kmitania sa vyskytuje vo frekvenčnom pásme od 369,198 Hz do 742,316 Hz, pozdĺžny mód kmitania je možné zaznamenať v pásme od 412,177 Hz do 901,179 Hz. V prípade konštantnej hodnoty Youngovho modulu pružnosti priradenej dužine jablka hodnota torzej rezonančnej frekvencie bola konštantná 524 Hz nezávisle

na geometrickom tvare. V prípade rovnakých materiálových vlastností dužiny a jadra a v prípade konštantnej hodnoty modulu pružnosti jadra možno považovať výsledky numerickej simulácie za totožné. Pre každý modelový prístup boli vypočítané hodnoty čísla podmienenosti. Na základe výsledkov Dopplerovskej laserovej vibrometrie sa pre odrodu GALA stanovila krivka dozrievania.

Kľúčové slová: jablká; tvrdosť; metóda konečných prvkov

Corresponding author:

Ing. MARTIN FRAŇO, Slovenská poľnohospodárska univerzita, Mechanizačná fakulta, Trieda A. Hlinku 2, 949 76 Nitra, Slovenská republika, tel.: + 421 87 51 17 51, fax: + 421 87 41 70 03, e-mail: frano@mech.uniag.sk

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