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Institute of Technology, EULS
St. Kreutzwaldi 56, 51014 Tartu, ESTONIA
E-mail: timo.kikas@emu.ee

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CONTENTS

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Comparison of tractor slip at three different driving wheels on grass

R. Abrahám[1,*], R. Majdan[2] and R. Drlička[3]

[1,2]Department of handling and transport machinery, Faculty of Engineering, Slovak University of Agriculture in Nitra, Tr. A. Hlinku 2, SK949 76 Nitra, Slovak Republic
[3]Department of Quality and Engineering Technologies, Faculty of Engineering, Slovak University of Agriculture in Nitra, Tr. A. Hlinku 2, SK949 76 Nitra, Slovak
[*]Correspondence: rudolf.abraham@uniag.sk

Abstract. The paper deals with a possibility of tractor slip reduction on a grass and evaluates an use of two versions of special wheels. Both prototypes were developed at the Department of Transport and Handling of the Slovak University of Agriculture in Nitra. The first system was designed in 2010 year as blades wheels. The second system (spikes device) consists of spikes which are mounted onto standard tractor tyres with special cuts, was designed in 2014 year. The spikes are settled in these cuts while moving on road surface. The second one is placed near the drive wheels and uses the blades. The spikes and blades are ejected to reduce wheels slip when tractor operates on grass or soil. The base position allows tractor transport on road with standard tyres. The goal of experiments realized on grass surface was to compare mutually slip behaviour achieved. The measurements were realized with standard tyres without any modification, too. A tractor with three types of drive wheels were loaded by heavier tractor. Drawbar pull and wheel rotation speed for slip calculation were measured in tests. The results show a fact that a loss of energy due to the wheels slip increases, while a penetrometric resistance in the surface layers of a soil decreases, at soil humidity 33.2%. An application of both prototypes is very advantageous because they reduce the wheels slip, increase tractor operation efficiency and so protect the soil.

Key words: tyres modification, spikes wheels, soil moisture, slip.

INTRODUCTION

The testing of tractors used in agriculture is continuously increasing because these machines directly influence the results of agricultural production. Adamchuk et al. (2016) presents that the tractor's energy saturation rate as the ratio between the installed engine power rating and the operating mass of the power unit is the criterion of its belonging either to the traction or the traction and power concepts, each of which feature their own system of unitising agricultural equipment. This criterion should be understood by the designers of any new mobile power units for operation in the agricultural industry.

Agricultural tractors are losing a lot of energy by the slip of drive wheels. To reduce the tyre slip, tractors are loaded with a heavy weight, which increases the drawbar pull but excessively increases soil compaction and tyre wear on a hard surface (Semetko et al., 2004; Jobbágy et al., 2016). The compacted soil is a problem for all ecosystems because worse water infiltration (Chyba et al., 2013; Chyba et al., 2014) is causing often flood on the present.

Nowadays, diesel oil and petroleum products belong to the most used fuels. Unfortunately, fossil fuels are non-renewable and exhaustible sources of energy (Müllerová, et al., 2012). The increase of tractor drawbar pull influences the fuel consumption and emissions of exhaust gases.

The drawbar pull, travel reduction (slip), and rolling resistance are the main criteria to describe the traction behaviour of off road vehicles. Besides the engine performance, the drawbar pull is influenced by the traction conditions such as soil and the tire parameters (Schreiber & Kutzbach, 2008).

The drawbar pull of tractor is influenced by various factors. Very significant parameter influencing the drawbar pull is a tyre pressure. Noréus & Trigell (2008) realized the measurement of drawbar pull at various tyre pressure. The test showed that the drawbar pull is vastly improved at lower tyre pressure.

Dabrowsky at al. (2006) realized the tests of terrain vehicle equipped with different tyre types. All-season tyres installed in a military truck provide slightly better traction for both terrain surfaces, at all three loading levels, or the differences between traction measures are not significant. Soil stress analysis showed that the difference between the two tread patterns is not significant. Generally, on soft surfaces all-season tyres performed no worse than snow tyres, while they are pronouncedly better for highway use.

Agricultural tractors can have different types of undercarriage such as two wheel drive, four-wheel drive, and steel tracks. Despite a higher tractive performance and lower soil compaction, steel-tracked tractors are not popular due to their complexity and the difficulties of moving steel-tracked vehicles on roads. Recently, rubber belt tracks have become a notable solution for agricultural tractors, because they unite tractive performance and lower soil compaction with a better trafficability (Molari et al., 2012).

We can concluded that as tractor power increases and as soil becomes weaker and less frictional, then the balance of advantage changes from two wheel to four wheel drive. The type of tyres is the next important factor to increase the drawbar pull and influence tractive performance, as well as soil stresses under a vehicle.

The results of a theoretical analysis reveal that, for a four-wheel-drive tractor to achieve the optimum tractive performance under a given operating condition, the thrust (or driving torque) distribution between the front and rear axles should be such that the slips of the front and rear tyres are equal. Field test data confirm the theoretical findings that, when the theoretical speed ratio is equal to 1, the efficiency of slip and tractive efficiency reach their respective peaks, the fuel consumption per unit drawbar power reaches a minimum, and the overall tractive performance is at an optimum (Wong et al., 1998).

MATERIALS AND METHODS

Two prototypes of drive wheels for tractors were developed and designed in Slovak University of Agriculture in Nitra, Faculty of Engineering, Department of Transport and Handling. Both drive wheels modify the properties of common tyres to improve the drawbar properties of tractor. The prototypes should decrease wheels slip and so protect the soil again damage, improve an operation economic of the tractor and increase drawbar pull if tractor cannot move due to 100% wheels slip. Design of prototypes which reduce the wheels slip and allow the tractor transport on standard road using the common tyres was aim of this research. We name the prototypes as spikes device and blades wheels. The first one requires a tyre-tread pattern modification but it is very simple, low cost design characterised by easy installation on common tyres. The second one doesn't require any tyre modification because it is installed near the tractor wheels. Design of blades wheels is more complicated and expensive. It can be predicted that the blades wheels will reach better drawbar properties compare with spikes device during the same test due to stronger construction but simplicity is the main advantage of spikes device.

Test procedure

Testing properties of both prototypes, a wheels slip and drawbar power were used in compare with common tyres TS-02 6.5/75-14 4PR TT type (Mitas a. s., Czech Republic). These parameters characterise the operation economic and influence of tractor on soil condition mainly soil compaction. To calculate wheels slip and drawbar power a measurement procedure according to following steps was realized.

Tractor type Mini 070 (Fig. 1) was equipped with different wheels to test prototypes properties. Characteristics of Mini 070 are listed in Table 1

Figure 1. The tractor type Mini 070 equipped with the spikes device.

Table 1. Specifications of the tractor type Mini 070

Characteristic	Value
Year of manufacture	1989
Construction weight	310 kg
	1.53 km h^{-1} at 1st gear
	2.72 km h^{-1} at 2nd gear
	4.96 km h^{-1} at 3rd gear
	14.4 km h^{-1} at 4th gear
	1 cylinder
	400 cm^3 (displacement)
	8 kW (maximum performance)
	3,600 rpm (rated rotation speed)

Preparing prototypes tests, a measuring sector (30 m) was staked on grass using two rods at the sector start and finish. Nest, a white mark was drawn on the tractor wheel perimeter for number of wheel revolves counting.

In first measurement, the tractor with no load passed whole sector, number of wheel revolves was counted and time measured. Return of the tractor to the start of measuring sector.

Attachment of a loading tractor (no gear engaged) to the tractor with tested wheel prototype via drawbar pull sensor (Fig. 1). Technical parameters and specification of tractor type TZ-4K14 used to brake the first one are listed in Table 2.

Table 2. Specifications of the bracking tractor type TZ-4K-14

Characteristic	Value
Year of manufacture	1987
Construction weight	820 kg
	1 cylinder
	900 cm^3 (displacement)
	12 kW (maximum performance)

Removal of heater plug from engine head of the loading tractor to achieve constant drawbar pull with 3rd and 4st gear engaged and stopped engine.

Start the stopwatch when the tractor front part passing the staring rods, start the drawbar pull measurement system and count the drive wheel rotates. The drawbar pull measurement of the tractor type Mini 070 (Fig. 1) equipped with different wheels was performed by means of a tensometric force sensor marked as 150 EMS (Emsyst s. r. o., Slovak Republic), as shown in Fig. 2. The force sensor was connected between the loading tractor TZ-4K-14 and the tractor type Mini 070 through a chain. A portable recording unit type HMG 3010 (Hydac GmbH, Germany) was used to record an electrical signals from the force sensor. A description of measurement devices and sensors are presented in the work published by Tulík et al. (2013). The tractor type Mini 070 was set the first gear (I gear) during the measurement. The connection of both tractors was realized according to work presented by Jablonický et al. (2014) and Procházka et al. (2015). Universal battery source (UANS) contains two accumulators (12 V) connected in series or parallel to supply the sensor and the recording unit with a direct voltage (12 V or 24 V). The power supply was manufactured as a portable device according to works presented by Takáč et al. (2011) and Cviklovič et al. (2012).

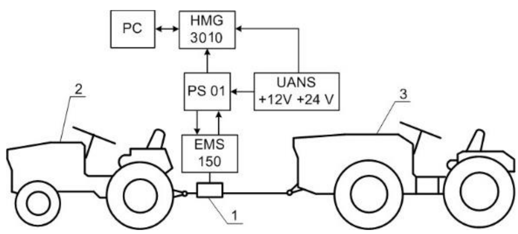

Figure 2. System for measurement of tractor drawbar pulls (Abrahám et al., 2014): 1 – force sensor EMS 150; 2 – tractor type Mini 070 equipped with different wheel types; 3 – loading tractor type TZ-4K-14, HMG 3010 – digital portable recording device, UANS – universal battery source, PC – personal computer, PS 01 – junction box.

Stop the stopwatch and counting of drive wheel rotates when tractor front part passes finish rods. Next, record values to table and repeat the measurement with loading tractor attached with fourth and then third gear engaged to spend all possibilities.

Calculation of wheels slip and drawbar power

Tractor slip moving on elastic base support measurement is realised according to common methodology mentioned above. First, measuring sector was staked on the grass plot using measuring tape and marked by two rods at the start and at the finish. Tractor movement time was measured using stopwatch starting when front part of tractor passes the start rods and ending when the same tractor part passes the finish rods. Tractor wheels slip was measured using line drawn on wheel serving to count number of revolves of drive wheel in the measuring sector. Actual tractor speed was calculated according to formula:

$$v = \frac{s}{t} \tag{1}$$

Theoretical speed is calculated according to formula:

$$v_t = \frac{2\,\pi\,r_d\,n_m}{i_c} \tag{2}$$

where r_d is the dynamic radius of drive tyre, m; n_m is the nominal engine speed, s^{-1}; s is the staked sector (length 30 m), m; t is the time to move over the sector, s.
Slip of the tractor drive wheels is calculated according to formula:

$$\delta = \left(1 - \frac{n_t}{n_{sk}}\right) \tag{3}$$

where n_t is the theoretic wheel speed with no load in the measuring sector, s^{-1}; n_{sk} is the actual wheel speed with load in the same measuring sector, s^{-1}.

Slip of drive wheels can be verified according to formula:

$$\delta = \left(1 - \frac{v}{v_t}\right) \tag{4}$$

where v is the actual speed, m s^{-1}; v_t is the theoretic speed, m s^{-1}.

The drawbar power is determined by drawbar pull and motion speed of tractor. Drawbar characteristics of tractor determine tractor drawbar capacity defined by its drawbar pull F_t at particular motion speed, specifying tractor drawbar power P_t. Tractor drawbar power determines significantly driving mechanism slip δ, particularly on unpaved supports. Slip values are therefore accompanying specification of drawbar parameters.

Tractor drawbar power can be calculated according to:

$$P_t = F_t\,v. \tag{5}$$

where F_t is the drawbar pull, N; v is the actual speed, m s^{-1}.

Prototypes of drive wheels

Both prototypes namely spikes device and blades wheels were designed for tractor type Mini 070. Using the small tractor the design was less expensive and the test of wheels properties sampler compare with standard size of tractor.

Spikes device (Fig. 3) consists of four segments (Fig. 4) connected together by carrying wire rope 3 and operated by control wire rope 4. Control wire 4 provides spikes tipping from tyre body and mutual holding of individual segments in the same position. Spikes are tilting to avoid need for removal when moving on the road and reduce the health risks for operator. The tilting is realised by spikes 1 rotation to tangential position not outreaching the tyre body (tread). Spikes 2 eject automatically due to tractor drive wheel slip, when mechanism 5 is locked-off. It is necessary to lock tilted position of spikes 1 using levers 5 to prevent spikes recline to transport position when generating drawbar pull back in reverse motion. Locked transport position suitable for movement on paved roads using levers 5 holding spikes 1 reclined is depicted in Fig. 3.

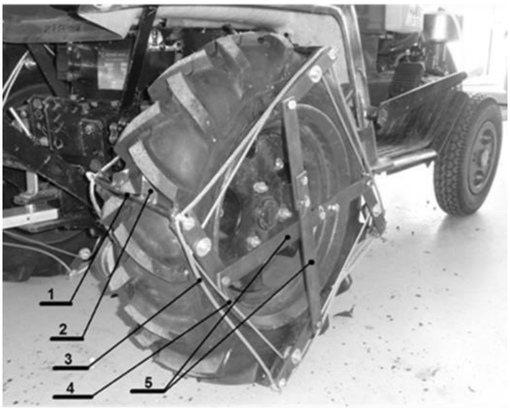

Figure 3. Spikes device on tractor wheel type TS – 02: 1 – cross-beam; 2 – spike; 3 – carrying wire rope; 4 – control wire rope; 5 – locking levers setting tilted/reclined position.

Blades wheels (Fig. 5) are equipped with automatically extensible blades. Wheels equipped with the blades were designed according to the work published by Sloboda et al. (2008). A main advantage is that they do not have to be removed from the tractor when passing on the road and also that they are automatically extended when the tractor drive wheels are slipping. Re-folding of driving blades occurs with the reverse movement of the tractor. The tractor needs not be equipped with additional load weights because they are replaced by wheels equipped with automatically extensible blades. Wheels equipped with automatically extensible blades are mounted to the wheel disc, and according to Fig. 5, they consist of the following parts.

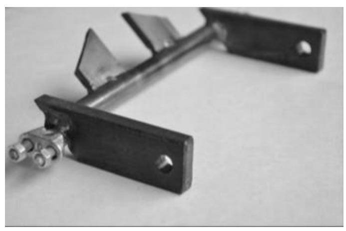

Figure 4. Detail of one spike segment.

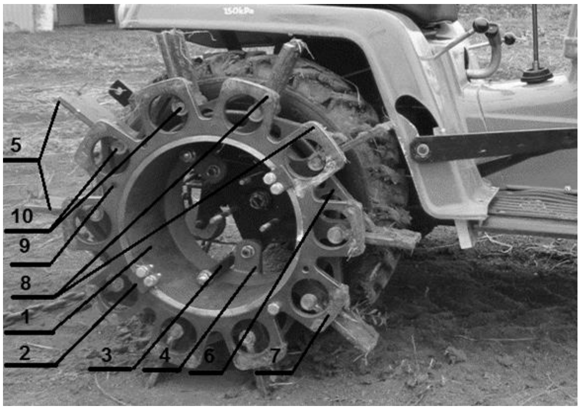

Figure 5. Blades wheel: 1 – support tube; 2 – locking tab; 3 – bracket fastening the mechanism to the wheel disc; 4 – spacer plates; 5 – blade; 6 – driving disc; 7 – blade control disc; 8 – guide pin; 9 – locking hole; 10 – blade pin; 11 – buffer plate.

A support tube (1) is a basic part of the whole mechanism. It enables the remaining parts of the whole mechanism to be attached to each other. On the support tube, there are welded three locking tabs (2), three brackets (3) by which the whole mechanism is connected to the tractor wheel, and a driving disc (6) containing blades (5) mounted by means of ten pins. On the support tube, there are also welded spacer plates (4) through which the mechanism position is centred with respect to the tractor wheel disc. After the driving disc (6), the support tube contains a freely rotating disc for the control of blades (7). The blade control disc contains on its circumference twenty pressed guide pins by means of which blades move into the extended and retracted positions. On the other side of the blade control disc, there are four locking holes (9) to fix the position of blades in the retracted position. Three buffer plates (11), attached by six screws to the locking tabs (2), fix the blade control disc on the support tube.

RESULTS AND DISCUSSION

The measurements were realised in March 2016 with average volume soil humidity 33.2% and soil volume weight 1.66 g cm^{-3}. The measurement were realised on the grass plane surface at sunny weather in Slovak Agricultural Museum in Nitra. The area for measurement was approximately 0.5 ha. Measuring sector limited by rods had rectangular shape with dimensions 30 x 25 m.

Results achieved (Tables 3, 4, 5) were divided for evaluation according to gear used on tractor MINI 070 when testing. Variances were observed in drawbar pull when using common tyre, blades wheels and spikes device, as it is shown in Fig. 6. These differences are caused by higher motion speed (Fig. 7) achieved by tractor with spikes device leading to higher engine speed of tractor TZ-4K-14, resulting in recorded higher drawbar pull and higher mechanical resistance. Similar variances were observed with second gear engaged (Fig. 8), with differences even more significant due to higher motion speed (Fig. 9).

Table 3. Measured values of drive tyres (30 m sector)

Tractor motion speed measurement with first gear engaged on grass							
	Travelling using common tyres						
	Travel time s	Speed, m s^{-1}	Theoretic wheel revolution	Wheel revolution under load	Wheels slip	Average drawbar pull, N	Drawbar power, W
No load	71	0.423		16			
No gear	78	0.385		16.9	0.053	1,174.879	451.876
4	83	0.361		17.3	0.075	2,336.123	844.382
3	110	0.273		23.0	0.304	2,986.495	814.499
Tractor motion speed measurement with second gear engaged on grass							
No load	39	0.769		16			
No gear	45	0.667		17.6	0.091	924.535	616.357
4	58	0.517		20.3	0.212	2,765.980	1,430.679
3	98	0.306		25.0	0.360	3,467.780	1,061.565

Table 4. Measured values of drive spikes tyres (30 m sector)

Tractor motion speed measurement with first gear engaged on grass							
	Travelling using spikes device						
	Travel time s	Speed, m s^{-1}	Theoretic wheel revolution	Wheel revolution under load	Wheels slip	Average drawbar pull, N	Drawbar power, W
No load	71	0.423		16			
No gear	74	0.405		16.8	0.048	1,094.605	443.759
4	78	0.385		18.2	0.121	2,542.857	978.022
3	103	0.291		23.3	0.313	3,210.570	935.117
Tractor motion speed measurement with second gear engaged on grass							
No load	39	0.769		17			
No gear	41	0.732		18.0	0.111	712.036	521.002
4	49	0.612		20.5	0.220	2,875.230	1,760.345
3	57	0.526		22.3	0.283	3,267.750	1,719.868

Table 5. Measured values of drive blades wheels (30 m sector)

Tractor motion speed measurement with first gear engaged on grass							
	Travelling using blades wheels						
	Travel time s	Speed, m s^{-1}	Theoretic wheel revolution	Wheel revolution under load	Wheels slip	Average drawbar pull, N	Drawbar power, W
No load	71	0.423					
No gear	73	0.411		16.5	0.002	706.357	290.284
4	77	0.390		17.3	0.049	2,456.860	957.218
3	102	0.294		23.0	0.284	3,224.495	948.381
Tractor motion speed measurement with second gear engaged on grass							
No load	39	0.769					
No gear	40	0.750		16.5	0.030	924.191	693.144
4	48	0.625		17.1	0.064	3,414.691	2,134.182
3	55	0.545		20.3	0.212	4,450.225	2,427.395

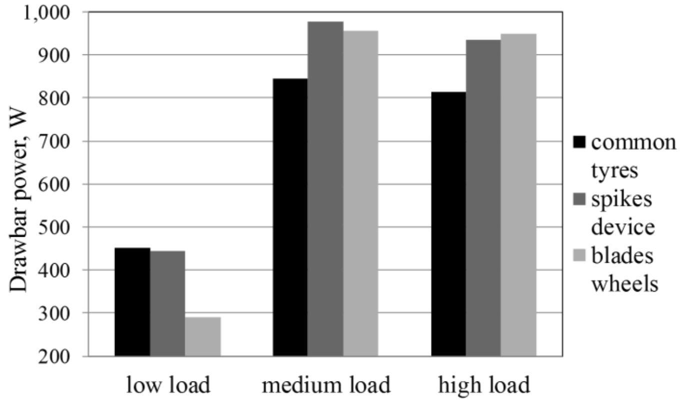

Figure 6. Drawbar power of tractor with two drive wheel prototypes and common tyres at the first gear.

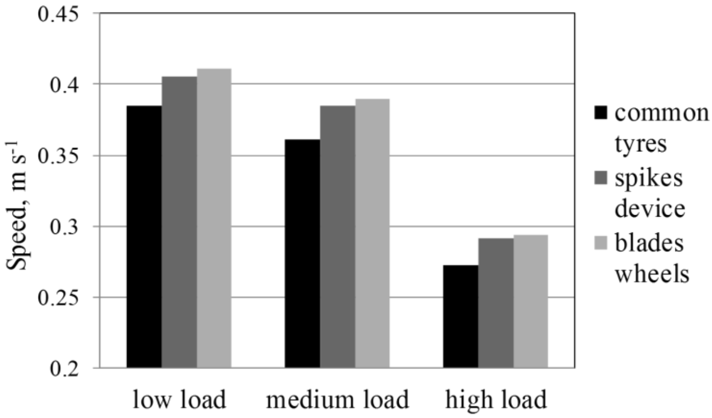

Figure 7. Speed of tractor with different drive wheels at the first gear.

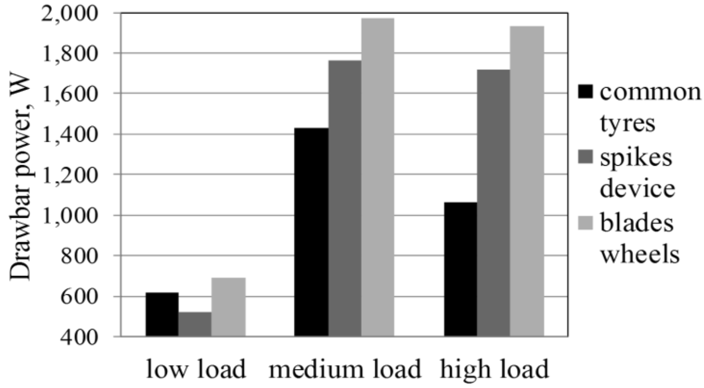

Figure 8. Drawbar power of tractor with two drive wheel prototypes and common tyres at the second gear.

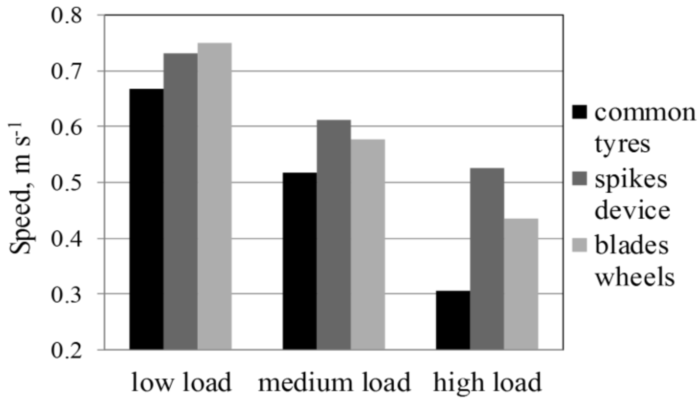

Figure 9. Speed of tractor with different drive wheels at the second gear.

Figs 10, 11 represent the best a comparison of efficiency of drawbar pull by wheel to surface transfer. Based on dependency of slip on drawbar power at 1st gear (results shown in Fig. 10), an improvement of drawbar pull is observed when both special wheels are used. This improvement can be characterized as linearly increasing slip with drawbar power rising up to some value in case of all three types of the drive wheels. The spikes device allow for higher drawbar power from 850 W approximately keeping linear dependency of slip on drawbar power up to value 1,000 W approximately, as it is apparent from Fig. 10. The tyres though change the dependency to parabolic from linear one and slip jumping up already at the drawbar power value 850 W. The most favourable slip dependency was found in case of the blade wheels with the linear dependency and considerably lower slip values. The dependency changed to parabolic one later at 950 W almost in same manner as in case of spikes device. It results from this comparison the efficiency of driving power transfer using blade wheels is most favourable till the moment of cohesion strength of soft base.

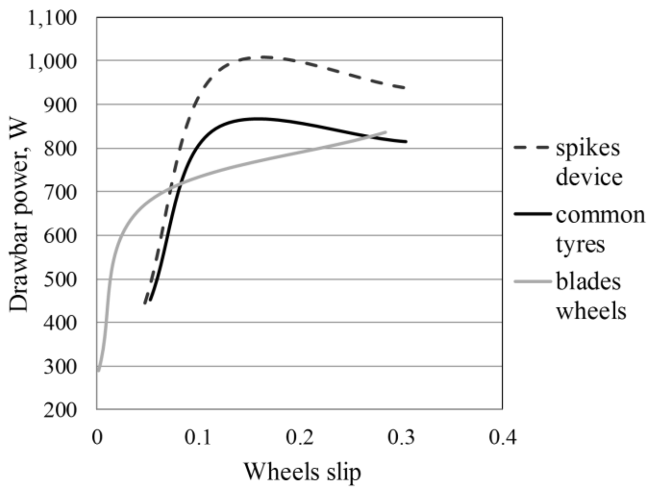

Figure 10. Comparison of the three types of slip on the drive wheels first gear.

Based on the dependency of the slip on drawbar power results (see Fig. 11) with 2nd gear, even higher improvement of the drawbar pull transfer to base is observed when spikes device as well as tyres with blade wheels used. This improvement can be characterized as linearly growing slip with increasing drawbar power up to certain value in all three drive wheel variations (Kielbasa & Korenko, 2006) The spikes device and even more blades wheels can generate higher drawbar power and keep linear dependency of slip on drawbar power longer, approximately up to value 1,800 W, as it is visible in Fig. 11. The dependency changes from linear to parabolic and slip raises sharp at the value 1,430 W in case of tyres. An improvement of the drawbar pull transfer from tyre to base efficiency compare to 1st gear should be noticed, the efficiency being slightly better compare to spikes tyres up to value 1,250 W.

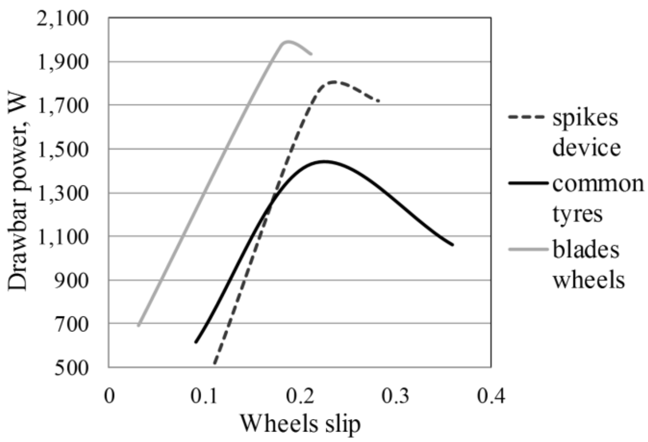

Figure 11. Comparison of the three types of slip on the drive wheels second gear.

Battiato & Diserens (2013) present in their work that, although the tractor developed higher drawbar pull both when tyre inflation pressure was decreased and wheel load was increased, only the decrease in tyre pressure produced improvements in terms of coefficient of traction, tractive efficiency, power delivery efficiency, and specific fuel consumption, while the only significant benefit due to the increase in wheel load was a reduction in the specific fuel consumption at a tyre pressure of 160 kPa and a slip of under 15%. Nadytko et al. (2015) and Kučera et al. (2016) present the tractive performance of tractor depending on tyre inflation, too. When comparing these results with those obtained in our study, we improved the tractor performance using a special spikes device. In this case the wheel load and tyre inflation do not be changed because the, as mentioned above, makes the slip lower in compare with tire without any modification.

Curves showing the dependence of drawbar power, tractive efficiency and specific fuel consumption on dynamic traction ratio and slip are presented in a work of Jenane et al. (1996).

The drive wheels drawbar properties improvement influences the soil compaction as well (Rataj et al., 2009). Lower slip causes less compacted soil and higher motion speed provide for gentle soil compaction. It comes from results achieved the higher motion speed were observed at the constant load when used spikes wheels and blade wheels. This implicates the soil compaction and deformation in the drive wheels track was lower.

CONCLUSIONS

The proposed prototypes for an improvement of drawbar properties of the tractor drive wheels was designed using structural steel grade S355J0 (STN EN 10025 : 2004) and made from common material profiles at the Faculty of Engineering SUA in Nitra. We designed two prototypes namely spikes device and blades wheels. Their properties were tested on the basis of wheels slip and drawbar power of the tractor operated on grass. The prototypes were compared with common tyres. The spikes and blades were designed to improve drawbar properties and allow tractor transport on road if they are placed in base position. Regarding automatic ejection, numbers and shape of spikes and blades were proposed. For function verification the spikes device was designed in the basic version with four spike segments. It is the base version to verify the strength, drawbar properties, self-cleaning of tyre-tread pattern and function of this prototype. The tests pointed out that the simply construction of spikes devices is suitable for drive wheels by reason of simply montage on wheel similar to snow chains, function of automatic ejection, only minimal impact on self-cleaning and improvement of drawbar properties. On the basis of stale fact that the numbers of segments around the wheel perimeter influences the drawbar properties, the number of the spike segments will be doubled to eight in a next research and tests with the same control system as in case of four segment device described. We predict that this solution will increase the drawbar pull of the tractor with the spikes device.

The blades wheels reached the best drawbar properties. The blades with sharp ending will be used for the next research by the reason of better penetration to the hard soil at low humidity. Under this soil condition may become a loss of contact between drive wheels and ground due to ineffective blades penetration.

From Figs 10 and 11 it can be observed that, once a certain amount of the wheel slip is exceeded, the drawbar power decreases. This commonly observed phenomenon mentions maximum drawbar power reached using the blades wheels. The spikes tyres reached lower drawbar power but higher than common tyres because rubber tire-tread pattern limited their drawbar properties. The spikes or blades of prototypes penetrate to the grass plot and therefore reached higher drawbar power due to better force transmission between drive wheels and ground.

The three wheel types were tested at high soil humidity intentionally to maximize display of differences in drawbar properties of the common tyres and both prototypes of drive wheels. The wheels were compared first time in these tests, assuming the improvements in drawbar properties will be even more considerable at the surfaces as the soil covered by manure or frozen subsurface with melted surface layer are.

As it arises from the results achieved of drawbar properties of the tractor tyre improvement, the spikes device have desirable effect on drive wheels slip reduction and improvement of the drawbar pull to soft base transfer efficiency at higher soil humidity 33.2% compare to common tractor tyres.

Both prototypes are also applicable for higher tractor size. Only one condition has to be meeting namely a possibility of tread with change. It creates the space between tyre and mudguard for spikes or avoids exceeding maximum tractor width in case of blades wheels. In addition the blades wheels have to be mounted straight on a wheel disc without ballast weight by the reason of tight connection with drive wheel. The weight of the blades wheels is so much to be ballast weight for drive wheels.

Experiment plans for the next future comprise tests of the spikes device inserted in the car off-road tyre body. The long term tests should include comparison of unpaved road ride in forest and driving in winter conditions. Certainly, the tyre tread deteriorates while using these devices. The tyre tread wear rate will be observed therefore as well. Anyway, the tyre can be used regardless of the changes made on it to apply spikes devices.

The tractor manufacturers should be interested not only in number of drive wheels and types of tractor undercarriage but also drive wheels modification because they show very interesting drawbar properties improvement.

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Investigations about the impact of the sowing time and rate of the biomass yield and quality of industrial hemp

A. Adamovics[1], S. Ivanovs[1,*] and V. Bulgakov[2]

[1]Latvia University of Agriculture, 2, Liela str., Jelgava LV-3001, Latvia
[2]National University of Life and Environmental Sciences of Ukraine, 15, Heroyiv Obrony str., Kyiv UK 03041, Ukraine
[*]Correspondence: semjons@apollo.lv

Abstract. The aim of this study was to find the optimum sowing rate of industrial hemp (*Cannabis sativa* L.) and to clarify the impact of the sowing rate on the production of biofuel from hemp biomass in Latvia. Field trials were carried out at the Research and Study Farm 'Pēterlauki' of the Latvia University of Agriculture in 2012–2014. The industrial hemp (*Cannabis sativa* L.) 'Futura 75' was sown in a Luvic Endogleyic Stagnosol soil: pHKCl 6.7; P – 52 mg kg^{-1}; K – 128 mg kg^{-1}; the organic matter content – 21–25 g kg^{-1}. Hemp was sown in 10 m^2 plots, triplicate, on May 8 and 17. The total sowing rate was 20 (100), 30 (150), 40 (200), 50 (250), 60 (300), 70 (350), 80 (400), 90 (450), and 100 (500) kg ha^{-1} (germinating seeds per 1 m^2). The plots were fertilised as follows: N – 120 kg ha^{-1}; P_2O_5 – 80 kg ha^{-1}; and K_2O – 112 kg ha^{-1}. Hemp was harvested when the first matured seeds appeared. The biometrical indices (height and stem diameter), harvesting time, the amount of fresh and dry biomass, and the fibre content were evaluated. Depending on the sowing rate, the yield of dry matter was on average 9.2–12.1 t ha^{-1} when hemp was sown at the beginning of May, and 7.9–10.0 t ha^{-1} when hemp was sown in the middle of May.

Key words: industrial hemp, sowing time and rate, yield, quality.

INTRODUCTION

Hemp is considered to be one of the most promising renewable biomass sources to replace the non-renewable natural resources for the manufacturing of a wide range of industrial products in the world and also in Latvia (Adamovics et al., 2012; Ivanovs et al., 2015; Lekavicius et al., 2015).

The efficiency of industrial hemp (*Cannabis sativa* L.) from seed requires the establishment of an ideal sowing rate, which determines the final plant sowing density. Under-sowing may result in undesirable product qualities and poor yield (Ranalli, 1999) in addition to increased competition by weeds (Mosjidis & Wehtje, 2011), harvesting difficulty associated with thicker stems (Bocsa & Karus, 1998), and particularly reduced radiation use efficiencies (Bullard et al., 2009). Excessive planting densities in hemp crops result in increased self-thinning and a slowing down of crop growth rate in the later stages of development (Van der Werf et al., 1999). The appropriate density of planting varies with the variety, season, soil type, and range of other agronomic practices adopted for the crop. Hence, sowing density for any variety should be optimised for the particular location of interest. Industrial hemp is also sown at different densities depending on the purpose of the crop: whether it is for fibre or for grain. The recommended seed rate for the latter (i. e., seed crop) is often around 30 kg ha^{-1} or 100–150 plants m^{-2} (Bocsa & Karus, 1998). Low sowing density for a seed crop allows for greater branching, shorter plant height, and heavy individual plant weight compared to fibre crops sown at higher density. The latter suppresses branching and induces taller and lighter individual plants.

Harvesting of hemp crops for fibre at maturity is much easier when plants are upright and have few branches, and the quality of fibre is better in unbranched plants. Planting density for fibre hemp is roughly twice that of seed hemp. Early researches (Bocsa & Karus, 1998) suggest that no more than 80 kg seed ha^{-1} be sown for fibre hemp as little differences in the final yields were observed from 60 to 100 kg ha^{-1} (300–500 plants m^{-2}). These rates are considered, however, excessive for non-textile fibre hemp that is produced for the volume of fibre rather than for the quality. Sowing rates for non-textile fibre may be adequate at 30 kg ha^{-1} (Burczyk et al., 2009). High sowing rates generally produce shorter and thinner stemmed plants (Amaducci et al., 2008) with a higher proportion of fibre in the stem material, which is desirable for fibre hemp (Van der Werfet et al., 1999).

The sowing rate, depending on the intended use, may not change greatly among the varieties. In a study conducted in Wales by Bennett and other researchers (2006), five varieties were sown at 150 and 300 plants m^{-2}. The results indicated that although the final total fibre yield increased at a higher density, no inter-varietal interaction with sowing rate was observed. The proportion of fibre in the harvested straw increased slightly at a higher density despite the proportion of the long fibre remaining the same. Hemp fibre yields of around 2–3 t ha^{-1} and the final plant heights of 1.5–3.0 m are typical of economically viable hemp crops in Europe (Bocsa & Karus, 1998). Crop maturity with respect to harvest times is often not well defined in the literature and differs depending on the final crop use or the opinion of the researcher (Hall et al., 2013).

Harvest times for the current experiment were based on growth rates (harvest was conducted when plant heights ceased to increase), which may have affected the quality of the final best fibres.

The aim of this study was to find the optimum sowing rate of industrial hemp (*Cannabis sativa* L.) and to clarify the impact of the sowing rate on the production of biofuel of hemp biomass in Latvia.

MATERIALS AND METHODS

Field trials were carried out at the Research and Study farm 'Pēterlauki' (56°53' N, 23°71' E), supervised by the Latvia University of Agriculture, in 2012–2014. The industrial hemp (*Cannabis sativa* L.) 'Futura 75' was sown in a Luvic Endogleyic Stagnosol soil: pHKCl 6.7; P – 52 mg kg^{-1}; K – 128 mg kg^{-1}; the organic matter content – 21–25 g kg^{-1}. 'Futura75' is a French monoecious variety, medium height (2.5–3.0 m), late-maturing in Latvia (125–135 days), grown for fibre and pulp.

Hemp was sown in 10-m^2 plots, triplicate, on May 8 and 17, using a 'Wintersteiger' plot sowing machine. The total sowing rate was 20 (100), 30 (150), 40 (200), 50 (250), 60 (300), 70 (350), 80 (400), 90 (450), and 100 (500) kg ha^{-1} (germinating seeds per 1 m^2). The plots were fertilised as follows: N – 120 kg ha^{-1}; P_2O_5 – 80 kg ha^{-1}; K_2O – 112 kg ha^{-1}. Hemp was harvested using a small mower MF-70, when first matured seed appeared. In the field rotation, the industrial hemp followed the previous crop – spring barley.

The parameters of meteorological conditions (mean air temperature, °C, and rainfall, mm) were recorded by the weather station located on the trial field (Adamovics et al., 2016). In the years 2012–2014, the period for hemp seed emergence was favourable, but in 2013, there was a lack of precipitation (the 1st ten-day period of June). In 2016, drought and warm weather were recorded in June and July, while in 2014, this period was much more abundant in rainfall. The rainfall in June and July is important as it strongly influences the yield. The mean air temperature in August was very similar in all the research years, but the amount of rainfall differed markedly: in 2014, it was twice as high as the long-term average, and in 2013, it was approximately twice as low as the long-term average. In September and in the 1st ten-day period of October, the weather was quite dry (not favourable) in all the research years.

The quality of fuel is characterized by the following main characteristics: higher and lower calorific value, ash content, and ash melting point. The net calorific value of biomass fuel is significantly affected by fuel moisture content. The gross calorific value was measured according to the standard LVS EN 14918 using the oxygen bomb calorimeter. Ash content was determined according to the standard LVS EN 14775. Ash melting temperature determination should be carried out using a number of recommendations for the standards ASTM D1857, ISO540, and LVS EN 15370-1. Ash melting temperature was determined using the standard ash cone shape change by heating the ash with oxygen-enriched environment. The combustion characteristics of the samples were tested in the company ‘Virsma' Ltd in accordance with the above mentioned standards.

Ash melting temperature tested according to the standard was defined for four characteristic points of a sample cone: DT, ST, HT, and FT.

Ash melting temperature has four phases: DT – the initial point of deformation, when the sharp peak is rounding; ST – softening temperature, when the ash cone deforms to such extent that the height of the structure reduces to the size of its diameter; HT – the point of the formation of hemisphere, or the cone collapses and becomes dome-shaped; FT – flow temperature, when the liquid ash dissipates along the surface (Kakitis et al., 2009). The chemical composition of biomass was determined in the Agricultural Scientific Laboratory for Agronomic Analyses of LLU. The yield of absolutely dry hemp biomass was calculated according to the data of fresh biomass and its moisture content at harvesting in the study years. The DM yield data were statistically processed using the analysis of variance. Means were separated by the LSD and were declared different at the $P < 0.05$ level.

RESULTS AND DISCUSSION

Field trials established that in Latvia’s agro-climatic conditions, the yield of hemp dry matter is dependent on hemp cultivation year, meteorological conditions, sowing times, and sowing rate. In the three-year study period independently of the sowing rate, the dry matter yield was on average 11.74 t ha^{-1} when hemp was sown at the beginning of May, and 10.75 t ha^{-1} when hemp was sown at the end of the second decade of May.

A 10-day delay of the sowing time decreased the hemp dry matter yield by approximately one ton per hectare (Table 1).

Table 1. The biomass yield of industrial hemp depending on different sowing times and rates, 2012–2014

Sowing rate (F_A)		Dry biomass, t ha^{-1}			
		Years (F_C)			
		2012	2013	2014	
Hemp was sown on May 8 (F_B)					
20	100	8.46	9.32	12.24	10.01
30	150	9.00	10.11	13.66	10.92
40	200	9.81	10.29	14.54	11.55
50	250	10.02	10.65	14.61	11.76
60	300	10.91	10.72	15.18	12.27
70	350	11.23	11.03	16.13	12.80
80	400	11.23	12.17	16.77	13.39
90	450	10.84	11.36	16.62	12.94
100	500	9.44	10.21	13.55	9.45
Average		10.10	10.65	14.81	11.86
Hemp was sown on May 17 (F_B)					
20	100	9.50	7.83	11.01	9.45
30	150	9.51	8.46	12.21	10.06
40	200	9.56	8.99	12.53	10.36
50	250	9.68	9.74	13.25	10.89
60	300	10.30	9.77	13.8	11.29
70	350	10.57	9.96	15.82	12.12
80	400	10.17	9.92	15.34	11.81
90	450	10.21	9.21	14.46	11.29
100	500	9.85	8.86	13.01	9.45
Average		9.93	9.19	13.49	10.87
$LSD(F_A)_{0.05}$ sowing rate			0.72		
$LSD(F_B)_{0.05}$ sowing time			0.42		
$LSD(F_C)_{0.05}$ year			1.53		
$LSD(ABC)_{0.05}$ trial			2.81		

The largest dry matter yield was obtained from the hemp 'Futura 75' when sowing it in an interval of 60–80 kg ha^{-1} or 300–400 germinating seeds per 1 m^2.

In the Directive 2009/28/EC set by the EU countries on the fuel quality parameters, the preferable ash content is set as 0.7–1.5% (Directive 2009/28/EC). In our research, the ash content in hemp differed widely and, on average, exceeded 1.5%, which is the permissible level for fuel.

The average ash content in hemp dry matter is 3.94% (Table 2), which is considerably higher than that of wood pellets and less than that of cereal straw (Kakitis et al., 2009).

An important parameter characterising the burning properties of biomass fuel is ash melting temperature. A low value of ash melting temperature leads to ash slag sintering and causes problems in boiler operation. Point DT characterizes the beginning of cone deformation, and it is the lowest temperature at which the ash melting starts. In all samples, the temperature at which deformation starts was found higher than 1,300 °C.

Ash flow point temperature for all samples exceeded 1,400 °C. The results are similar to wood ash melting point and significantly exceed the cereal straw ash melting temperature (Kakitis et al., 2009). Ash melting temperature is high enough to avoid ash melting and sintering inside the burners. A significant change in the ash melting temperature depending on the sowing norm was not detected.

Reduction of melting temperature is most commonly associated with potassium oxide content increase (Kalnačs et al., 2008). The researchers explain the differences even within the same species by the chemical composition of plants or individual elements, which under the influence of high temperature result in certain chemical reactions (Kaķītis et al., 2009).

The use of wood pellets ensures the use of automatic boilers. In order to ensure automaticity, ash melting temperature should be at least 1,100 °C. The most important phase is DT, as it is usually the shortest phase and more affected by different conditions: chemical composition, applied fertiliser, and the precipitation and air temperature during the period of vegetation (Poisa & Adamovics, 2012; Poisa et al., 2013). In comparison with coal, the ash melting temperature of which exceeds 1,000 °C (Kakitis et al., 2009) or 1,150–1,500 °C (Kronbergs, Šmits, 2009), biomass has a comparatively low ash melting temperature (usually between 750 and 1,000 °C), as it has a very different ash chemical and mineralogical composition (Kakitis et al., 2009).

The research on the relationship between the changes in hemp chemical composition and sowing rate failed in the three-year trials; therefore, the studies should be continued.

The average crude fiber content in hemp DM was 57.3%, lignin content – 9.29% (Table 2).

Table 2. Biomass yield quality of industrial hemp depending on different sowing rates, 2012–2014

Sowing rate of hemp		Content in DM				
kg ha^{-1}	germinating seeds per 1 m^2	Crudefiber, %	Lignin, %	Ash, %	C, %	S, ppm
20	100	56.70	9.14	3.68	42.47	287.23
30	150	58.20	8.08	4.15	43.34	305.12
40	200	56.64	8.99	4.27	42.01	311.12
50	250	58.85	10.11	3.96	44.32	387.74
60	300	60.63	9.55	4.16	41.69	457.50
70	350	56.58	9.57	4.20	43.57	487.58
80	400	55.57	9.94	4.03	43.27	547.47
90	450	57.25	9.12	3.37	41.15	589.65
100	500	55.28	9.14	3.68	42.47	415.15
Average		57.30	9.29	3.94	42.70	420.95

The lignin-containing products could be used to supplant fossil resources (Gosselink et al., 2004). At present, there is a lot of research regarding lignin as a by-product of wood-pulp processing. In Latvia, it is traditional to produce energy from wood products, and in the light of the steep price increase for fossil energy, it has become advantageous also to produce energy from the biomass of agricultural plants.

Lignin content is of great importance for energy crop plants, as chemical additives (glue, lacquer, etc.) are not allowed in granule production. Lignin holds the biomass granule together and does not allow it to disintegrate.

Our results demonstrated only a small difference in the carbon content of hemp depending on the sowing rate, and on average it made 42.70 (41.15–44.32)% in hemp stalk. Also, other studies have shown that carbon content differs within various genera of one family, within various sorts of one species, and even within parts of a single plant (Baxter & Koppejan, 2005; Kronbergs & Šmits, 2009). The content of sulphur in hemp was on average 420.95 (287–589) ppm, which increased with the increase in the sowing rate.

Calorific value is one of the most important indicators characterising the fuel quality. Gross calorific value is the energy contained in the mass unit of the dry matter of fuel. Standards for biofuel from grass (LVS EN ISO 17225 – 6:2014) indicate that the calorific value should comprise 16.3–19 MJ kg^{-1}.

The features of hemp stalks have a large resemblance to the characteristics of wood-pulp. There are cellulose and lignin both in hemp stalks and in wood-pulp. The calorific value of stalks is the same as that of wood-pulp; besides, in the burning process, less ashes are produced. By briquetting or making granules of hemp stalks, good solid fuel can be produced.

In the experiments, it was found that the gross calorific value at constant volume $Q_{gr\ ar}$ of the tested hemp varied from 16.02 to 17.15 MJ kg^{-1}. No significant impact of hemp sowing rates on the calorific values was detected.

In practice, the essential parameter is the total amount of energy that can be obtained from one ha of biomass fuels.

CONCLUSIONS

Hemp with its energy qualities – the high thermal capacity and relatively large dry matter yield – is a good source material for the production of energy, especially if it is utilised mixed with other energy source materials.

In order to obtain hemp biomass for energy production and shives, approximately 60–80 kg ha^{-1} of seed should be sowed. Such seed density produced higher raw fibre yields and qualities associated with the harvest of good-fibre hemp such as thin stalks than did lower planting densities.

The dry matter yield was on average 11.74 t ha^{-1} when hemp was sown at the beginning of May. A 10-day delay of the sowing time decreased the hemp dry matter yield by approximately one ton per hectare.

In all investigated hemp samples, ash melting temperature was higher than 1,300 °C, which indicates the potential of hemp for the production of qualitative solid biofuel.

The carbon content depending on the sowing rate differed only slightly and on average made 42.70%.

The gross calorific value at a constant volume of all tested hemp sowing rates varied from 16.02 to 17.15 MJ kg^{-1}. The average ash content in hemp dry matter was 3.94%, which is considerably higher than that of wood pellets but less than that of cereal straw.

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Energy balance of sunflower production

S. Akdemir[1,*], C. Cavalaris[2] and T. Gemtos[2]

[1]Namık Kemal University, Technical Sciences Vocational School, TR 59030 Tekirdag, Turkey
[2]University of Thessaly, Department of Agriculture Crop Production and Rural Environment, Fytokou str., N. Ionia, GR-384 46 Volos, Greece
[*]Correspondence: sakdemir@nku.edu.tr

Abstract. The aim of the present study was to make an energy analysis of sunflower crop in the Trakya Region of Turkey, to evaluate the potential for using it as bioenergy source. Actual data for the common cropping practices applied in the region were collected with questionnaires given to the farmers. Literature data were used to obtain necessary energy indices. The collected information was used to establish energy budgets. Two alternative scenarios were examined: 1st- using only the seed for biofuel production and 2nd -using the seed for biofuel and the stalks as biomass for bioenergy. The results showed that sunflower presented positive energy balance for both cases. Net energy was 35,334 MJ ha^{-1} when only the seed was taken into account and 87,308 MJ ha^{-1} for both seed and stalks. Energy efficiency was 3.67 and 7.34 respectively. Fertilization was the most energy intensive input (6,594 MJ ha^{-1}) accounting for 48–50% of the total inputs. Tillage was the second most energy intensive input (3,595 MJ ha^{-1}) accounting for 26–27% of total inputs. There were 6 different tillage operations such as ploughing, 4 machinery passages for seedbed preparation and hoeing in the sunflower production. All these operations increased energy inputs of the tillage. The total energy inputs were relatively low because it was possible to achieve high yields without irrigation.

Key words: sunflower, energy analysis, Trakya Region.

INTRODUCTION

Energy analysis is an important tool to evaluate the energy efficiency of production systems. In agriculture, it can offer an in depth knowledge of the energy flows and can reveal more energy efficient cropping practices. It is therefore important to make the analysis of the existing systems as a basis to improve their efficiency. There is no standard methodology established for this analysis. It is generally difficult to analyse different management options because of the complexity of the production systems and the lack of specific parameters for each case. For that reason a more general approach is followed most of the times using literature data from wider areas. Erdogan (2009), developed an internet based software, namely AgrEN_I/O v 1. 0 Beta, for energy input-output analyses for crop production. As an example, the software was run for a maize crop production in the Cukurova region. Energy equivalent of total input, yield, other output were determined as 28,090.71 MJ ha^{-1}, 132,300 MJ ha^{-1} for 9 t ha^{-1} seed yield and 187,416 MJ ha^{-1}for 49.32 t ha^{-1} other output. Energy ratio was calculated as 11.58 for Cukurova Region of Turkey. Romanelli & Milan (2005) aimed to develop a methodology that would support the development of a model using a spreadsheet, and use it to analyse the energy balance of production systems. The model was applied to a traditional production system of maize (*Zea mays* L.) silage and a Bermuda grass (*Cynodon* spp.) haylage. The gross energy balance presented was 14.1 energy units of output per energy input for maize silage and 0.98 for haylage. For the digestible energy balance, the values were 9.1 and –0.99, respectively. The best alternative scenarios for improving energy efficiency in maize silage and haylage production were the reduction of fertilizer rates and irrigation use (Romanelli & Milan, 2005).

Azarpour (2012) determined energy efficiency (energy output to input ratio) for winter wheat seed and straw to be 2.47 and 2.48, respectively, showing the effective use of energy in wheat production. Energy balance efficiency (production energy to consumption energy) for seed and straw was calculated 1.50 and 1.29, respectively. Arin & Akdemir (1987) determined energy consumption per unit area in dry onion production. Total input was determined as 41,665 MJ ha^{-1} and the output was 25,050 MJ ha^{-1}. Arin et al. (1988) also determined agricultural inputs and outputs for wheat, sunflower, rice and onion production. They calculated energy inputs per kg produced. Energy use was 5.93 MJ kg^{-1} of wheat, 6.34 MJ kg^{-1} of sunflower, 5.36 MJ kg^{-1} of rice.

Gemtos et al. (2013) carried out a research in Thessaly, Central Greece to assess the potential of using irrigated sunflower, rain fed rapeseed and irrigated sweet sorghum as energy crops. They produced energy analysis taking into account as output either only for the seed or including the stalks as well. Their results showed that the energy balances were positive. The overall results gave maximum energy efficiency coefficients of 2.89 without the stalks and 6.16 with stalks. Analysis of the inputs showed that energy for irrigation was the most energy intensive input in the irrigated crops while nitrogen fertilisation was the rain fed rapeseed.

Baran & Karaağac (2014) studied the energy balance in sunflower as second crop in a year. The results showed that energy output/input rate was 3.21, the specific energy value was 8.19 MJ kg^{-1} and the net energy was 34,404 MJ ha^{-1}. Another study by Baran & Gökdoğan (2014) determined the energy balance in watermelon and melon production in Kirklareli province. Energy output/input ratio, specific energy, and energy productivity of watermelon were determined at 4.74, 0.40 MJ kg^{-1}, and 2.49 kg MJ^{-1} respectively. The energy output/input ratio, specific energy and energy productivity of melon were determined at 2.97, 0.63 MJ kg^{-1}, and 1.56 kg MJ^{-1} respectively. Fertilizers had the highest contribution to the energy inputs and were followed by fuel and human energy consumption. Dilay et al. (2010) studied Karaman apple (Malus communis L.) production and determined the energy balance. According to their findings energy use efficiency was estimated as 2.33 MJ kg^{-1}. Gokdogan (2011) determined energy output/input ratio in peach production as 1.52 and energy productivity at 0.80 kg MJ^{-1}.

Sunflower as energy and oil crop is very important for Turkey and Greece. It is widely produced in Trakya Region of Turkey. Sunflower was planted in 720,108 ha, with total production of 1,670,000 tonnes and yield of 2,320 kg ha^{-1} in 2016. Due to the importance of the crop, sunflower energy balance were analysed by TUIK (2017). Energy crops have been produced in Greece and Turkey because their profitability is higher than cereals. Governments give support for growing energy crops. The aim of the present study was to make energy analysis for sunflower crop in Trakya region and to investigate the potential to use it as an energy crop.

MATERIALS AND METHODS

The common cropping practices in sunflower production at the region of Trakya are shown in Table 1. The data about field operations, speed, time, man power, agricultural machinery size, etc. were obtained from a big local farm which has 6,045 ha production area including different size parcels for sunflower production. In addition production data obtained from Kirklareli Soil, Water Agrometeorology Research Institute. The data were collected from three main cultivation areas of Trakya: Tekirdağ, Edirne and Kirklareli that cultivated 300,226 ha with total annual production of 682,583 tonnes of seed (Table 2). The data are for 2015 which was a typical year for sunflower production. In this research conventional farming practices that are widely used in Trakya Region were taken into account to establish the energy budget. A general production model was assumed to determine agricultural inputs.

The boundary of the system was assumed to be the ‘Farm gate’. One hectare was used as functional unit for all the estimations.

Table 1. Summary records of cultivation practices for sunflower

	Starting time	Ending time	Type of the Input	Amount of the Input
Ploughing	September	November		
Cultivator	March	March		
Cultivator	April	April		
Toothed harrow	April	April		
Sowing	April	May		
Row spacing			cm	70
Sowing rate			Number Seeds ha^{-1}	40,000–55,000
Sowing rate			kg ha^{-1}	3–3,5
Fertiliser application kg ha^{-1}	April	April	20-20-0(N-P-K)	200–250
			Ammonium nitrate	110–130
Sprayer (Herbicide) kg ha^{-1}	April	April	Pendimethalyn	3.11
			Prometryne	3.32
Toothed harrow	April	May		
Rolling cylinder	April	May		
Fertiliser spreader	June	June		
Hoeing machine	June	June		
Sprayer	June	June		
Combine harvester	August	September		

Table 2. Trakya region sunflower production (TUIK, 2017)

Region	Harvested area (ha)	Production (ton)	Seed yield (fresh weight) (kg ha^{-1})
Tekirdağ	128,468	267,012	2,078
Edirne	98,406	226,573	2,302
Kırklareli	73,352	188,998	2,577
Total/Average	300,226	682,583	2,319

Energy inputs estimation

The energy analysis was mainly based on a methodology developed by the Laboratory of Farm Mechanisation of the University of Thessaly (Gemtos et al., 2013).

There are three main paths of energy inflow in the field. The first path is the solar energy. This is captivated by the plants during the photosynthesis process. As it is provided for free, it is not considered to the energy inputs and this is the reason why, contrary to other energy transformation processes, in agriculture the energy budget is usually positive. The second path, is direct energy consumed in the farm for field operations such as tillage, sowing, and irrigation etc. This path uses mainly fuel, lubricants and human labour as energy inputs. The third path is indirect energy that is consumed outside the farm boundaries to produce any input (machinery, chemicals) used in farm. In that case, any material brought into the farm is considered as ‘energy input’ (Tables 3 & 5) embodying all the energy included in raw materials as well as the energy sequestered for manufacturing, transportation and commodity uses.

Energy ‘outputs’ were considered all agricultural goods produced in the field and sold to the ‘market’. According to the energy inputs and outputs, energy budgets for sunflower crop were estimated. Direct and indirect energy consumption was estimated for the inputs shown in Table 1 as described below.

Machinery inputs

Machinery inputs include direct energy use for the operation of the machinery in the field (fuel, lubricants and human labour) and indirect energy as the energy sequestered in the materials of the machinery. Indirect energy was estimated as the energy sequestered to the tractor and the machinery during manufacturing as well as the energy added to them during their estimated life for repairs and maintenance. The manufacturing energy was estimated as the sum of the energy used for the raw materials production and the energy for the machinery construction (Bowers, 1992). The energy estimated to be spent for transportation and handling of the machinery was also added at 8.8 MJ kg^{-1} (Bowers, 1992). The energy spent for repair and maintenance during the life of the machine was estimated as a percentage of the energy spent to produce the machinery, using the Coefficients for Repair and Maintenance (CRM) (Bowers, 1992). The total sequestered energy (manufacturing and repairs/maintenance) was then divided by the estimated working life of the machinery to estimate the hourly energy input and then by the field performance (estimated from the working width, the travel speed and the field efficiency) for each operation to find the energy spent per ha (Table 3). For all the operations two tractors were assumed to be used. A 4 WD tractor for the heavy field operations like tillage and transportation and a 2WD tractor to carry out the lighter operations like sowing, spraying and fertilization. This represents the common practice for the region under study.

For the direct energy, fuel consumption and lubricants had to be added. Human energy is a very small in today’s mechanised agriculture and therefore, it was not included in the calculations. Fuel consumption (L ha^{-1}) was estimated from the research conducted retrieving empirical values from the farmers of Trakya (Table 4). Fuel consumption was then converted to energy by using the energy content of the fuel (38.66 MJ L^{-1}) and the production and handling energy (9.12 MJ L^{-1}), giving total energy content of 47.78 MJ L^{-1} (Pimentel, 1992). This was equal to 57.57 MJ kg^{-1}, if 0.83 t m^{-3} density was taken into account. The consumed energy by lubricants was taken at 4% of the fuel energy (Fluck, 1992). The sum of fuel and lubricant energy was the total direct energy inputs (Table 4).

Table 3. Indirect energy consumption for field operations

-	Weight kg	ME(1) MJ kg^{-1}	Working width m	Working speed (u) m s^{-1}	fe(2)	Field performance (fp) ha h^{-1}	Estimated Life (LE) hours	c_{RM}(3)	Indirect Energy Implement MJ ha^{-1}	Tractor	Total
Main Tractor 4WD	4,200	86.8					16,000	0.49			
Secondary Tractor2WD	2,520	86.8					12,000	0.49			
Tillage implements											
Ploughing	500	52.8	1.4	6.00	0.85	0.71	2,000	0.97	39.5	50.8	90.3
Cultivator (1st)	370	52.8	3.4	9.00	0.85	2.60	2,000	0.51	6.3	13.9	20.2
Cultivator (2nd)	370	52.8	3.4	9.00	0.85	2.60	2,000	0.51	6.3	13.9	20.2
Toothed harrow	170	52.8	4	15.00	0.85	5.10	2,000	0.61	1.6	5.7	7.2
Rolling cylinder	650	52.8	5	12.00	0.80	4.80	2,000	0.61	6.3	6.0	12.4
Hoeing machine	230	52.8	3.75	7.00	0.85	2.23	2,000	0.51	4.6	16.2	20.8
Other implements											
Row crop seeder	400	56.9	3	7.10	0.65	1.38	1,500	0.43	17.4	1.4	18.8
Sprayer	130	56.9	16	14.00	0.65	14.56	1,500	0.37	0.5	2.0	2.5
Fertilizer spreader	150	52.8	16	14.00	0.70	15.68	1,200	0.49	0.7	1.8	2.5
Sunflower picker	7,000	86.8	3.75	4.0	0.65	1.0	2,000	0.24	417.8		417.8
Harvesting											
Combine harvester	7,700	86.8	5.6	5.0	0.65	1.82	2000	0.24			246.2

(1)ME = Manufacturing energy (Batty & Keller 1980; Bowers 1992); (2) fe = field efficiency (ASABE D497.4)
(3)cRM = coefficient used to estimate the energy sequestered in repairs and maintenance (Bowers 1992); * kg per ha was estimated for the pipelines weight.

Table 4. Direct energy consumption for field operations

	Fuel consumption (FC) (l ha^{-1})	Direct energy (E_V) MJ ha^{-1}
Tillage implements		
Ploughing	29.90	1,486
Cultivating (1st pass)	9.85	489
Cultivating (2nd pass)	7.80	388
Tooth harrowing	3.95	196
Rolling cylinder	4.50	223
Hoeing	8.80	437
Other implements		
Sowing	7.05	350
Spraying	3.60	17
Fertilizer application	3.45	16
Harvesting	14.6	1,117

Consumable goods

Consumable goods were used in several stages of crop growth. For most of them energy sequestered values was found in the literature. The values and the sources are shown in Table 5. Helsel (1992) estimated the total energy of the N fertilizer at 69.5 GJ t^{-1} for production, 2.6 GJ t^{-1} for packaging, 4.5 GJ t^{-1} for transportation and 1.6 GJ t^{-1} for the application. Energy values for pesticides were also taken from the literature.

Table 5. Consumable goods energy consumption

Consumable goods	Energy content (MJ kg^{-1})	Source
Fertilisers		
N	78.1	Helsel (1992)
P_2O_5	17.0	Helsel (1992)
K_20	13.7	Helsel (1992)
Sunflower Seeds	26.3	Kalivrousis et al.(2002)
Herbicides		
Pendimethalyn	461	Heichel (1980)
Prometryne	461	

Energy consumed for transportation

A platform weighing 900 kg was used to transport the final products to the storage facilities. The payload was 5,000 kg. The energy sequestered for manufacturing was taken at 52.78 MJ kg^{-1} plus 8.8 MJ kg^{-1} for transportation and handling (Fluck, 1992) giving an initial energy for the platform of 55,422 MJ. For repair and maintenance a coefficient 0.8 of the manufacturing energy was used or 38,001 MJ. Total indirect energy for the platform was then 93,423.6 MJ and for the 82 kW tractor, which towed this platform, was 347,980 MJ. Working life of the platform was 3,000 h and of the tractor 16,000 hours (ASABE 2007 Standards). As such, the energy per hour was 31.14 MJ h^{-1} for the platform and 21.75 MJ h^{-1} for the tractor. With an average transportation speed at 20 km h^{-1} and travelling distance 10 km (5+5 km) and delivery efficiency of 0.6 the travelling time was 0.83 h, the work rate 6 t h^{-1} and the fixed energy was 0.0052 MJ kg^{-1} for the platform, 0.0036 MJ kg^{-1} for the tractor and the total 0.0088 MJ kg^{-1} of transported material. The direct energy consumption was estimated by considering the value given for trucks by Fluck (1992), 0.0018 MJ kg^{-1} km^{-1}.

Harvesting energy

Indirect energy inputs derived from the use of the harvesting machinery were estimated as described earlier (Table 3). Direct energy was estimated by literature data (Leach, 1976) (Table 4).

Energy output estimation

The sunflower production (seed) from three main cultivation areas from Trakya was taken into account (Table 2). Considering an average of 15% of seed moisture content during harvesting, seed weigh was converted to dry seed weight. Apart from the seed, the stalks were also considered as potential output. Field measurements in Greece by Gemtos et al. (2013) gave dry stalk/seed ratio of 1.23. Multiplying the dry seed yield by 1.23 gave an estimation of stalk yields for Trakya Region. The authors also considered energy content for seed at 25.55 MJ kg^{-1} and for stalks 17.3 MJ kg^{-1}. These values were taken into account to estimate the seed and stalk energy outputs in the present study.

Energy efficiency estimation

Three indices were used for the energy efficiency estimation. The net energy which was the energy output minus the energy input measured in MJ. The energy efficiency coefficient was obtained by dividing the energy output by the energy input, which was a dimensionless number. Finally, the energy productivity was the energy spent per kg of output measured in kg MJ^{-1}.

RESULTS AND DISCUSSION

Table 6 shows an analysis of the energy inputs for the sunflower production. Ploughing was among the most intensive field operations and accounted for 1,576 MJ ha^{-1}, almost half of the total energy spent for tillage operations. In tillage operations, the most energy intensive input was the direct energy used for the fuel (3,416 MJ ha^{-1} compared to indirect inputs of 178 MJ ha^{-1}). For sowing, the most important input comes from the use of the sowing machine (388.75 MJ ha^{-1} compared to 85.48 MJ ha^{-1} for the seed). Regarding fertilisation, the most important were the indirect inputs coming from the use of fertilizers (6,557 MJ ha^{-1}) and especially nitrogen (5,837 MJ ha^{-1}) which was the higher energy demanding commodity to be used.

The use of pesticides was another indirect energy input accounting for 1,404 MJ ha^{-1}. Harvesting contributed to the energy balance with significant amounts of direct and indirect energy inputs. For the combine harvester it was estimated that a total of 1,116 MJ ha^{-1} was consumed while for the round baler, in the case of stalk harvesting, another 469 MJ ha^{-1} were required. Finally, transportation contributed a small amount to the energy inputs with 46 MJ ha^{-1} for only the seed and 95 MJ ha^{-1} for both seed and stalks. It is important however to mention that it is crucial to have well established regional network of biomass use plants in order to keep short travel distance for the product otherwise the energy inputs could be significantly increased. Concluding indirect energy inputs related with the use of agricultural equipment accounted for

753 MJ ha^{-1} (5.5% of total inputs), direct energy inputs for machinery use accounted for 4,522 MJ ha^{-1} (32.8% of total inputs) giving a total machinery input (direct and indirect) of 5,275 MJ ha^{-1} (42.2% of the total inputs). Additionally direct energy inputs related to the use of the consumable goods (fertilizers, pesticides, seeds etc.) accounted for 7,961 MJ ha^{-1} (57.8% of total inputs). The total inputs for sunflower production (machinery and consumable goods) were estimated at 13,768 MJ ha^{-1}. In a similar study in Greece, Kalivrousis et al. (2001) have found that the total energy inputs for sunflower production were 10,490 MJ ha^{-1}. The difference is mainly owed to almost half energy consumption for soil tillage in their research. Indeed the authors accounted for three tillage operations to prepare the seedbed while for the region of Turkish Trakya the common practice was five or more operations.

Table 6. Summary of machinery and consumable goods inputs

	Machinery Energy Inputs (MJ ha^{-1})	Energy of Consumable Goods (MJ ha^{-1})	Total (MJ ha^{-1})
Tillage			
Ploughing	1,576		1,576
Cultivating (1st pass)	510		510
Cultivating (2nd pass)	409		409
Harrowing	407		407
Rolling cylinder	236		236
Hoeing	458		458
Total	3,595		3,595
Sowing			
Seed		85	85
Sowing	389		389
Total			474
Fertilizer application			
Nitrogen		5,837	5,837
Phosphorus		720	720
Application	37.4		37
Total		6,557	6,594
Pesticide application			
Pendimethalyn		519	519
Prometryne		886	886
Application	19.4		19
Total		1,405	1,424
Harvesting			
Combine harvester	1,117		1,117
Round baler	469		469
Total	1,585		1,585
Transportation			
Total	95		95
Total Energy Inputs	5,275	7,961	13,768

Table 7 shows the energy budgets for the sunflower production for the two alternative scenarios. The first one for using only the seed for bioenergy production while the stalks remain in the field and the second for using both seed and stalks as a bioenergy stock material. On both scenarios, crop fertilization was the most energy intensive input and required (6,594 MJ ha^{-1}) accounting for 48-50% of the total inputs. This is also in agreement with the findings by Kalivrousis et al. (2001). From that point of view, improving industry efficiency for the nitrogen fertiliser production and promoting practices for increasing Nitrogen Use Efficiency (NUE) will significantly improve energy efficiency of the crop (Romanelli and Milan, 2005). Soil tillage was the second most energy intensive input (3,595 MJ ha^{-1}) accounting for 26–27% of total energy inputs. The promotion of conservation agriculture practices and the exclusion of ploughing can offer significant energy savings as well as environmental benefits (Cavalaris et al., 2008). Pesticides use accounted for 1,424 MJ ha^{-1} that represented 10–11% of total inputs. Harvesting consumed 1,117 MJ ha^{-1} when using only the seed and reached 1,585 MJ ha^{-1} when harvesting the stalks as well. It represented 8% and 12% of the total energy inputs respectively. Sowing required 474 MJ ha^{-1} which was 3–4% of the total inputs and the minimum requirements was for transportation to a distance up to 5 km (41 MJ ha^{-1} for only the seed and 95 MJ ha^{-1} for the both seed and stalks). It is important to mention that on a similar research carried out by Gemtos et al. (2013) in the region of Thessaly, central Greece, the most energy intensive input was irrigation that accounted for over 50% of the total inputs. On another study, Cavalaris et al. (2008) showed that irrigation in sunflower reached 34,784 MJ ha^{-1} (71% of the total inputs) when the water was pumped from deep aquifers (> 100 m). This is an important advantage for the Trakya region as the crop can be cultivated as rain fed with yields over 2,000 kg ha^{-1}.

Table 7. Energy budgets for the sunflower production in the region of Trakya

Energy Budget Energy Inputs (MJ ha^{-1})	Without the stalks	With the stalks
Tillage	3,595	3,595
Sowing	474	474
Fertilization	6,594	6,594
Pesticide application	1,424	1,424
Harvest	1,117	1,585
Transportation	41	95
Total	13,244	13,768
Yield (dry matter kg ha^{-1})		
Seed	2,020	2,020
Stalks		3,035
Energy Outputs (MJ ha^{-1})		
Seed	48,578	48,578
Stalks		52,498
Total	48,578	101,076
Energy Budget		
Net Energy (MJ ha^{-1})	35,334	87,308
Energy Efficiency	3.67	7.34
Energy Productivity (kg MJ^{-1})	0.15	0.37

The average sunflower seed yield for the studied region in 2015 was 2,320 kg ha^{-1}. The total energy outputs for seed was 30,852 MJ ha^{-1} derived from the oil and 17,727 MJ ha^{-1} derived from the cake. This made a total of 48,578MJ ha^{-1}. If the stalks would also be utilized another 52,498 MJ ha^{-1} could be obtained. In that case the total outputs reached 101,076 MJ ha^{-1}. With a total energy input of 13,244 MJ ha^{-1} in the first scenario and 13,768 MJ ha^{-1} in the second, a net energy balance of 35,334 MJ ha^{-1} and 87,308 MJ ha^{-1} respectively was obtained. Energy efficiency coefficients were 3.67 and 7.34 and energy productivity 0.15 kg MJ^{-1} and 0.37 kg MJ^{-1} respectively. Kalivrousis et al. (2002) reported energy efficiency of 4.5 for dry land sunflower production in Greece and Cavalaris et al. (2008) reported energy efficiency of 3.81 for irrigated sunflower. As these studies were carried out in a similar climate they are indicators of the potential to use sunflower as an energy crop in the region. It definitely presents an advantage compared with other dry land crops like wheat which presented coefficient of energy efficiency 2.47 (Azarpoor, 2012).

From the presented results it is definite that in both cases the energy budgets are positive, even if only the seed is utilized but the gains could be doubled if also the stalks can be used. According to the Turkish Statistic Institute, in Turkey the total planted area for sunflower is 615,349 ha (TUIK, 2017). With an average seed yield of 2,440 kg ha^{-1} it results in an annual production of approximately 1,500,000 tonnes per year (TUIK 2017). Sunflower oil, cake and stalk may be used as energy sources. Annual sunflower seed production was 1,500,000 tonnes in 615,349 hectares for 2016 in Turkey. Stalk/seed ratio was assumed as 1.23. This means that there is an annual production of 1,843,000 tonnes of stalks. Energy content of the stalks was 17.3 MJ kg^{-1}. Potential energy for sunflower was calculated as 31,918,500 GJ per year. Total harvested area was 300,225 hectares and seed production was 682,583 tonnes in Trakya Region for 2016 (TUIK, 2017). Energy potential from stalk would be 14,540.445 MJ per year. Sunflower seeds can be used for biodiesel production. But Turkey imports sunflower and other oils for food. Decreasing of petroleum prices and additional taxes decreased biodiesel production of Turkey even though there are many companies with license to produce biodiesel. There is also a potential to use sunflower cakes for animal feedstuff and stalks as biomass energy production.

The removal however of the whole plant material from the field is an issue that requires further investigation. Leaving the soil bare, without any crop residues returned into it, could lead to soil degradation problems such as soil erosion, loss of soil organic matter and large amounts of nutrients removed from the soil and should be replaced by additional fertilizers. In that case, alternative cropping systems should be developed using winter cover crops most probably mixtures of cereals and legumes to protect the soil and add organic matter and nutrients to replace the removed stalks.

CONCLUSIONS

From the presented results the following conclusions can be drawn:

1) Sunflower as an energy crop shows good adaptation to the climatic conditions of the Trakya region where no irrigation is required. It presents positive energy balance. Therefore, it is a suitable energy crop candidate for the region.

2) Fertilization was the most energy intensive input in sunflower production at the Trakya region and soil tillage by using mouldboard plough was the second one.

3) The use of the crop residues improves significant the energy balance.

4) The energy efficiency was 3.67 when only the seed is used and increased to 7.34 when the stalks were included.

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Reed canary grass cultivation's energy efficiency and fuel quality

A. Annuk[1,*], A. Allik[1] and K. Annuk[2, ┼]

[1]Estonian University of Life Sciences, Institute of Technology, Department of Energy Engineering, Fr.R. Kreutzwaldi 56, EE51014 Tartu, Estonia
[2]Estonian University of Life Sciences, Institute of Agricultural and Environmental Sciences, Fr.R. Kreutzwaldi 5, EE51014 Tartu, Estonia
[*]Correspondence: andres.annuk@emu.ee

Abstract. The article discusses the energy yield and yield capacity of reed canary grass stands in semi-natural and cultivated meadows with edaphic conditions most favourable for species growing on fertile soil. Energy grass production yields have been assessed with respect to the issues of precipitation, sunshine, and frozen ground. In Estonia, a dried matter level of 4.2–8.5 t ha^{-1} of reed canary grass may produce 72.91–147.56 GJ ha^{-1} gross energy by using 1.48–3.06 GJ ha^{-1} input energy, which consequently nets 71.44–1,445.00 GJ ha^{-1}. The above finding indicates that 1 MJ input energy enables the production of 2.8 kg dry matter. The efficiency of energy production (ratio of energy returned on energy invested) depends on the amount of input energy used to grow and harvest reed canary grass. The input energy payback ratio for the given case was 48.2–49.4, which was higher than cases with lower and higher dry matter yield levels. Precipitation during the second part of the Estonian summer, heavy winter snow cover and a simultaneous frequent lack of frozen ground reduce the productivity of reed canary grass as energy hay because the winter or early spring harvest cannot be used.

Key words: bioenergy, energy payback ratio, fuel quality, harvest yield, *phalaris arundinacea*.

INTRODUCTION

Notwithstanding fossil fuels' price, the time of needing these fuels has passed. General energy needs to be used more sustainably now to replace fossil energy with alternative energy sources (wind, water, solar, and bioenergy) if possible. The use of fallow land left out of agricultural production to cultivate energy grass has become fashionable. The need to grow energy grass at any cost and in enormous quantities as opposed to confining production to the amount of herbaceous plants suitable for energy grass needs to be analysed. These plants are an inevitable by-product of production (straw from cereal and grass seed fields, stems of canola and melilot) and are obtained from natural grasslands, especially those that until now have often not been harvested, have been recovered from areas already harvested by natural protection and from grasslands not managed by farmers.

Reed canary grass (*Phalaris arundinacea* L.) is a more interesting energy grass culture for the studied conditions. In suitable edaphic conditions (on fluvisols and minerotrophic soils), the yield capacity of this species surpasses that of other species;

moreover, its lodging resistance also surpasses that of other species. Although reed canary grass does not perish even after 9 months of flooding (variety 'Pedja'), it does not tolerate high stagnant ground water levels (Espenberg, et al., 2016). It does not produce sufficient yields in acid wastelands, humus on mineral soils or acid, poor cutaway peat lands in exhausted milled peat fields (Heinsoo et al., 2011). As a natural species in flood meadow communities, reed canary grass has been extensively used in Estonian territories at least since the appearance of the scythe (from the middle or the third quarter of the first millennium AD) (Laul & Tõnisson, 1991). Due to spring flooding, reed canary grass has been used for late-summer single harvesting. Because of the distribution of floodplain use among many farmsteads, the late harvesting and the long distances among the farmsteads primarily prevented the use of the flood aftermath. This single harvesting of soils with good nutrient supplies, with floodwater providing additional nutrients, guarantees the productive longevity of reed canary grass. Reed canary grass is a rather newly cultivated plant. It was sown for the first time in England in 1813 (Vose, 1959). According to current knowledge, reed canary grass was sown for the first time in Estonia at Sangaste Manor in 1910 (EAA…, 2014).

The aim of our study was to evaluate the reed canary grass cultivation energy payback ratio based on the yield levels, yield quality and influence of cultivation conditions to assess the potential of Estonia as a northern country for bioenergy production.

MATERIALS AND METHODS

Placement and weather conditions in the experimental site

The study site (58.1279 N; 27.5268 E) was a polder field near Räpina in Estonia on the coast of Lake Peipsi. Based on the data of the Estonian Environment Agency (Estonian…, 2014) the climate in the region is semi-continental with an annual average temperature of 5.6 °C and precipitation of 646 mm over the past thirty years.

Base data of the experimental plots

The paper presents data (Table 1) on the reed canary grass herbage stands of five different yield levels. The first two (1.2 t ha^{-1}and 4.2 t ha^{-1}) are semi-natural herbage stands, the yields of which (1.5 t ha^{-1} and 5.0 t ha^{-1}) as hay have been calculated on a dry matter basis to be 1.2 and 4.2 t ha^{-1} (Krall et al., 1980). This work describes experiments carried out according to those outlined in one of the author's previous studies (Annuk, 1992). Three of the experiments were made with different fertilizer levels. The ferilizers and the achieved yields were:

a) N (0), P_2O_5 (0), K_2O (0) – 8.5 t ha^{-1};
b) N (0), P_2O_5 (60), K_2O (120) – 11.5 t ha^{-1};
c) N (200), P_2O_5 (120), K_2O (240) – 15.1 t ha^{-1}.

Energy determination of the grassland biomass

We determined the energy contained in the dry matter of reed canary grass (17.36 MJ kg^{-1}) using a macro-calorimeter, ELVI-MK-1 (Annuk et al., 1991). Notably, the dry matter energy concentration of the same material determined according the chemical composition with four different formulae in different countries was 4.6–6.0% higher than the one directly determined by the calorimeter (Annuk et al., 1991). This finding confirmed the of calorific value data for reed canary grass from Sweden (17.6 MJ kg^{-1}) (Burvall, 1997). The ash content of reed canary grass grown on peaty soil is slightly lower. Therefore, the energy contained in its dry matter is slightly higher than that of reed canary grass grown on mineral soil (Heinsoo et al., 2011).

To calculate the input energy of the yield from the semi-natural meadows, we solely considered the energy used for mowing, baling, and transport over a distance of 20 km. For cultivated meadows, we first calculated the energy cost of establishment (soil cultivation, fertilisers, fertiliser drilling, seeds, seeding, and meadow management). To calculate the cost of production, we considered the energy spent on establishment during the crop years within a range of 1/8, similar to financial expenses (EUR kg^{-1}) (Haabpiht, 2006). The input energy of the years of meadow use was obtained by adding the energy spent (fertiliser energy, fertiliser drilling, mowing, baling, and transport) during the years of use to the energy spent on establishment (1/8). To calculate the energy use of the input energy, we have taken the standards for energy values of different tasks and substances from works by the Finnish authors J. Ahokas and H. Mikkola (Ahokas & Mikkola, 2007; Mikkola & Ahokas, 2009; Mikkola & Ahokas, 2010; Ahokas et al., 2013).

RESULTS

The productivity of reed canary grass may vary considerably, as shown in Table 1. The yields are given as dry matter for ease of comprehension. The data background for Table 1 is described in the chapter of: Base data of the experimental plots. A large range of dry matter yields was sampled to better evaluate the energy parameters of the production of reed canary grass. The experiments for the last three samples in Table 1 were carried out in triplicate for the used fertilisers and cultivated land; therefore, increased yields were observed. According this table, the DM yield, input and output energy amounts increased. The net energy also simultaneously increased.

Table 1. Reed canary grass as energy grass (DM – dry matter of grass)

Grass stand	Harvested yield, (t DM ha^{-1})	Output (GJ ha^{-1})	Input (GJ ha^{-1})	Net energy Output- input (GJ ha^{-1})
	1.2	20.83	0.90	19.93
	4.2	72.91	1.48	71.44
	8.5*	147.56	3.06	144.50
	11.5*	199.64	6.31	193.33
	15.1*	262.14	19.27	242.86
*LSD $_{0.05}$	2.4			

LSD – least significant difference.

The difference in the interval between the DM yield of cultivated meadow reed canary grass fertilising experiments varieties exceeded the LSD value (2.4 t DM), which shows that the yield data are reliable to a confidence level of 0.05. These findings indicate that reed canary grass reacts to fertiliser containing phosphorus- potassium and nitrogen despite the high natural productivity (8.5 t DM ha^{-1}) of flood plain meadow soils.

Table 2 was compiled to better understand the output energy production in Table 1. The first column gives the reed canary grass DM yield and input energy amounts per ha. The second column gives the maximum possible DM amount per 1 MJ of input energy. The third column gives the energy payback ratio, which is the ratio of the output and input energies. The last column presents the input energy per ton. The marked three boxes of the table show (similarly) the input energy productivity and the advantage of yield levels 4.2 and 8.5 t ha^{-1} both over the lower (1.2 t ha^{-1}) and higher (11.5 and 15.1 t ha^{-1}) yield levels based on the production of 1 ton of dry matter.

Table 2. Input energy payback ratio and expense for the production of 1 ton dry matter

Yield (t DM ha^{-1}) / Input (MJ ha^{-1})	Productivity (kg DM MJ^{-1})	Energy payback ratio (output)/(input)	Input (MJ t^{-1} DM)
$\frac{1.2}{900}$	1.3	23.1	750
$\frac{4.2}{1,476}$	2.8	49.4	351
$\frac{8.5}{3,062}$	2.8	48.2	360
$\frac{11.5}{6,307}$	1.8	31.7	548
$\frac{15.1}{19,272}$	0.8	13.6	1276

In the best energy payback ratio conditions, a DM level of 4.2–8.5 t ha^{-1} reed canary grass (Table 1):

a) may produce 73.91–148.56 GJ ha^{-1} gross energy;
b) has been produced using 1.48–3.1 GJ ha^{-1} input energy;
c) will consequently produce 71.44–1,445.00 GJ ha^{-1} net energy.

The findings above indicate that 1 MJ of input energy allows the production of 2.8 kg dry matter (Table 2). In this case (4.2–8.5 t ha^{-1} DM) the input energy payback ratio is 48.2–49.4 which is higher than in the cases of the lower and higher dry matter yield levels. Thus, the input energy expense for the production of 1 t dry matter is lower (351–360 MJ t^{-1} DM).

Nevertheless, a trend towards single mowing performed in the spring following the yield year persists in energy grass production (Landström et al., 1996; Burvall, 1997; Hadders & Olsson, 1997; Paulrud & Nilsson, 2001; Lötjönen, 2008). The breeding of special reed canary grass varieties for energy grass is under way (Christian et al., 2006). Single mowing is necessary for the longevity of reed canary grass stands, which reduces the cost of machinery operation. In its semi-natural communities, reed canary grass has only been single-harvested throughout its period of use. Furthermore, it has produced high yields and been long-lived if double-harvested as a cultivated plant (Fig. 1). However, triple-harvesting during the summer for fodder production significantly diminished the yield level of the following years and the permanence of the grass stand. Reed canary grass is more sensitive to triple-harvesting than to higher harvesting frequencies (4, 5). The yield quantity, structure of the mown mass (leaves, stems), and the amount of harvesting loss may depend on the harvesting period of the grass stands consisting of mown graminaceous plants. Among other perennial graminaceous plants, reed canary grass has a lodging resistance that surpasses that of other species, granting less harvesting loss at mowing. The lodging resistance of reed canary grass is difficult to explain even with its physical characteristics (stem wall thickness, stem diameter, burst and shear strength) of the lower internodes of its stem compared to brome grass (*Bromus inermis* Leyss.). The lodging resistance of reed canary grass may possibly derive from the morphological peculiarities of the lower internodes of its stem or from the slightly higher crude fibre and lignin content of its lower internodes compared to that of brome grass (Strašil, 2012).

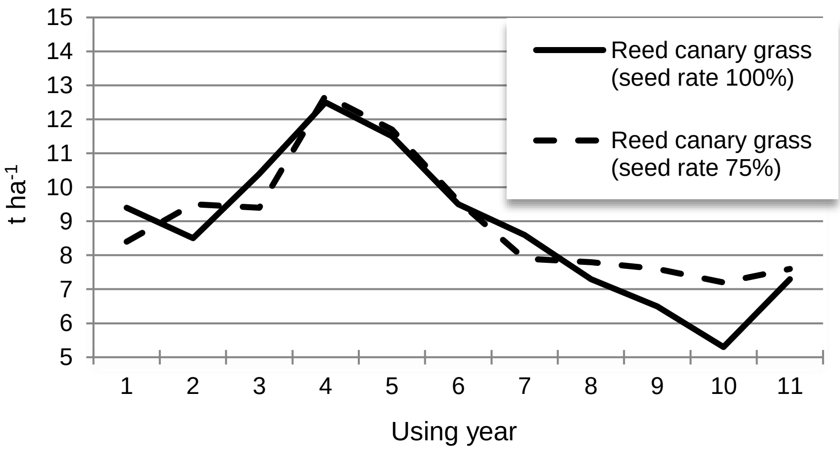

Figure 1. Hay yield (83% of DM).

The term ‘winter loss’ has been used at spring harvesting, which evidently involves leaf loss due to mowing and snow or gales as well as the leaching of mineral substances. At the spring harvesting of reed canary grass, the ‘winter loss’ of dry matter is 25% in southern Sweden and 15% in northern Sweden (Landström & Lomakka, 1996). At summer harvesting, more than 30% of the fresh weight of reed canary grass consists of leaves. Snow and large storms in winter result in a comparatively high leaf loss, which increases the stem ratio of spring harvested herbage mass (Hadders & Olsson, 1997). The quality of the chemical composition of fuel produced from spring-harvested stem-rich reed canary grass is higher than that of reed canary grass harvested in summer, as shown in Table 3 (Landström et al., 1996). Table 3 shows a decrease (20–25%) in the biomass ash content during spring harvesting. The ash content of herbaceous biomass is a critical problem during biomass burning (Fahmi et al., 2007); for example, the ash content in wood does not exceed 2% (Obernberger et al., 2006), while this figure is several times higher in herbaceous biomass (Table 3). According to Lewandovski & Schmidt (2006), the melting temperature interval of reed canary grass ash is 1,100–1,650 °C. Data gathered by Burvall (1997) on the melting temperature of reed canary grass ash also indicate the advantage of spring harvested (March–May, 1,404 °C) mass compared to summer harvesting (July–October, 1,074 °C). This difference may also be due to leaf loss and the leaching out of mineral substances. In late summer, the melting temperature of reed canary grass ash is 1,100 °C; however, it is 1,400 °C for spring harvesting (Hadders & Olsson, 1997).

Table 3. Nutrient and ash concentration (% of DM) in the leaf and stem of reed canary grass (Landström et al., 1996)

Harvest time	Element analysed	n	Leaf		Stem	
			Mean	SE	Mean	SE
Summer (August)	N	21	2.32	0.07	0.62	0.05
	K	21	1.59	0.07	0.9	0.07
	P	21	0.25	0.01	0.11	0.01
	Ca	21	0.69	0.03	0.1	0.01
	Mg	21	0.26	0.02	0.06	0.01
	Cl	21	1.07	0.07	0.52	0.03
	Ash	21	8.51	0.31	4.21	0.23
Spring (April, May)	N	26	1.86	0.07	0.7	0.04
	K	26	0.35	0.05	0.24	0.03
	P	26	0.2	0.01	0.08	0.01
	Ca	22	0.35	0.02	0.12	0.01
	Mg	22	0.1	0.01	0.04	0
	Cl	22	0.1	0.02	0.11	0.02
	Ash	26	6.6	0.34	3.42	0.2

The given data indicates an up to six-fold decrease in the Cl and K contents during the winter and ten- and four-fold differences in Cl and K according to Table 3 (Landström et al., 1996). The Cl and K contents in the ash negatively correlate with the fuel quality (Obernberger et al., 1997). Therefore, the content of alkali metals and Cl in ash lowered the melting point of ash and caused slag formation on the boiler fender and fireplace surfaces (Obernberger et al., 2006).

DISCUSSION

The data in Table 1 show that reed canary grass can be produced under suitable edaphic conditions in a collection of dry matter that can reach the upper bound of the biological potential calculated for graminaceous plants in an Estonian climate (14.0–16.2 t ha^{-1} DM) (Tooming, 1988). However, the data in Table 1 question the necessity of gaining the maximum biological potential of herbaceous plants in production.

The energy return on investment depends on the amount of input energy (Zentner et al., 2011). Dry matter yields ranging from 4.2–8.5 t ha^{-1} are evidently sufficient. Approximately 70.00–145.00 GJ ha^{-1} of energy has been produced in the form of solid fuel. The lowest energy payback ratio was obtained for yield levels of 1.2 and 15.1 t DM ha^{-1} at 23.1 and 13.6, respectively. The energy payback ratio was maximised for yield levels of 4.2 and 8.5 t DM ha^{-1} at 49.4 and 48.2, respectively. The energy payback ratio of this cultivation process demonstrates an effective use of input fossil energy. The input fossil energy is inversely proportional to the energy payback ratio. Similar energy yields have been reported for graminaceous biomass (Heinsoo et al., 2010; Melts et al., 2013). The energy payback ratio fluctuates by harvest year (Ferraro, 2012), but this study evaluated the energy parameters as a function of the given input energy. This approach may or may not have included a small expense on the input energy for the establishment of the grassland. Fertilisers have either not been used at all, or only the aftereffects of the fertilisers have been observed (P_2O_5 at 60 and K_2O for the establishment of 120 kg ha^{-1}) in addition to the expenses of the input energy on harvesting. This type of energy can be produced if one can use either semi-natural or cultivated meadows of reed canary grass long-term; furthermore, annual establishment costs are either absent or low, and liming, sprinkler irrigation, large quantities of fertilisers, herbicides, or pesticides are not necessary. The existing machinery for fodder production can be used for harvesting. Although large quantities of mineral fertilisers allow the total energy output to be significantly increased, they also increase the amount of energy input used, which decreases the net energy (Tonn et al., 2009; Kukk et al., 2010; Kukk et al., 2011).

Fertilising, the mowing frequency, or the harvesting season has been claimed to minimally affect the energy value of herbaceous plants (Runge, 1973). We have also witnessed that the energy content of the dry matter of herbaceous plant varieties (clover and timothy grass) currently used for fodder do not differ significantly (Mikkola & Ahokas, 2010).

Producing quality energy grass in Estonia is difficult, the main obstacle being the unstable weather. The climate is characterised by a large number of rainy days (more than 200 a year) (Kirde, 1939) and a small number of sunny hours (fewer than 266 a year) (Russak & Kallis, 2003). The snow cover and the upper 10 cm of soil horizon melt simultaneously in spring. Extreme years (2010/2011) feature a thick snow cover and a complete lack of frozen ground. On average, the end of the snowmelt occurs between the 27th of March and 10th of April in Estonia. The soil melts from the surface to a depth of 10 cm between the 2nd and 12th of April (Kivi, 1976).

If energy grass that has reached the right quality cannot be harvested under the winter conditions, the possibility and need for using a single harvest grass stand are eliminated. Late single mowing will be useless, as the formed aftermath lacks practical use due to the low yield; moreover, the main crop also cannot be used without artificial drying because of the autumn precipitation. Separate buildings and high energy use will be necessary for the drying. For the favourable wintering of reed canary grass and with regard to next summer's yield, the last mowing during the vegetation period should be carried out when pre-winter aftermath formation is absent; i.e., the mowing should take place as late as October (Annuk, 1993; Pahkala, 2007). The only option for producing energy grass from reed canary grass is double-harvest, with the yield of the second mowing utilised for biogas production or only silage. The yield does not significantly depend on single-species sowing (100% reed canary grass in the seed mixture) or on its dominance in the seed mixture (75%) (Fig. 1). For double-harvest use, meadow foxtail (*Alopecurus pratensis* L.) and timothy grass (*Phleum pratense* L.) may be added to reed canary grass in approximately equal quantities. The first mowing accounts for 65–75% and the second mowing accounts for 25–35% of the gross summer yield (Bassam, 2010; Kallionen, 2012).

In addition to the research conducted in Finland on the transportation distances of reed canary grass as energy grass (Lindh et al., 2009), we cannot recommend the large-scale concentrated production of reed canary grass as an energy grass based on the potential quality of the reed canary grass as a fuel and the scarcity of suitable boiler houses for its direct use. The present-day land use of polders also does not favour large-scale energy grass production. Evidently, the use of reed canary grass as a supplementary fuel may be convenient when adding wood and peat in regional boiler houses (Ericsson, 2007). This scenario necessitates diffuse production and the use of reed canary grass as a fuel, similar to the recommendations for the use of common reed (*Phragmites australis* (car) Trin. Ex Steud) as a fuel (Aavik & Kask, 2010).

CONCLUSIONS

In the northern country of Estonia, the grass stand of reed canary grass is the highest-yielding stand for energy grass production. Growing reed canary grass as energy hay is reasonable at median yield levels to maximise the energy return on investment. The lowest energy efficiency was observed for yield levels of 1.2 and 15.1 t DM ha^{-1} at 23.1 and 13.6, respectively. The energy payback ratio was maximised for yield levels of 4.2 and 8.5 t DM ha^{-1} at 49.4 and 48.2, respectively. The energy payback ratio of this cultivation process demonstrates the effective use of input fossil energy. The input fossil energy is inversely proportional to the energy payback ratio.

The ideal result is hampered by the unstable climate in Estonia, which does not permit the single-mowing frequency and, thus, spring (post-winter) harvesting for reed canary grass production. The precipitation in the second part of the Estonian summer, heavy winter snow cover and simultaneous frequent lack of frozen ground reduce the use of reed canary grass productivity as energy hay because the winter or early spring harvest time cannot be utilised. The double-harvest of reed canary grass, in cooperation with biogas or fodder production, must be applied, using the first mowing for energy grass and the second mowing either for biogas or silage production.

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Effect of controlled traffic farming on weed occurrence

M. Barát[1,*], V. Rataj[1], Š. Týr[2], M. Macák[1] and J. Galambošová[1]

[1]Slovak University of Agriculture in Nitra, Faculty of Engineering, Department of Machines and Production Biosystems, Tr. Andreja Hlinku 2, SK 94976 Nitra, Slovakia
[2]Slovak University of Agriculture in Nitra, Faculty of Agrobiology and Food Resources, Department of Sustainable Agriculture and Herbology, Tr. Andreja Hlinku 2, SK 94976 Nitra, Slovakia
[*]Correspondence: xbarat@is.uniag.sk

Abstract. Soil compaction caused by field traffic is one of the most important yield limiting factors. Moreover, published results report that soil over-compaction inhibits the uptake of plant nutrients and decreases their ability to compete with weeds. Controlled Traffic Farming (CTF) is technology which prevents excessive soil compaction and minimizes compacted area to the least possible area of permanent traffic lines. A long-term experiment was established at University farm in Kolinany (Slovakia) in 2010 with 6 m OutTrack CTF system. Random Traffic Farming (RTF) is simulated by 1 annual machinery pass crossing the permanent traffic lines. Aim of presented study was to assess the effect of CTF on weed infection pressure. To achieve this, weed occurrence at different traffic treatments was determined. Emerged weeds per square meter were counted, identified and recorded at 14 monitoring points. Results showed that higher weed infection was found at the area with one machinery pass compared to the non-compacted area. Following weeds were identified: *Bromus secalinus* L., *Stellaria media* (L.) VILL., *Veronica persica* POIR. in LAMK., *Poa annua* L., *Polygonum aviculare* L., *Convolvulus arvensis* L. Occurrence of these weeds could be used as soil compaction indicator. Based on these results it can be concluded, that CTF technology has potential to decrease weed infestation in comparison to RTF system due to ration of non-compacted to compacted area. Moreover, with exact localization of weeds in traffic lines together with exact identification of weed species, it is possible to target the application of herbicides.

Key words: Controlled Traffic Farming, soil compaction, weed infection.

INTRODUCTION

Technological development in agriculture heads to increasing the working width of the machines along with the increasing power of tractors. Strong and heavy machinery has a negative impact on soil and its properties (Rataj et al., 2014).

Slightly compacted soil is important for water and nutrient supply. For better seed germination, the soil should be loosened in the top layer, and slightly compacted in the bottom of seed bed. (Pospíšil & Candráková, 2015). However, heavy machinery and its multiple passes may cause significant problems. Since 1966, the mean weight and power of agricultural machinery has increased three times (Kumhála et al., 2013). Moreover, most of the field operations are conducted in so called 'random traffic' system. In conventional tillage system, 88% of field is trafficked in one year. In minimum tillage, the trafficked area can be lowered to 65% (Kumhála et al., 2013; Rataj et al., 2014). Schjonning et al. (2016) has shown that multiple machinery passes have big influence on yield of arable crops. They also showed, that the first machinery pass did not have impact on yield. The yield loss was significant in compacted subsoil. Botta et al. (2016) determined the influence of heavy harvesting machines on growing soybean. Yield of soybean was influenced by weight of harvesting machines and design of wheels. Emergency of soybean was not affected by compaction of upper part of soil. Javůrek & Vach (2008) reported, that yield loss due to compaction in cereal was 10–20%, in corn – 10–15%, and in pulses – 15–20%. In dry conditions crop yields could be positively affected (DeJong-Hughes, 2001). Several measures can be taken to minimize machinery induced soil compaction. For example, Godwin et al. (2015) suggested that Low Ground Pressure (LGP) can avert soil compaction. In this system, special tires are used, that are able to operate at inflation pressure of 0.7 bar. Recently, Controlled Traffic Farming (CTF) is considered as a management method that could lower the trafficked area and optimize the growing conditions. CTF creates two zones: non-trafficked crop beds and cropped or non-cropped traffic lanes (Chamen, 2015). This system can be established also with normal machinery without special adjustment, with 68% non-trafficked area (Gutu, 2015). Botta et al. (2007) has shown, that with reduction of traffic intensity, yield increased by 29%, which resulted in increased income by US$134 ha^{-1}.

Weeds are generally more resistant to environmental constrains than arable crops and occurrence of some weeds can indicate actual soil properties and problems in soil structure. Some weeds cannot fully grow on compacted soil, but certain weed species are able to resist harder conditions and can compete with other weeds and plants. Those weed species can be used as indicators of soil compaction (Derr, 2000; Hill & Ramsay, 2005).

Excessive soil compaction inhibits nutrient uptake of arable crops and their ability to compete with weeds. Reintam & Kuht (2012) have shown that in compacted soil without fertilizer easily eliminable weeds are replaced by weed species that are hard to eliminate. The problem is in selection and competing ability of weed species. In extremely compacted soil even weeds are not able to grow, and available nutrient could pollute environment. Kuht et al. (2001) has shown, that in experiment with wheat nutrient uptake (N, P, K, Ca, Mg) in compacted soil occurrence of certain weed species was visible. Nutrient uptake of spring wheat was decreased by 30% in compacted soil by 4–6 passes. Lowered nutrient uptake of weeds was registered only on extremely compacted soil and still wasn't so significant. Reintam et al. (2006) has shown that soil compaction decreased competition ability of spring barley and increased weed infection from 20% to 53%. She has also stated, that the negative effect of soil compaction can be reduced by using fertilizer. Kuht et al. (2012) has also shown, that the adaptability of weeds on soil degraded by excessive compaction was remarkably strong, which resulted in decreased competitiveness of barley.

The aim of this work was to evaluate presence of specific weed species at Controlled Traffic Farming field with different traffic intensities areas.

MATERIALS AND METHODS

A long-term experiment with Controlled Traffic Farming (CTF) system was established at University farm in Kolinany (Slovakia) in 2010. The field size is 16 ha with silty loam (51% silt, 30% sand, 19% clay). A 6 m OutTrack CTF system is used. Further details can be found in Godwin et al. (2015). The field is cultivated using shallow non-inversion tillage practice. Crop rotation includes cereals, maize and oil-seed rape. Considering soil compaction, areas with no pass, one pass, and multiple passes can be found on experimental field. Random Traffic Farming (RTF) is simulated using 1 annual machinery pass in three strips as is indicated in Fig. 1 left. The orthophotograph (Fig. 1 – right) was taken in early April during vegetation of winter wheat. There is visible difference in coverage between compacted and non–compacted area that was caused mostly by weed emergency. This information was the first impulse to conduct this study and was used to target the monitoring points where weed infection was evaluated.

Figure 1. Satellite image (left) showing 1 pass (compacted) area for RTF simulation and orthophotograph (right) during vegetation with visible difference in compacted and non-compacted area.

Monitoring points were targeted at areas with different traffic intensities: non-compacted area and area with one machinery pass. The characteristics of the soil structure at these two areas is well documented with significant difference in penetration resistance measured in the depth of 0–40 cm as shown in Fig. 2. These are average data for the two areas with different traffic intensities measured in year 2012 (left), 2013 (middle) and 2015 (right) at the experimental field within other research activities. The average dry bulk density in depth 10–20 cm was 1,506 kg m^{-3} for non-compacted area and 1,560 kg m^{-3} for 1x compacted area in year 2015.

For this study, 14 monitoring points were selected (7 at compacted and 7 at non–compacted area). Samples were taken randomly with 5 replications at each point.
Emerged weeds were counted from area of 1 square meter and each weed species was identified. Weed infestation during experiment in 1x compacted area is shown in Fig. 3.

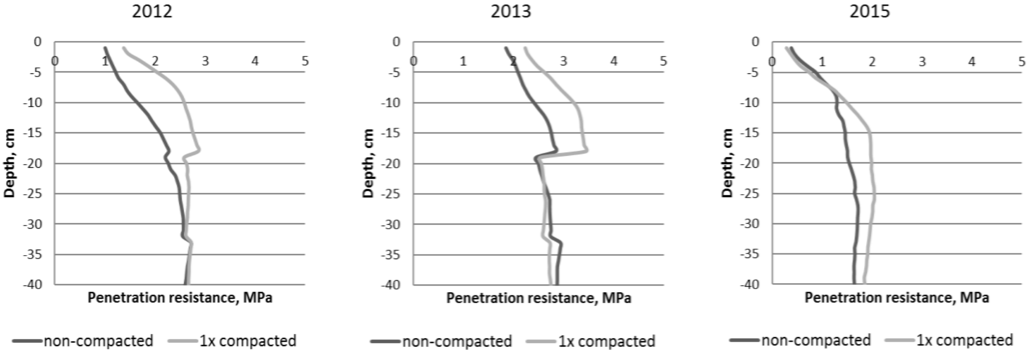

Figure 2. Penetration resistance in depth of 0–40 cm for years 2012, 2013 and 2015.

Figure 3. Weed infection in 1x compacted area.

RESULTS AND DISCUSSION

On experimental field with CTF technology 10 species of weed were found. The most frequently present weed was Annual Bluegrass (*Poa annua* L.) with 3,236 pcs and Chickweed (*Stellaria media* (L.) VILL) with 824 pcs. Some weeds were represented by a little number, such as Creeping Thistle (*Cirsium arvense* L. Scop.) with 8 pcs, Goosegrass (*Galium aparine* L.) with 4 pcs, and Common Dandelion (*Taraxacum officinale* (L.) Weber ex F.H. Wigg.) with 4 pcs. The number of these weed species is not significant, so they will not appear in further results.

Comparison of number of weeds at our two experimental locations is presented in Fig. 4. Almost all of the weed species have bigger numbers at area with one machinery pass compared to non–compacted area. The biggest counts at compacted area have Annual Bluegrass *(Poa annua* L.) with 2,728 pcs, and Chickweed (*Stellaria media* (L.) VILL.) with 808 pcs. Only Common Horstail (*Equisetum arvense* L.) has bigger number in non-compacted area (172 pcs). That could indicate the sensitivity of this weed to soil compaction and all of the soil properties that are typical for compacted soil.

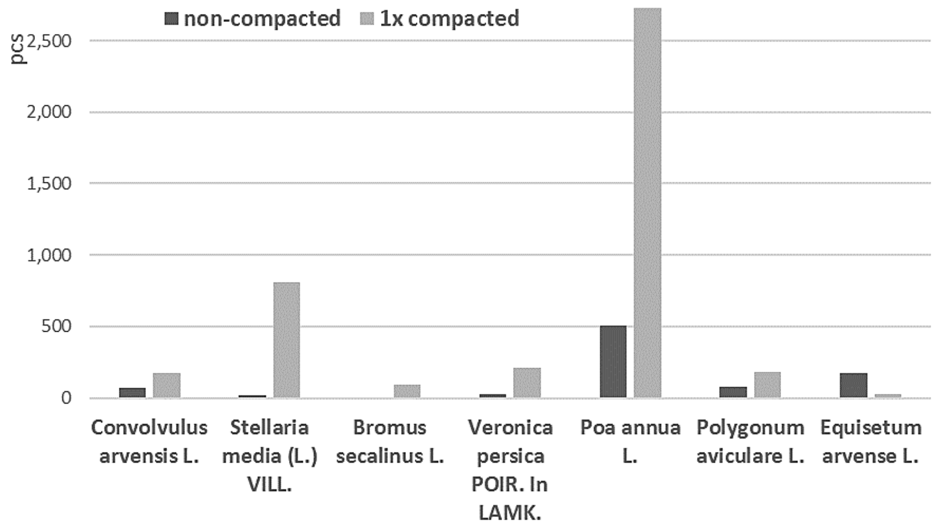

Figure 4. Weed counts in non-compacted and 1x compacted area.

Percentage composition of weed species at non–compacted and at area with one machinery pass is shown in Fig. 5. Results show that some weeds were present only at compacted area. These are Chickweed (*Stellaria media* (L.) VILL.) and Rye Brome (*Bromus secalinus* L.). All of the other weeds except Common Horstail (*Equisetum arvense* L.) grew mostly at compacted area with a minimum percentage share of 70%.

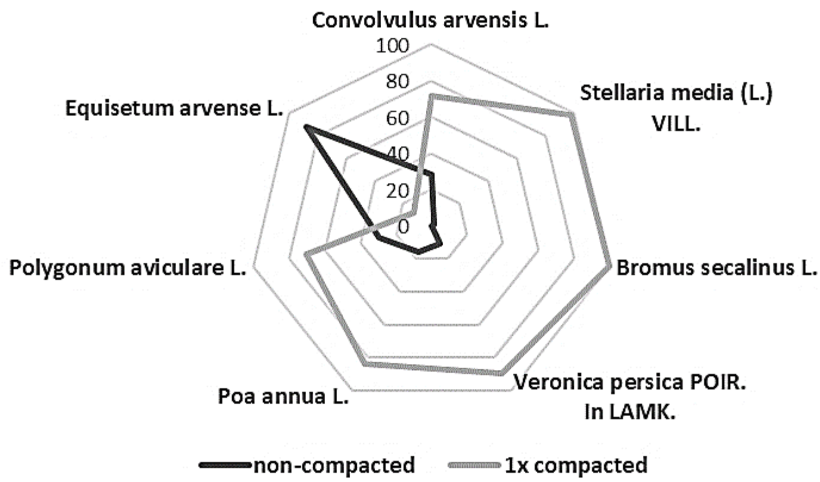

Figure 5. Percentage composition of weeds in non-compacted area and 1x compacted area.

It was found out that most of these weed species grew mostly at compacted soil with one machinery pass. This could indicate, that those weed species need growing conditions that appear after the soil is compacted. In comparison, at non–compacted area only 24.8% of weeds was identified in total. These results also indicate, that it is possible to reduce weed infection and growth by reducing field traffic and soil compaction.

CONCLUSIONS

Soil compaction caused by heavy agricultural machinery has big impact not only on soil properties, but also on composition of grown plants and weeds. At area with one machinery pass, weed numbers were 4–times higher than at non–compacted area. Some of the weed species grew mostly at compacted area. Based on these knowledge, we can assume that those weeds could be used as indicators of soil compaction and soil health.

CTF technology minimizes compacted area by concentrating traffic on specific field lines. Based on this study it can be concluded, that CTF technology suppress weed growth in comparison to Random Traffic Farming. This could have big environmental effect based on lowering herbicides application, or even precisely applying herbicides only on compacted areas (track lines), also with the effect of lowering input costs in crop growth.

Effects of CTF system may be evident after some time from establishment. This experiment indicates, that soil compaction caused by traffic has a big impact on weed emergence and growth, and it is necessary to continue with this study to fully explain this problem.

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The assessment of hazelnut mechanical harvesting productivity

B. Bernardi[1], J. Tous[2], S. Benalia[1,*], L.M. Abenavoli[1], G. Zimbalatti[1], T. Stillitano[1] and A.I. De Luca[1]

[1]University Mediterranea of Reggio Calabria, Department of Agraria, Feo di Vito IT89122 Reggio Calabria, Italy
[2]EMP Agrícola. Sant Antoni 26, ES 43480 Vila-seca Tarragona, Spain
[*]Correspondence: soraya.benalia@unirc.it

Abstract. Hazelnut cultivation represents a new opportunity for Calabrian mountainous and sloping areas (Southern Italy), where no alternative fruit crops, except forestry, could be settled. In this Region, hazelnut production doubled during the last fifty years, inciting the farmers to introduce mechanization in cropping practices such as harvesting in order to increase productivity and decrease production costs. Indeed, harvesting is currently one of the most expensive processes of the productive cycle, moreover to be time consuming if carried out manually. Mechanization degree depends significantly on the terrain topography: in sloping areas, rakes are often associated to aspirating machines to harvest the fallen fruit, while the employment of harvesting machines from the ground prevails in flat areas. In this context, the present paper aims to assess technical and economic aspects of harvesting operation, using a harvester from the ground model 'Jolly 2800' (GF s.r.l., Italy). Particularly, for technical purposes data about operational working time as well as working productivity were collected according to CIOSTA requirements, in two harvesting sites, whereas, for mechanical harvesting economic evaluation, an estimation model was applied to calculate machinery cost per hour. Moreover, the cost per kg of hazelnut in shell and the average cost per hectare were estimated also. The obtained results show a working productivity of 0.065 ha h^{-1} op^{-1} in the first harvesting site, while it was equal to 0.022 ha h^{-1} op^{-1} in the second one. Concerning the average cost per hectare, the second harvesting site showed the worst economic performances, with 550.76 € ha^{-1} against 182.54 € ha^{-1} obtained in the first one.

Key words: hazelnut, mechanical harvesting, tractor-mounted harvester, work productivity, economic analysis, sloping terrain.

INTRODUCTION

Hazelnut (*Corylus avellana*, L.) that belongs to the family of *Betulaceae*, is extended on about 915,550 ha in the world in 2014, with a production of 713,451 tonnes of hazelnut in shell. With more than 75,000 tonnes, Italy is the second producer in the world after Turkey, which produces 450,000 tonnes (FAOSTAT, 2014). In Calabria, it has been introduced since 17th century and it is currently spread over an area of 325 hectares producing more than 761.5 tonnes of hazelnuts in shell according to the Italian National Institute for Statistics data (ISTAT, 2016). It represents a key cultivation for

Calabrian hilly territories, especially for those areas where there are no alternative crops, except forestry.

However, most of the orchards do not enable to reach high and regular yields. Indeed, they are mainly plants with irregular planting layout, situated in sloping terrain or terraces in mountainous area, where labour becomes ever scarcer. This determines high production costs and consequently the marginalization of this natural resource that could contribute significantly to the development of local territories (Abenavoli & Proto, 2015). Harvesting is currently one of the most expensive processes of the productive cycle; an operation that can engrave up to 40–60% on the production cost, moreover to be time consuming if carried out manually. According to the producers, mechanical harvesting is an essential factor for the subsistence of hazelnut cultivation (Blandini & Schillaci, 2007). It is therefore necessary for the relaunch of such a cultivation to introduce efficient and economically sustainable mechanized models adapting the orchard design as well (Tous et al., 1994). In Italy, hazelnut mechanical harvesting has been developed during the last years, in order to overcome labour scarcity and cost management of this practice (Blandini & Schillaci, 2007). Indeed, the necessity to reduce harvesting costs and the relative operating time, have pushed machines industries to realize diverse and ever more innovative models for harvesting from the ground such as self-propelled, trained, or mounted machines (Pagano, 2008). These machines permit with little labour a fast harvesting of hazelnuts from the ground. However, harvesting period has to be as brief as possible; in way to avoid that fallen hazelnuts could have alterations that compromise their marketing (Ascopiemonte, 2009).

In this context, experimental trials were carried out in two hazelnut orchards situated in Calabria, in view to assess technical and economic aspects of a tractor mounted harvest machine (Jolly 2800 model, GF s.r.l., Italy), which is commonly used for hazelnut harvesting from the ground.

MATERIALS AND METHODS

Orchard description

Experimental trials were carried out in two orchards situated in the municipality of Torre di Ruggiero (Province of Catanzaro, Southern Italy) that grow at 590 m above sea level. The orchards are mainly composed by shrubs of '*Tonda Gentile Romana*' main variety and some pollinators (as '*Tonda Giffoni*'), of 12 to 14 years old, with an almost regular planting distance of 4.6 x 4.6 m in a flat terrain for the first orchard having a yields about 2,372 kg ha^{-1} during trials, and somehow 4.5 x 4.5 m in a sloping terrain (up to 13%) for the second one which had an average yields of 2,083 kg ha^{-1}.

Operational working time

Hazelnut harvesting was carried out using the Jolly 2800 (GF s.r.l., Italy). It was mounted in the rear of a Lamborghini 660F Plus tractor (44 kW) with power take-off and three-points attachment (Fig. 1). Four people composed both of the harvesting sites, one specialized operator drived the tractor, two operators gathered the fallen nuts in windrows using backpack blowers (SA2062, Efco/Emak S.p.A., Italy) (Fig. 2), in order to facilitate the harvester work (Colorio & Pagano, 2011). The fourth operator was charged to handle the harvested product and replace the full bags by the empty ones in the machine.

In order to asses harvesting site working productivity referred to the operative time, working time of the machine was measured as reported by several authors (Monarca et al. 2009; Bernardi et al. 2013) according to CIOSTA (Commission Internationale de l'Organisation Scientifique du Travail en Agriculture) requirements (Bolli & Scotton, 1987). The operative time (OT) includes the effective time (ET) during which the activity is carried out as well as the accessory time (AT) needed for moving and discharging; and excludes the idle time. Time measurement started when the harvester was positioned at the beginning of the row, ready to start gathering.

Figure 1. Hazelnut mechanical harvesting from the ground using the Jolly 2800 machine.

Figure 2. Hazelnut gathering in windrows using backpack blowers.

Economic analysis

Furthermore, technical and economic data were recorded. An estimation model based on Miyata (1980), as described in Behjou et al. (2009), Bernardi et al. (2016), Cho et al. (2016) and Sánchez-García et al. (2016) was applied in order to calculate the machinery cost per hour (e.g., agricultural tractor cost) and the equipment cost (e.g., Jolly 2800, Efco-SA2062), taking into account also the operator-machine labour cost. The used model was however modified according to the experimental trials considering hazelnut harvesting (Table 1).

To compare the two working sites, the cost per kg of hazelnut in shell and the average cost per hectare were estimated also. Specifically, the cost per kg in shell was calculated dividing the total harvesting cost per hour by the harvesting yield per hour.

To evaluate the average cost per hectare, the harvesting cost per kg was multiplied by the harvesting yield per hectare. The harvesting cost analysis was performed by splitting the operating cost into its variable and fixed components.

Table 1. The considered parameters for the economic analysis in the Calabrian hazelnut orchards

Cost item	Symbol	Source
Fuel consumption cost € h^{-1})	FCC	Fuel consumption (l h^{-1})*fuel price (€ l^{-1})
Oil consumption cost (€ h^{-1})	OCC	Oil consumption (kg h^{-1})*oil price (€ kg^{-1})
Maintenance (€ h^{-1})	M	Field survey
Worker labour cost (€ h^{-1})	WLC	Worker (n)*average wage per hour (€ h^{-1})
Total variable costs per hour (€ h^{-1})	THVC	FCC+OCC+M+ WLC
Interests on capital goods (€ $year^{-1}$)	ICG	((Machinery value (€)+salvage value (€))/2)*interest rate (%)
Depreciation (€ $year^{-1}$)	D	(Machinery value (€)-salvage value (€))/ economic life of machinery (years)
Insurance (€ $year^{-1}$)	I	Field survey
Space cost (€ $year^{-1}$)	SC	Area occupied by the machine (m^2)* price per m^2 (€ m^2)*(0.01~0.03)
Total fixed costs per year (€ $year^{-1}$)	TYFC	ICG+D+I+SC
Total fixed costs per hour (€ h^{-1})	THFC	TYFC/average annual machine use (h $year^{-1}$)
Total harvesting work site cost per hour (€ h^{-1})	THC	THFC + THVC
Harvesting cost per kg in shell (€ kg^{-1})	HCkg	THC/ harvesting yield per hour (kg h^{-1})
Harvesting cost per hectare (€ ha^{-1})	HCha	HCkg* harvesting yield per hectare (kg ha^{-1})

Variable costs included fuel and oil consumption of the tractor and the backpack blowers, as well as maintenance and human labour cost. Within the fixed costs, depreciation, insurance, interest on capital goods and the occupied space cost of the machinery were taken into account. In particular, labour cost was estimated in terms of opportunity cost that corresponds to the employment of temporary workers for manual and mechanical operations considering the local current hourly wage (Stillitano et al., 2016). For this purpose, for qualified workers employed for mechanical operations, such as the tractor driver, a compensation of 9.46 € per hour was considered, while, for the generic workers 8.57 € per hour was considered. Interests on capital goods (machines) were determined by applying an interest rate of 2%. The machinery salvage value was estimated as demolition material selling (steel and iron), which is equal to 10% of the initial purchase cost. Input costs (e.g. fuel and oil consumption) were calculated according to the market pricing referred to 2016.

RESULTS AND DISCUSSION

Elaborated data revealed that the operative time OT (OT=ET+AT) was equal to 3.79 h ha^{-1} in the first harvesting site (flat) while it was equal to 11.34 h ha^{-1} in the second one (hilly orchard). Both values are higher than those found by ENAMA (2004), Monarca et al. (2009) and Zimbalatti et al. (2012), which correspond respectively to 2.61 h ha^{-1}, from 2.13 to 2.27 h ha^{-1} and 3.50 h ha^{-1}. The results of statistical analysis (Table 2) did not highlight any significant difference, between the two harvesting sites, for the operative time as well as for the effective time; however, it did for the accessory time. Indeed, it was necessary to spend more accessory time to move between the rows and to position correctly the harvester in the second harvesting site due to the slope as well as to the irregularity of planting layout.

Table 2. One-Way Analysis of Variance (ANOVA) results of related to the working times

	Df	Sum Sq	Mean Sq	F value	Pr(> F)
Effective Time (ET)					
HS	1	1,632	1,632	0.539	0.469
Residuals	30	90,848	3,028		
Accessory Time (AT)					
HS	1	2,868	2,867.5	9.029	0.00504 **
Residuals	33	10,480	317.6		
Operative Time (OT)					
HS	1	324,896	324,896	5.754	0.096
Residuals	3	169,391	56,464		

*α = 0.05 Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1,* HS: Harvesting site (Variation source).

Working capacity in the first harvesting site (flat orchard) was equal to 0.26 ha h^{-1} corresponding to 631 kg h^{-1}. While, working productivity was equal to 0.065 ha h^{-1} op^{-1} corresponding to 158 kg h^{-1} op^{-1}. Regarding the second harvesting site (hilly), working capacity was equal to 0.088 ha h^{-1} corresponding to 184 kg h^{-1}. While, working productivity was equal to 0.022 ha h^{-1} op^{-1} corresponding to 46 kg h^{-1} op^{-1}. Employing the same harvesting machine, ENAMA (2004) obtained a work rate of 0.38 ha h^{-1} corresponding to 263 kg h^{-1}. Monarca et al. (2009) obtained values of working capacity equal to 0.47 ha h^{-1} and 0.44 ha h^{-1} corresponding to a working productivity of 940 kg h^{-1} and 1,100 kg h^{-1} respectively, whereas, Zimbalatti et al. (2012) obtained a value of 13 kg h^{-1}.

Economic analysis shows a total hourly cost equal to 48.58 € h^{-1} for both harvesting sites, 89.4% among which represent the variable costs due to labour costs (80.97% of the variable costs). Machinery and equipment ownership costs (i.e., depreciations) account for a large share of the total fixed costs, corresponding to 77.3%. Moreover, the two analysed harvesting sites were compared considering the cost per kg of hazelnut in shell as well as the average cost per hectare (Table 3). The findings are clearly influenced by the obtained yields referred to the operative time (OT) in each orchard. Indeed, a higher cost per kg of hazelnut in shell, corresponding to 0.26 € kg^{-1}, was obtained in the second harvesting site (hilly), while in the first one, this cost was equal to 0.08 € kg^{-1}. Concerning the average cost per hectare, the second harvesting site showed the worst economic performances, with 550.76 € ha^{-1} against 182.54 € ha^{-1} obtained in the first one. This is mainly due to the greater amount of time dedicated to harvesting, which is linked to the terrain conditions. These results differ from those obtained by Tous et al. (1994) and Yildiz (2016), who obtained an average cost per hectare around 490 \$ ha^{-1} and 436.47 € ha^{-1} respectively, using a mechanical harvester from the ground and blowers, with different plant productivity and workers' number.

Table 3. Comparison between the two analysed hazelnut orchards

Parameter	Harvesting site 1 (flat)	Harvesting site 2 (hilly)
Operative time (hours ha^{-1})[1]	3.79	11.34
Working capacity (ha $hour^{-1}$)	0.26[2] (631 kg $hour^{-1}$)	0.09[3] (184 kg $hour^{-1}$)
Working productivity (ha $hour^{-1}$ op^{-1})	0.065 (≈ 158 kg $h^{-1}op^{-1}$)	0.022 (46 kg $h^{-1}op^{-1}$)
Machinery cost (€ $hour^{-1}$)	48.58	48.58
Cost per Kg in shell (€ kg^{-1})	0.08	0.26
Harvest cost per ha (€ ha^{-1})	182.54	550.76

[1]Operative time (OT) = ET+AT; [2] aprox. 1,5 ha day^{-1}, [3] aprox. 0.5 ha day^{-1}.

The achieved analyses clearly showed the low performances obtained in the studied harvesting sites, and particularly in the hilly orchard, from both technical and economic points of view. However, it is to be stated that this cultivation has been subject, during the considered campaign, to wild boar (*Sus scrofa*) damages. These latter concerned not only the production but impeded also usual agricultural practices prior harvesting.

CONCLUSIONS

The recovery and valorization of hazelnut cultivation that plays a multifunctional role is guaranteed only if a careful planning of machinery employment to accomplish the diverse agricultural practices, especially harvesting, is carried out. Indeed, in order to reduce accessory time and increase productivity using the above-described harvester, orchards should be well managed, and trees planted according to a regular layout. Further trials using other mechanical harvesting machines and devices as well as diverse site organization should be carried to compare the obtained results and look for more sustainable solutions.

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Theoretical research into the motion of combined fertilising and sowing tractor-implement unit

V. Bulgakov[1], V. Adamchuk[2], M. Arak[3], I. Petrychenko[2] and J. Olt[3,*]

[1]National University of Life and Environmental Sciences of Ukraine, 15 Heroyiv Oborony Str., UA03041 Kyiv, Ukraine
[2]National Scientific Centre, Institute for Agricultural Engineering and Electrification, 11 Vokzalna Str., Glevaкha-1, Vasylkiv District, UA08631 Kiev Region, Ukraine
[3]Estonian University of Life Sciences, Institute of Technology, 56 Kreutzwaldi Str., EE51014 Tartu, Estonia
[*]Correspondence: jyri.olt@emu.ee

Abstract. A mathematical model has been developed representing the motion of a seed drill combination simultaneously performing the preceding banded placement of mineral fertilisers. Such a combined unit comprises the gang-up wheeled tractor, the fertiliser distribution module behind the tractor attached to it with the use of a hitch and intended for the banded placement of mineral fertilisers and the grain drill behind the fertiliser distribution module attached to it also with the use of a hitch. For the components of this dynamic system the coordinates of their centres, their masses as well as the external forces and the reactions of the soil surface applied to them have been determined. In order to use the original dynamic equations in the form of the Lagrange equations of the second kind, the generalised coordinates and kinetic energy relations have been determined. Following the necessary transformations, a system of six differential equations of motion has been generated, which characterises the behaviour of the combined machine unit during its plane-parallel motion. In this system, two line coordinates and one angular coordinate characterise the behaviour of the propulsion and power unit (wheeled tractor), while three angular coordinates characterise the rotations of the draft gear and the centres of the machines integrated with its use.

Key words: tractor, generalised force, kinetic energy, plane-parallel motion, modelling.

INTRODUCTION

The methodology of generating analytical mathematical models of agricultural machines and machine units is rather comprehensively presented in the numerous works by P.M. Vasilenko (1996; 1980) and A. Vilde & A. Rucis (2012). It is to be noted that the main type of motion of just agricultural machines (towed, direct-mounted and self-propelled) is their plane-parallel motion, because this type of motion determines the quality of performance of the aimed work processes. Many studies have been published about the research into the operation of combined agricultural machine units (Endrerud, 1999; Macmillan, 2002; Kutkov, 2004; Karayel & Özmerzi, 2008; Schreiber & Kutzbach, 2008; Jingling et al., 2011; Xin et al., 2012. Altikat et al., 2013; Fleischmann et al., 2013; Šarauskis & Vaitauskiene, 2014; Valainis et al., 2014; Nadykto et al., 2015; Bulgakov et al., 2016).

It should be stressed that the agro-technical and performance data of combined machine and tractor units as well as their productivity depend to a considerable extent on the nature of just their plane-parallel motion. Therefore, research into the plane-parallel motion of various machine units is needed both for the comparative assessment of the existing ones and the design of new concepts. The basic method of such research is the generation and solution of differential equations of the motion of machine combinations (Vasilenko, 1996).

The aim of this study was optimising the kinematic and design parameters of the combined fertilising and sowing tractor-implement unit that comprises a wheeled combine tractor with a fertiliser distributor for strip fertilisation and a grain drill trained behind the tractor, on the basis of the computational solution of the derived differential equations of its plane parallel motion.

MATERIALS AND METHODS

The methods of generating analytical mathematical models for machines and machine units, based on the use of the theoretical mechanics, the higher mathematics, the theory of tractor, programming and numerical calculations with the use of the PC have been used in the study.

The completed numerous agronomical experimental field studies have shown that the application of fertilisers together with the planting of grain and other agricultural crops, when the starter doses of fertilisers are applied on the seed bed and the main doses of fertilisers are applied below the seeding-down level with an offset in the horizontal plane, allows to achieve the substantial saving of fertilisers, 30…45% on average. Thus, the combined performance of the grain and other agricultural crop seeding operation simultaneously with the main fertiliser application to the soil proves to be an efficient resource-saving measure. Thereby, it becomes necessary to arrange and study such combined tractor-implement units, which could implement simultaneously both the seeding-down and the application of the starter and main doses of fertilisers.

In order to achieve that aim, the analytical mathematical model of the said combined tractor-implement unit need to be generated. The unit includes the wheeled combine tractor, to which first the fertilising unit is hitched with the use of an implement-attaching linkage, then follows the seeding unit kinematically connected, also with the use of an implement-attaching linkage, to the fertilising unit.

In order to generate the analytical mathematical model of such a combined fertilising and sowing unit, certain provisions generally applied in modelling will be used. We will begin with designing the equivalent schematic model of the combined unit under consideration, which requires first making certain assumptions.

For example, it is necessary to take into account only the main elements of the combined tractor-implement unit, which effect various motions, while being parts of a dynamic system. Since the dynamic system under consideration is a multi-mass system, the calculations can be simplified by taking into consideration only the motions that have an effect on the quality of the work process performance. The machine unit (dynamic system) will be referred to the fixed Cartesian coordinate system Oxyz. It is also assumed that, during the progression of the combined unit on the surface of the field, all its points move in the planes that are parallel to plane xOy (Fig. 1).

In order to generate the system of differential equations of motion of the mechanical system under consideration, it will be taken in its current position, then its position during its motion on the plane will be described with the use of six independent generalised coordinates. Also, it is assumed that at the initial instant $t = 0$ the mechanical system was aligned along the axis Ox and started moving from the quiescent state.

Because of that, the motion of the mechanical system under consideration will be described by six differential equations of second order with reference to the mentioned independent generalised coordinates. Hence, the mathematical model of the tractor-implement unit will also be the model of a mechanical system with six degrees of freedom.

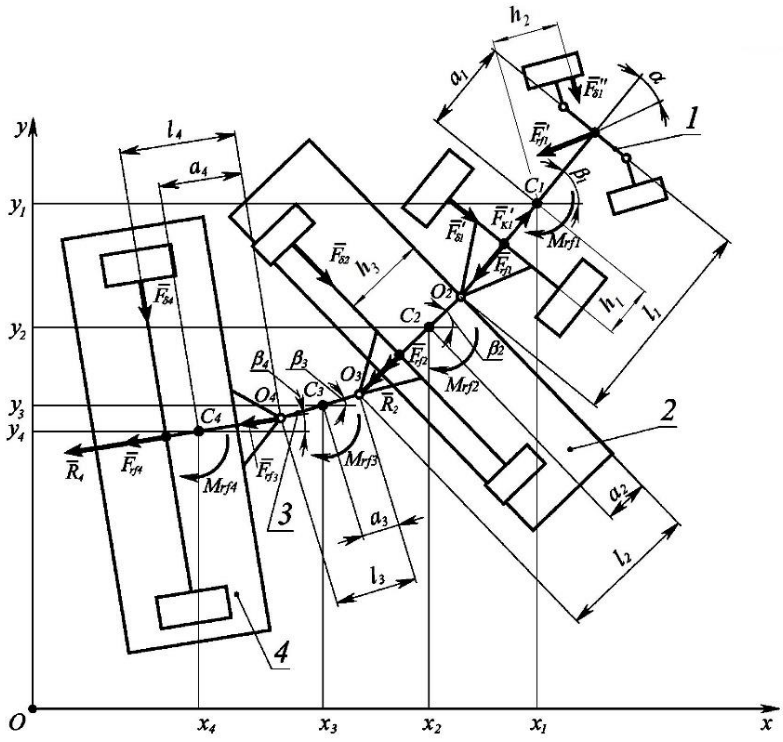

Figure 1. Equivalent schematic model of combined fertilising and sowing tractor-implement unit: 1 – tractor; 2 – fertilising unit; 3 – trailing arm; 4 – seeding unit.

The mechanical system under study will be referred to the fixed Cartesian coordinate system Oxyz. The axes Ox and Oy will be situated in the horizontal plane (i.e. in the field surface plane), while the axis Oz will point vertically up.

In order to generate the differential equations of motion of the obtained mechanical system, it will be put in arbitrary motion in the positive direction and its position during the motion will be characterised with six independent generalised coordinates: x_1, y_1, where x_1, y_1 – coordinates of the tractor's centre of mass; $\beta_1, \beta_2, \beta_3, \beta_4$ – respective angles between the longitudinal axes of the mechanical system's members and the axis Ox;

$m_i(i=\overline{1.4})$ – masses of the mechanical system's members; $C_i(x_i,\ y_i)$ – centre of mass of the *i*-th member of the system, $(i=\overline{1.4})$; a_i – distance from the member's centre of mass to its front articulation joint; l_i – distance between the adjacent articulation joint axes.

Let the mechanical system at the initial instant (t = 0) be aligned along the axis Ox and start moving from the quiescent state.

The motion of the obtained mechanical system will be described following the established method with the use of Lagrange equations of the second kind:

$$\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{q}_s}\right)-\frac{\partial T}{\partial q_s}=Q_s,\ \ (s=\overline{1.6}), \tag{1}$$

where T – kinetic energy of the mechanical system; q_s – generalised coordinate; s – number of the coordinate; Q_s – generalised force that corresponds to the generalised coordinate q_s.

After determining all the components needed for substitution into the original equations (1) and performing all necessary transformations in each of the mentioned generalised coordinates (Adamchuk et al., 2015), the following system of differential equations of the plane parallel motion of the combined fertilising and sowing tractor-implement unit is obtained (each of the six equations in the said system of differential equations is assigned its own reference number from (2) to (7)):

$$\begin{aligned}&\left(F'_{\delta 1}-F_{\delta 2}\right)\beta_1-F_{\delta 2}\beta_2-F_{\delta 4}\beta_4=\\&=F_{k1}-F'_{rf1}-F_{\delta 2}\alpha-F_{rf1}-F_{rf2}-R_2-F_{rf3}-F_{rf4}-R_4;\end{aligned} \tag{2}$$

$$\begin{aligned}&\left(m_1+m_2+m_3+m_4\right)\ddot{y}_1-\left(m_2+m_3+m_4\right)\left(l_1-a_1\right)\ddot{\beta}_1-\left(m_2a_2+m_3l_2+m_4l_2\right)\ddot{\beta}_2-\\&-\left(m_3a_3+m_4l_3\right)\ddot{\beta}_3-m_4a_4\ddot{\beta}_4+\left(m_2+m_3+m_4\right)\left(l_1-a_1\right)\beta_1\dot{\beta}_1^2+\\&+\left(m_2a_2+m_3l_2+m_4l_2\right)\beta_2\dot{\beta}_2^2+\left(m_3a_3+m_4l_3\right)\beta_3\dot{\beta}_3^2+m_4a_4\beta_4\dot{\beta}_4^2-\\&-\left(F'_{k1}-F'_{rf1}-F_{rf1}\right)\beta_1+\left(F_{rf2}+R_2\right)\beta_2+F_{rf3}\beta_3+\left(F_{rf4}+R_4\right)\beta_4=\\&=-F'_{\delta 1}+F'_{rf1}\alpha-F'_{\delta 2}-F_{\delta 2}-F_{\delta 4};\end{aligned} \tag{3}$$

$$\begin{aligned}&-\left(m_2+m_3+m_4\right)\left(l_1-a_1\right)\ddot{y}_1+\Bigg[I_1+m_2\left(l_1-a_1\right)^2+m_3\left(l_1-a_1\right)^2+m_4\left(l_1-a_1\right)^2+\\&+2I_{k1}\left(\frac{d_1}{r_{k1}}\right)^2+\frac{2I'_{k1}\left(d_0+d_1\right)\left[\left(d_0+d_1\right)+a_1\alpha\right]}{\left(r'_{k1}\right)^2}\Bigg]\ddot{\beta}_1+\\&+\left[m_2a_2+m_3l_2+m_4l_2\right]\left(l_1-a_1\right)\ddot{\beta}_2+\left(m_3a_3+m_4l_3\right)\left(l_1-a_1\right)\ddot{\beta}_3+m_4\left(l_1-a_1\right)a_4\ddot{\beta}_4-\\&-\left(m_2+m_3+m_4\right)\left(l_1-a_1\right)^2\beta_1\dot{\beta}_1^2-\left(m_2a_2+m_3l_2+m_4l_2\right)\left(l_1-a_1\right)\beta_2\dot{\beta}_2^2-\\&-\left(m_3a_3+m_4l_3\right)\left(l_1-a_1\right)\beta_3\dot{\beta}_3^2-m_4\left(l_1-a_1\right)a_4\beta_4\dot{\beta}_4^2+\frac{2I'_{k1}\left(d_0+d_1\right)d_0\alpha}{\left(r'_{k1}\right)^2}\dot{\beta}_1^2-\\&-\left(-F_{rf2}-R_2-F_{rf3}-F_{rf4}-R_4\right)\left(l_1-a_1\right)\beta_1-\left(F_{rf2}+R_2\right)\left(l_1-a_1\right)\beta_2-F_{rf3}\left(l_1-a_1\right)\beta_3-\\&-\left(F_{rf4}+R_4\right)\left(l_1-a_1\right)\beta_4=M_{C1}+\left(F_{\delta 2}+F_{\delta 4}\right)\left(l_1-a_1\right);\end{aligned} \tag{4}$$

$$
\begin{aligned}
&-\left(m_2a_2+m_3l_2+m_4l_2\right)\ddot{y}_1+\left(m_2a_2+m_3l_2+m_4l_2\right)\left(l_1-a_1\right)\ddot{\beta}_1+\\
&+\left[I_2+m_2a_2^2+m_3l_2^2+m_4l_2^2+\frac{I_{k2}}{r_{k2}^2}\left(d_{l_2}^2+d_{r_2}^2\right)\right]\ddot{\beta}_2+\left(m_3l_2a_3+m_4l_2l_3\right)\ddot{\beta}_3+\\
&+m_4l_2a_4\ddot{\beta}_4-\left(m_2a_2+m_3l_2+m_4l_2\right)\left(l_1-a_1\right)\beta_1\dot{\beta}_1^2-\left(m_2a_2^2+m_3l_2^2+m_4l_2^2\right)\beta_2\dot{\beta}_2^2-\\
&-\left(m_3l_2a_3+m_4l_2l_3\right)\beta_3\dot{\beta}_3^2-m_4a_4l_2\beta_4\dot{\beta}_4^2-\left(-F_{rf3}l_2-F_{rf4}l_2-R_4l_2\right)\beta_2-\\
&-F_{rf3}l_2\beta_3-\left(F_{rf4}l_2+R_4l_2\right)\beta_4=M_{O2}+F_{\delta 4}l_2;
\end{aligned}
\qquad (5)
$$

$$
\begin{aligned}
&-\left(m_3a_3+m_4l_3\right)\ddot{y}_1+\left(m_3a_3+m_4l_3\right)\left(l_1-a_1\right)\ddot{\beta}_1+\left(m_3a_3l_2+m_4l_3l_2\right)\ddot{\beta}_2+\\
&+\left[I_3+m_4l_3^2+\frac{I_{k3}}{r_{k3}^2}\left(d_{l_3}^2+d_{r_3}^2\right)\right]\ddot{\beta}_3+m_4l_3a_4\ddot{\beta}_4-\left(m_3a_3+m_4l_3\right)\left(l_1-a_1\right)\beta_1\dot{\beta}_1^2-\\
&-\left(m_3a_3l_2+m_4l_3l_2\right)\beta_2\dot{\beta}_2^2-m_4l_3^2\beta_3\dot{\beta}_3^2-m_4l_3a_4\beta_4\dot{\beta}_4^2-\\
&-\left(-F_{rf4}l_3-R_4l_3\right)\beta_3-\left(F_{rf4}l_3+R_4l_3\right)\beta_4=M_{O3}+F_{\delta 4}l_3;
\end{aligned}
\qquad (6)
$$

$$
\begin{aligned}
&-m_4a_4\ddot{y}_1+m_4a_4\left(l_1-a_1\right)\ddot{\beta}_1+m_4a_4l_2\ddot{\beta}_2+m_4a_4l_3\ddot{\beta}_3+\\
&+\left[I_4+m_4a_4^2+\frac{I_{k4}}{r_{k4}^2}\left(d_{l_4}^2+d_{r_4}^2\right)\right]\ddot{\beta}_4-m_4a_4\left(l_1-a_1\right)\beta_1\dot{\beta}_1^2-\\
&-m_4a_4l_2\beta_2\dot{\beta}_2^2-m_4a_4l_3\beta_3\dot{\beta}_3^2-m_4a_4^2\beta_4\dot{\beta}_4^2=M_{O4};
\end{aligned}
\qquad (7)
$$

Respectively, the above equations of the obtained system, expressed in terms of constant coefficients, will appear as follows:

$$
\left.
\begin{aligned}
&A_{11}\ddot{y}_1+A_{12}\ddot{\beta}_1+A_{13}\ddot{\beta}_2+A_{14}\ddot{\beta}_3+A_{15}\ddot{\beta}_4+A_{16}\beta_1\dot{\beta}_1^2+A_{17}\beta_2\dot{\beta}_2^2+A_{18}\beta_3\dot{\beta}_3^2+\\
&+A_{19}\beta_4\dot{\beta}_4^2+A_{110}\beta_1+A_{111}\beta_2+A_{112}\beta_3+A_{113}\beta_4+A_{114}\dot{\beta}_1^2=B_1,\\[6pt]
&A_{21}\ddot{y}_1+A_{22}\ddot{\beta}_1+A_{23}\ddot{\beta}_2+A_{24}\ddot{\beta}_3+A_{25}\ddot{\beta}_4+A_{26}\beta_1\dot{\beta}_1^2+A_{27}\beta_2\dot{\beta}_2^2+A_{28}\beta_3\dot{\beta}_3^2+\\
&+A_{29}\beta_4\dot{\beta}_4^2+A_{210}\beta_1+A_{211}\beta_2+A_{212}\beta_3+A_{213}\beta_4+A_{214}\dot{\beta}_1^2=B_2,\\[6pt]
&A_{31}\ddot{y}_1+A_{32}\ddot{\beta}_1+A_{33}\ddot{\beta}_2+A_{34}\ddot{\beta}_3+A_{35}\ddot{\beta}_4+A_{36}\beta_1\dot{\beta}_1^2+A_{37}\beta_2\dot{\beta}_2^2+A_{38}\beta_3\dot{\beta}_3^2+\\
&+A_{39}\beta_4\dot{\beta}_4^2+A_{310}\beta_1+A_{311}\beta_2+A_{312}\beta_3+A_{313}\beta_4+A_{314}\dot{\beta}_1^2=B_3,\\[6pt]
&A_{41}\ddot{y}_1+A_{42}\ddot{\beta}_1+A_{43}\ddot{\beta}_2+A_{44}\ddot{\beta}_3+A_{45}\ddot{\beta}_4+A_{46}\beta_1\dot{\beta}_1^2+A_{47}\beta_2\dot{\beta}_2^2+A_{48}\beta_3\dot{\beta}_3^2+\\
&+A_{49}\beta_4\dot{\beta}_4^2+A_{410}\beta_1+A_{411}\beta_2+A_{412}\beta_3+A_{413}\beta_4+A_{414}\dot{\beta}_1^2=B_4,\\[6pt]
&A_{51}\ddot{y}_1+A_{52}\ddot{\beta}_1+A_{53}\ddot{\beta}_2+A_{54}\ddot{\beta}_3+A_{55}\ddot{\beta}_4+A_{56}\beta_1\dot{\beta}_1^2+A_{57}\beta_2\dot{\beta}_2^2+A_{58}\beta_3\dot{\beta}_3^2+\\
&+A_{59}\beta_4\dot{\beta}_4^2+A_{510}\beta_1+A_{511}\beta_2+A_{512}\beta_3+A_{513}\beta_4+A_{514}\dot{\beta}_1^2=B_5,\\[6pt]
&A_{61}\ddot{y}_1+A_{62}\ddot{\beta}_1+A_{63}\ddot{\beta}_2+A_{64}\ddot{\beta}_3+A_{65}\ddot{\beta}_4+A_{66}\beta_1\dot{\beta}_1^2+A_{67}\beta_2\dot{\beta}_2^2+A_{68}\beta_3\dot{\beta}_3^2+\\
&+A_{69}\beta_4\dot{\beta}_4^2+A_{610}\beta_1+A_{611}\beta_2+A_{612}\beta_3+A_{613}\beta_4+A_{614}\dot{\beta}_1^2=B_6.
\end{aligned}
\right\}
\qquad (8)
$$

where

$$A_{11}=0;\ A_{12}=0; A_{13}=0; A_{14}=0; A_{15}=0; A_{16}=0; A_{17}=0; A_{18}=0; A_{19}=0;$$
$$A_{110}=F'_{\delta 1}-F_{\delta 2}; A_{111}=-F_{\delta 2}; A_{112}=0; A_{113}=-F_{\delta 4}; A_{114}=0;$$
$$A_{21}=m_1+m_2+m_3+m_4;\ A_{22}=-(m_2+m_3+m_4)(l_1-a_1);$$
$$A_{23}=-(m_2a_2+m_3l_2+m_4l_2);\ A_{24}=-(m_3a_3+m_4l_3);\ A_{25}=-m_4a_4;$$
$$A_{26}=(m_2+m_3+m_4)(l_1-a_1);\ A_{27}=(m_2a_2+m_3l_2+m_4l_2);$$
$$A_{28}=(m_3a_3+m_4l_3);\ A_{29}=m_4a_4;\ A_{210}=-\left(F'_{k1}-F'_{rf1}-F_{rf1}\right);$$
$$A_{211}=F_{rf2}+R_2;\ A_{212}=F_{rf3};\ A_{213}=F_{rf3}+R_4;\ A_{214}=0;$$
$$A_{31}=-(m_2+m_3+m_4)(l_1-a_1);\ A_{32}=I_1+(m_2+m_3+m_4)(l_1-a_1)^2+$$
$$+2I_{k1}\left(\frac{d_1}{r_{k1}}\right)^2+\frac{2I'_{k1}(d_0+d_1)\left[(d_0+d_1)+a_1\alpha\right]}{(r'_{k1})^2};$$
$$A_{33}=[m_2a_2+m_3l_2+m_4l_2](l_1-a_1);\ A_{34}=(m_3a_3+m_4l_3)(l_1-a_1);$$
$$A_{35}=m_4(l_1-a_1)a_4;\ A_{36}=-(m_2+m_3+m_4)(l_1-a_1)^2;$$
$$A_{37}=-(m_2a_2+m_3l_2+m_4l_2)(l_1-a_1);\ A_{38}=-(m_3a_3+m_4l_3)(l_1-a_1);$$
$$A_{39}=-m_4(l_1-a_1)a_4;\ A_{310}=-\left(-F_{rf2}-R_2-F_{rf3}-F_{rf4}-R_4\right)(l_1-a_1);$$
$$A_{311}=-\left(F_{rf2}+R_2\right)(l_1-a_1);\ A_{312}=F_{rf3}(l_1-a_1);$$
$$A_{313}=-\left(F_{rf4}+R_4\right)(l_1-a_1);\ A_{314}=\frac{2I'_{k1}(d_0+d_1)d_0\alpha}{(r'_{k1})^2};$$
$$A_{41}=-(m_2a_2+m_3l_2+m_4l_2);\ A_{42}=(m_2a_2+m_3l_2+m_4l_2)(l_1-a_1);$$
$$A_{43}=I_2+m_2a_2^2+m_3l_2^2+m_4l_2^2+\frac{I_{k2}}{r_{k2}^2}\left(d_{l_2}^2+d_{r_2}^2\right);$$
$$A_{44}=m_3l_2a_3+m_4l_2l_3;\ A_{45}=m_4l_2a_4;\ A_{46}=-(m_2a_2+m_3l_2+m_4l_2)(l_1-a_1);$$
$$A_{47}=-\left(m_2a_2^2+m_3l_2^2+m_4l_2^2\right);\ A_{48}=-(m_3l_2a_3+m_4l_2l_3);$$
$$A_{49}=-m_4a_4l_2;\ A_{410}=0;\ A_{411}=-\left(-F_{rf3}l_2-F_{rf4}l_2-R_4l_2\right);\ A_{412}=-F_{rf3}l_2;$$
$$A_{413}=-\left(F_{rf4}l_2+R_4l_2\right);\ A_{414}=0;\ A_{51}=-(m_3a_3+m_4l_3);$$
$$A_{52}=(m_3a_3+m_4l_3)(l_1-a_1);\ A_{53}=(m_3a_3+m_4l_3)l_2;$$
$$A_{54}=I_3+m_4l_3^2+\frac{I_{k3}}{r_{k3}^2}\left(d_{l_3}^2+d_{r_3}^2\right);\ A_{55}=m_4l_3a_4;$$
$$A_{56}=-(m_3a_3+m_4l_3)(l_1-a_1);\ A_{57}=-(m_3a_3+m_4l_3)l_2;\ A_{58}=-m_4l_3^2;$$
$$A_{59}=-m_4l_3a_4;\ A_{510}=0;\ A_{511}=0;\ A_{512}=-\left(-F_{rf4}-R_4\right)l_3;$$
$$A_{513}=-\left(F_{rf4}+R_4\right)l_3;\ A_{514}=0;\ A_{61}=-m_4a_4;\ A_{62}=m_4a_4(l_1-a_1);$$
$$A_{63}=m_4a_4l_2;\ A_{64}=m_4a_4l_3;\ A_{65}=I_4+m_4a_4^2+\frac{I_{k4}}{r_{k4}^2}\left(d_{l_4}^2+d_{r_4}^2\right);$$
$$A_{66}=-m_4a_4(l_1-a_1);\ A_{67}=-m_4a_4l_2;\ A_{68}=-m_4a_4l_3;\ A_{69}=-m_4a_4^2;$$
$$A_{610}=0;\ A_{611}=0;\ A_{612}=0;\ A_{613}=0;\ A_{614}=0;$$
$$B_1=F_{k1}-F'_{rf1}-F_{\delta 2}\alpha-F_{rf1}-F_{rf2}-R_2-F_{rf3}-F_{rf4}-R_4;$$
$$B_2=-F'_{\delta 1}+F'_{rf1}\alpha-F'_{\delta 2}-F_{\delta 2}-F_{\delta 4};\ B_3=M_{C1}+(F_{\delta 2}+F_{\delta 4})(l_1-a_1);$$
$$B_4=M_{O2}+F_{\delta 4}l_2;\ B_5=M_{O3}+F_{\delta 4}l_3;\ B_6=M_{O4};$$
$$M_{C1}=F'_{\delta 1}\cdot h_1-F'_{\delta 2}\cdot h_2;\ M_{O2}=F_{\delta 2}\cdot h_3;\ M_{O3}=0;\ M_{O4}=F_{\delta 4}\cdot l_4.$$

Further, it is assumed that, when the angles β_1, β_2, β_3, β_4 are small, the velocities $\dot{\beta}_1$, $\dot{\beta}_2$, $\dot{\beta}_3$, $\dot{\beta}_4$ will also be small. The assumption is based on the sufficiently great inertia of the unit's constituent masses and the actual conditions of the unit movement on the field surface (during small displacements the components of the unit are unable to accelerate to high velocities).

Under the made assumption, especially at a first approximation, the products $\beta_1 \cdot \dot{\beta}_1^2$, $\beta_2 \cdot \dot{\beta}_2^2$, $\beta_3 \cdot \dot{\beta}_3^2$, $\beta_4 \cdot \dot{\beta}_4^2$, can be regarded as sufficiently small. Therefore, the terms of the equations in the system that contain the mentioned products can be discarded, which will result in the considerable simplification of the system of differential equations, the latter acquiring the form of a linear system of differential equations, which will appear as follows:

$$\begin{aligned}&\left(F'_{\delta 1}-F_{\delta 2}\right)\beta_1-F_{\delta 2}\beta_2-F_{\delta 4}\beta_4=\\&=F_{k1}-F'_{rf1}-F_{\delta 2}\alpha-F_{rf1}-F_{rf2}-R_2-F_{rf3}-F_{rf4}-R_4;\end{aligned}\tag{9}$$

$$\begin{aligned}&\left(m_1+m_2+m_3+m_4\right)\ddot{y}_1-\left(m_2+m_3+m_4\right)\left(l_1-a_1\right)\ddot{\beta}_1-\\&-\left(m_2a_2+m_3l_2+m_4l_2\right)\ddot{\beta}_2-\left(m_3a_3+m_4l_3\right)\ddot{\beta}_3-\\&-m_4a_4\ddot{\beta}_4-\left(F'_{k1}-F'_{rf1}-F_{rf1}\right)\beta_1+\left(F_{rf2}+R_2\right)\beta_2+\\&+F_{rf3}\beta_3+\left(F_{rf4}+R_4\right)\beta_4=-F'_{\delta 1}+F'_{rf1}\alpha-F'_{\delta 2}-F_{\delta 2}-F_{\delta 4};\end{aligned}\tag{10}$$

$$\begin{aligned}&-\left(m_2+m_3+m_4\right)\left(l_1-a_1\right)\ddot{y}_1+\Bigg[I_1+m_2\left(l_1-a_1\right)^2+m_3\left(l_1-a_1\right)^2+m_4\left(l_1-a_1\right)^2+\\&+2I_{k1}\left(\frac{d_1}{r_{k1}}\right)^2+\frac{2I'_{k1}\left(d_0+d_1\right)\left[\left(d_0+d_1\right)+a_1\alpha\right]}{\left(r'_{k1}\right)^2}\Bigg]\ddot{\beta}_1+\\&+\left[m_2a_2+m_3l_2+m_4l_2\right]\left(l_1-a_1\right)\ddot{\beta}_2+\left(m_3a_3+m_4l_3\right)\left(l_1-a_1\right)\ddot{\beta}_3+\\&+m_4\left(l_1-a_1\right)a_4\ddot{\beta}_4-\left(-F_{rf2}-R_2-F_{rf3}-F_{rf4}-R_4\right)\left(l_1-a_1\right)\beta_1-\\&-\left(F_{rf2}+R_2\right)\left(l_1-a_1\right)\beta_2-F_{rf3}\left(l_1-a_1\right)\beta_3-\\&-\left(F_{rf4}+R_4\right)\left(l_1-a_1\right)\beta_4=M_{C1}+\left(F_{\delta 2}+F_{\delta 4}\right)\left(l_1-a_1\right);\end{aligned}\tag{11}$$

$$\begin{aligned}&-\left(m_2a_2+m_3l_2+m_4l_2\right)\ddot{y}_1+\left(m_2a_2+m_3l_2+m_4l_2\right)\left(l_1-a_1\right)\ddot{\beta}_1+\\&+\left[I_2+m_2a_2^2+m_3l_2^2+m_4l_2^2+\frac{I_{k2}}{r_{k2}^2}\left(d_{l_2}^2+d_{r_2}^2\right)\right]\ddot{\beta}_2+\\&+\left(m_3l_2a_3+m_4l_2l_3\right)\ddot{\beta}_3+m_4l_2a_4\ddot{\beta}_4-\left(-F_{rf3}l_2-F_{rf4}l_2-R_4l_2\right)\beta_2-\\&-F_{rf3}l_2\beta_3-\left(F_{rf4}l_2+R_4l_2\right)\beta_4=M_{O2}+F_{\delta 4}l_2;\end{aligned}\tag{12}$$

$$-\left(m_3a_3+m_4l_3\right)\ddot{y}_1+\left(m_3a_3+m_4l_3\right)\left(l_1-a_1\right)\ddot{\beta}_1+\left(m_3a_3l_2+m_4l_3l_2\right)\ddot{\beta}_2+$$
$$+\left[I_3+m_4l_3^2+\frac{I_{k3}}{r_{k3}^2}\left(d_{l_3}^2+d_{r_3}^2\right)\right]\ddot{\beta}_3+m_4l_3a_4\ddot{\beta}_4-\left(-F_{rf\,4}l_3-R_4l_3\right)\beta_3- \tag{13}$$
$$-\left(F_{rf\,4}l_3+R_4l_3\right)\beta_4=M_{O3}+F_{\delta 4}l_3;$$

$$-m_4a_4\ddot{y}_1+m_4a_4\left(l_1-a_1\right)\ddot{\beta}_1+m_4a_4l_2\ddot{\beta}_2+m_4a_4l_3\ddot{\beta}_3+$$
$$+\left[I_4+m_4a_4^2+\frac{I_{k4}}{r_{k4}^2}\left(d_{l_4}^2+d_{r_4}^2\right)\right]\ddot{\beta}_4=M_{O4}. \tag{14}$$

It can be seen that only two equations of the system are identical: (2) and (9). Respectively, the equations (9) – (14) expressed in terms of constant coefficients will appear as follows:

$$\left.\begin{aligned}
&A_{11}\ddot{y}_1+A_{12}\ddot{\beta}_1+A_{13}\ddot{\beta}_2+A_{14}\ddot{\beta}_3+A_{15}\ddot{\beta}_4+\\
&+A_{16}\beta_1+A_{17}\beta_2+A_{18}\beta_3+A_{19}\beta_4=B_1,\\
&A_{21}\ddot{y}_1+A_{22}\ddot{\beta}_1+A_{23}\ddot{\beta}_2+A_{24}\ddot{\beta}_3+A_{25}\ddot{\beta}_4+\\
&+A_{26}\beta_1+A_{27}\beta_2+A_{28}\beta_3+A_{29}\beta_4=B_2,\\
&A_{31}\ddot{y}_1+A_{32}\ddot{\beta}_1+A_{33}\ddot{\beta}_2+A_{34}\ddot{\beta}_3+A_{35}\ddot{\beta}_4+\\
&+A_{36}\beta_1+A_{37}\beta_2+A_{38}\beta_3+A_{39}\beta_4=B_3,\\
&A_{41}\ddot{y}_1+A_{42}\ddot{\beta}_1+A_{43}\ddot{\beta}_2+A_{44}\ddot{\beta}_3+A_{45}\ddot{\beta}_4+\\
&+A_{46}\beta_1+A_{47}\beta_2+A_{48}\beta_3+A_{49}\beta_4=B_4,\\
&A_{51}\ddot{y}_1+A_{52}\ddot{\beta}_1+A_{53}\ddot{\beta}_2+A_{54}\ddot{\beta}_3+A_{55}\ddot{\beta}_4+\\
&+A_{56}\beta_1+A_{57}\beta_2+A_{58}\beta_3+A_{59}\beta_4=B_5,\\
&A_{61}\ddot{y}_1+A_{62}\ddot{\beta}_1+A_{63}\ddot{\beta}_2+A_{64}\ddot{\beta}_3+A_{65}\ddot{\beta}_4+\\
&+A_{66}\beta_1+A_{67}\beta_2+A_{68}\beta_3+A_{69}\beta_4=B_6.
\end{aligned}\right\} \tag{15}$$

where

$$A_{11}=0;\ A_{12}=0;\ A_{13}=0;\ A_{14}=0;\ A_{15}=0;$$
$$A_{16}=F'_{\delta 1}-F_{\delta 2};\ A_{17}=-F_{\delta 2};\ A_{18}=0;\ A_{19}=-F_{\delta 4};$$
$$A_{21}=m_1+m_2+m_3+m_4;\ A_{22}=-\left(m_2+m_3+m_4\right)\left(l_1-a_1\right);$$
$$A_{23}=-\left(m_2a_2+m_3l_2+m_4l_2\right);\ A_{24}=-\left(m_3a_3+m_4l_3\right);$$
$$A_{25}=-m_4a_4;\ A_{26}=-\left(F'_{k1}-F'_{rf1}-F_{rf1}\right);$$
$$A_{27}=F_{rf2}+R_2;\ A_{28}=F_{rf3};\ A_{29}=F_{rf4}+R_4;$$
$$A_{31}=-\left(m_2+m_3+m_4\right)\left(l_1-a_1\right);\ A_{32}=I_1+\left(m_2+m_3+m_4\right)\left(l_1-a_1\right)^2+$$
$$+2I_{k1}\left(\frac{d_1}{r_{k1}}\right)^2+\frac{2I'_{k1}\left(d_0+d_1\right)\left[\left(d_0+d_1\right)+a_1\alpha\right]}{\left(r'_{k1}\right)^2};$$
$$A_{33}=\left[m_2a_2+m_3l_2+m_4l_2\right]\left(l_1-a_1\right);\ A_{34}=\left(m_3a_3+m_4l_3\right)\left(l_1-a_1\right);$$
$$A_{35}=m_4\left(l_1-a_1\right)a_4;\ A_{36}=-\left(-F_{rf2}-R_2-F_{rf3}-F_{rf4}-R_4\right)\left(l_1-a_1\right);$$
$$A_{37}=-\left(F_{rf2}+R_2\right)\left(l_1-a_1\right);\ A_{38}=F_{rf3}\left(l_1-a_1\right);$$
$$A_{39}=-\left(F_{rf4}+R_4\right)\left(l_1-a_1\right);$$
$$A_{41}=-\left(m_2a_2+m_3l_2+m_4l_2\right);\ A_{42}=\left(m_2a_2+m_3l_2+m_4l_2\right)\left(l_1-a_1\right);$$
$$A_{43}=I_2+m_2a_2^2+m_3l_2^2+m_4l_2^2+\frac{I_{k2}}{r_{k2}^2}\left(d_{l_2}^2+d_{r_2}^2\right);$$
$$A_{44}=m_3l_2a_3+m_4l_2l_3;\ A_{45}=m_4l_2a_4;$$
$$A_{46}=0;\ A_{47}=-\left(-F_{rf3}l_2-F_{rf4}l_2-R_4l_2\right);\ A_{48}=-F_{rf3}l_2;$$
$$A_{49}=-\left(F_{rf4}l_2+R_4l_2\right);$$
$$A_{51}=-\left(m_3a_3+m_4l_3\right);\ A_{52}=\left(m_3a_3+m_4l_3\right)\left(l_1-a_1\right);$$
$$A_{53}=\left(m_3a_3+m_4l_3\right)l_2;\ A_{54}=I_3+m_4l_3^2+\frac{I_{k3}}{r_{k3}^2}\left(d_{l_3}^2+d_{r_3}^2\right);$$
$$A_{55}=m_4l_3a_4;\ A_{56}=0;\ A_{57}=0;\ A_{58}=-\left(-F_{rf4}-R_4\right)l_3;$$
$$A_{59}=-\left(F_{rf4}+R_4\right)l_3;$$
$$A_{61}=-m_4a_4;\ A_{62}=m_4a_4\left(l_1-a_1\right);$$
$$A_{63}=m_4a_4l_2;\ A_{64}=m_4a_4l_3;\ A_{65}=I_4+m_4a_4^2+\frac{I_{k4}}{r_{k4}^2}\left(d_{l_4}^2+d_{r_4}^2\right);$$
$$A_{66}=0;\ A_{67}=0;\ A_{68}=0;\ A_{69}=0;$$
$$B_1=F_{k1}-F'_{rf1}-F_{\delta 2}\alpha-F_{rf1}-F_{rf2}-R_2-F_{rf3}-F_{rf4}-R_4;$$
$$B_2=-F'_{\delta 1}+F'_{rf1}\alpha-F'_{\delta 2}-F_{\delta 2}-F_{\delta 4};\ B_3=M_{C1}+\left(F_{\delta 2}+F_{\delta 4}\right)\left(l_1-a_1\right);$$
$$B_4=M_{O2}+F_{\delta 4}l_2;\ B_5=M_{O3}+F_{\delta 4}l_3;\ B_6=M_{O4};$$
$$M_{C1}=F'_{\delta 1}\cdot h_1-F'_{\delta 2}\cdot h_2;\ M_{O2}=F_{\delta 2}\cdot h_3;\ M_{O3}=0;\ M_{O4}=F_{\delta 4}\cdot l_4.$$

Further, the numerical analysis of the obtained system of equations (15) is to be carried out with the use of the PC and the software programmes developed by the authors.

Under the condition that $A_{11}\ldots A_{15} = 0$, the first equation of the system (15) becomes static, i.e. equal to zero, therefore, it is omitted in the following considerations.

The examined mathematical model of the combined fertilising and sowing tractor-implement unit represents its inertia properties. This is indicated by the differential equations of the analytical mathematical model, which contain only the second derivatives of the independent coordinates (i.e. $\ddot{y}_1,\ \ddot{\beta}_1,\ \ddot{\beta}_2,\ \ddot{\beta}_3$ and $\ddot{\beta}_4$).

It is to be noted that the inertia of the third member of the combined tractor-implement unit under consideration can be ignored on account of its relatively small mass. Under the assumption that $m_3 = l_3 = \alpha_3 = 0$, the system of equations (15) will assume the following form:

$$\left.\begin{aligned}
&A_{21}\ddot{y}_1 + A_{22}\ddot{\beta}_1 + A_{26}\beta_1 + A_{23}\ddot{\beta}_2 + A_{27}\beta_2 + A_{25}\ddot{\beta}_4 + A_{29}\beta_4 = K\alpha + K_1,\\
&A_{31}\ddot{y}_1 + A_{32}\ddot{\beta}_1 + A_{36}\beta_1 + A_{33}\ddot{\beta}_2 + A_{37}\beta_2 + A_{35}\ddot{\beta}_4 + A_{39}\beta_4 = B_3,\\
&A_{41}\ddot{y}_1 + A_{42}\ddot{\beta}_1 + A_{46}\beta_1 + A_{43}\ddot{\beta}_2 + A_{47}\beta_2 + A_{45}\ddot{\beta}_4 + A_{49}\beta_4 = B_4,\\
&A_{61}\ddot{y}_1 + A_{62}\ddot{\beta}_1 + A_{66}\beta_1 + A_{63}\ddot{\beta}_2 + A_{67}\beta_2 + A_{65}\ddot{\beta}_4 + A_{69}\beta_4 = B_6,
\end{aligned}\right\} \quad (16)$$

where $K = F'_{rf1},\ \ K_1 = -F'_{\delta 1} - F'_{\delta 2} - F_{\delta 2} - F_{\delta 4}$.

In order to simplify the process of solving the system of differential equations (16), the Laplace transformation will be applied. It implies, as is known, the transition from the original function to its mapping via the introduction of a special operator – complex variable $p = \frac{d}{dt}$. It provides, as a result, the possibility to change from the complicated system of differential equations to a relatively simple system of algebraic equations. The following will be obtained:

$$\left.\begin{aligned}
&K_{21}\cdot y_1(p) + K_{22}\cdot\beta_1(p) + K_{23}\cdot\beta_2(p) + K_{25}\cdot\beta_4(p) = K\cdot\alpha(p) + K_1\cdot 1(p),\\
&K_{31}\cdot y_1(p) + K_{32}\cdot\beta_1(p) + K_{33}\cdot\beta_2(p) + K_{35}\cdot\beta_4(p) = B_3\cdot 1(p),\\
&K_{41}\cdot y_1(p) + K_{42}\cdot\beta_1(p) + K_{43}\cdot\beta_2(p) + K_{45}\cdot\beta_4(p) = B_4\cdot 1(p),\\
&K_{61}\cdot y_1(p) + K_{62}\cdot\beta_1(p) + K_{63}\cdot\beta_2(p) + K_{65}\cdot\beta_4(p) = B_6\cdot 1(p),
\end{aligned}\right\} \quad (17)$$

where

$$\begin{aligned}
&K_{21} = A_{21}\cdot p^2, && K_{31} = A_{31}\cdot p^2, && K_{41} = A_{41}\cdot p^2, && K_{61} = A_{61}\cdot p,\\
&K_{22} = A_{22}\cdot p^2 + A_{26}, && K_{32} = A_{32}\cdot p^2 + A_{36}, && K_{42} = A_{42}\cdot p^2, && K_{62} = A_{62}\cdot p,\\
&K_{23} = A_{23}\cdot p^2 + A_{27}, && K_{33} = A_{33}\cdot p^2 + A_{37}, && K_{43} = A_{43}\cdot p^2 + A_{47}, && K_{63} = A_{63}\cdot p,\\
&K_{25} = A_{25}\cdot p^2 + A_{29}, && K_{35} = A_{35}\cdot p^2 + A_{39}, && K_{45} = A_{45}\cdot p^2 + A_{49}, && K_{65} = A_{65}\cdot p.
\end{aligned}$$

The system of equations (17) represents the dynamic state of the combined fertilising and sowing tractor-implement unit under the effect of the controlling $[\alpha(p)]$ and perturbing input variables. The latter ones include the singular exposures $K_0 \cdot 1(p)$ and $B_3 =\cdot\, 1(p)$, $B_4 =\cdot\, 1(p)$, and $B_6 =\cdot\, 1(p)$. The coordinate y_1 and the angles β_1, β_2 and β_4 are the original variables of this system of equations.

The transfer function (W_α) of the combined fertilising and sowing tractor-implement unit under consideration, which represents the controllability of its motion, is expressed in the form of the ratio of two determinants:

$$W_\alpha = \frac{D_\alpha}{D}. \tag{18}$$

This function characterises the reaction of the combine tractor in terms of the change of its course angle (β_1) under the effect of the control action, which is represented by the angular displacement of the front wheels of the power unit (combine tractor) – α.

The principal determinant of the system (17) comprising the coefficients in its left part appears as follows:

$$D = \begin{vmatrix} K_{21} & K_{22} & K_{23} & K_{25} \\ K_{31} & K_{32} & K_{33} & K_{35} \\ K_{41} & K_{42} & K_{43} & K_{45} \\ K_{61} & K_{62} & K_{63} & K_{65} \end{vmatrix} \tag{19}$$

In order to generate the determinant D_α, the second column in the principal determinant D, which represents the course angle β_1 of the turning combine tractor, will be replaced by the column comprising those coefficients in the right part of the system of equations (17), which are related to the element $\alpha(p)$. It can be seen that the described condition is met by a column with the coefficient K in its first row and zeroes in the rest of the rows. That results in the following:

$$D_\alpha = \begin{vmatrix} K_{21} & K & K_{23} & K_{25} \\ K_{31} & 0 & K_{33} & K_{35} \\ K_{41} & 0 & K_{43} & K_{45} \\ K_{61} & 0 & K_{63} & K_{65} \end{vmatrix} \tag{20}$$

Taking into account what was stated above, the transfer function of the response of the combined fertilising and sowing tractor-implement unit to the control action will eventually take the following form:

$$W_\alpha = \frac{p^2\left(F_4 \cdot p^4 + F_2 \cdot p^2 + F_0\right)}{p^2\left(C_6 \cdot p^6 + C_4 \cdot p^4 + C_2 \cdot p^2 + C_0\right)} \tag{21}$$

where

$$F_4 = K\left(A_{31} \cdot A_{45} \cdot A_{63} - A_{31} \cdot A_{43} \cdot A_{65} + A_{41} \cdot A_{33} \cdot A_{65} - A_{41} \cdot A_{35} \cdot A_{63} - A_{33} \cdot A_{61} \cdot A_{45} + A_{43} \cdot A_{61} \cdot A_{35}\right),$$

$$F_2 = K\left(A_{31} \cdot A_{63} \cdot A_{49} - A_{31} \cdot A_{47} \cdot A_{65} - A_{41} \cdot A_{63} \cdot A_{39} + A_{41} \cdot A_{37} \cdot A_{65} - A_{33} \cdot A_{61} \cdot A_{49} + \right.$$
$$\left. + A_{43} \cdot A_{61} \cdot A_{39} + A_{61} \cdot A_{35} \cdot A_{47} - A_{61} \cdot A_{45} \cdot A_{37}\right),$$

$$F_0 = K\left(A_{61} \cdot A_{37} \cdot A_{49} - A_{61} \cdot A_{37} \cdot A_{49}\right),$$

$$
\begin{aligned}
C_6 = {} & A_{21} \cdot A_{32} \cdot A_{43} \cdot A_{65} - A_{21} \cdot A_{32} \cdot A_{45} \cdot A_{63} - A_{21} \cdot A_{33} \cdot A_{42} \cdot A_{65} + A_{21} \cdot A_{33} \cdot A_{62} \cdot A_{45} + \\
& + A_{21} \cdot A_{42} \cdot A_{35} \cdot A_{63} - A_{21} \cdot A_{43} \cdot A_{35} \cdot A_{62} - A_{22} \cdot A_{31} \cdot A_{43} \cdot A_{65} + A_{22} \cdot A_{31} \cdot A_{45} \cdot A_{63} + \\
& + A_{22} \cdot A_{41} \cdot A_{33} \cdot A_{65} - A_{22} \cdot A_{41} \cdot A_{35} \cdot A_{63} - A_{22} \cdot A_{33} \cdot A_{61} \cdot A_{45} + A_{22} \cdot A_{43} \cdot A_{61} \cdot A_{35} + \\
& + A_{31} \cdot A_{23} \cdot A_{43} \cdot A_{65} - A_{31} \cdot A_{23} \cdot A_{62} \cdot A_{45} - A_{31} \cdot A_{42} \cdot A_{25} \cdot A_{63} + A_{31} \cdot A_{25} \cdot A_{43} \cdot A_{62} - \\
& - A_{23} \cdot A_{32} \cdot A_{41} \cdot A_{65} + A_{23} \cdot A_{32} \cdot A_{61} \cdot A_{45} + A_{23} \cdot A_{41} \cdot A_{35} \cdot A_{62} - A_{23} \cdot A_{42} \cdot A_{61} \cdot A_{35} + \\
& + A_{32} \cdot A_{41} \cdot A_{25} \cdot A_{63} - A_{32} \cdot A_{25} \cdot A_{43} \cdot A_{61} - A_{41} \cdot A_{33} \cdot A_{25} \cdot A_{62} + A_{33} \cdot A_{42} \cdot A_{25} \cdot A_{61} - \\
& - A_{21} \cdot A_{32} \cdot A_{63} \cdot A_{49}\,, \\
C_4 = {} & A_{21} \cdot A_{32} \cdot A_{47} \cdot A_{65} + A_{21} \cdot A_{33} \cdot A_{62} \cdot A_{49} + A_{21} \cdot A_{42} \cdot A_{63} \cdot A_{39} - A_{21} \cdot A_{42} \cdot A_{37} \cdot A_{65} - \\
& - A_{21} \cdot A_{43} \cdot A_{62} \cdot A_{39} + A_{21} \cdot A_{43} \cdot A_{36} \cdot A_{65} - A_{21} \cdot A_{35} \cdot A_{62} \cdot A_{47} + A_{21} \cdot A_{62} \cdot A_{45} \cdot A_{37} - \\
& - A_{21} \cdot A_{36} \cdot A_{45} \cdot A_{63} + A_{22} \cdot A_{31} \cdot A_{63} \cdot A_{49} - A_{22} \cdot A_{31} \cdot A_{47} \cdot A_{65} - A_{22} \cdot A_{41} \cdot A_{63} \cdot A_{39} - \\
& + A_{22} \cdot A_{41} \cdot A_{37} \cdot A_{65} - A_{22} \cdot A_{33} \cdot A_{61} \cdot A_{49} + A_{22} \cdot A_{43} \cdot A_{61} \cdot A_{39} + A_{22} \cdot A_{61} \cdot A_{35} \cdot A_{47} - \\
& - A_{22} \cdot A_{61} \cdot A_{45} \cdot A_{37} - A_{31} \cdot A_{23} \cdot A_{62} \cdot A_{49} + A_{31} \cdot A_{42} \cdot A_{27} \cdot A_{65} - A_{31} \cdot A_{42} \cdot A_{63} \cdot A_{29} + \\
& + A_{31} \cdot A_{25} \cdot A_{62} \cdot A_{47} - A_{31} \cdot A_{43} \cdot A_{26} \cdot A_{65} + A_{31} \cdot A_{43} \cdot A_{29} \cdot A_{29} + A_{31} \cdot A_{26} \cdot A_{46} \cdot A_{63} - \\
& - A_{31} \cdot A_{62} \cdot A_{27} \cdot A_{45} + A_{23} \cdot A_{32} \cdot A_{61} \cdot A_{49} + A_{23} \cdot A_{41} \cdot A_{62} \cdot A_{39} - A_{23} \cdot A_{41} \cdot A_{36} \cdot A_{65} - \\
& - A_{23} \cdot A_{42} \cdot A_{61} \cdot A_{39} + A_{23} \cdot A_{61} \cdot A_{36} \cdot A_{45} - A_{32} \cdot A_{41} \cdot A_{27} \cdot A_{65} + A_{32} \cdot A_{41} \cdot A_{63} \cdot A_{29} - \\
& - A_{32} \cdot A_{25} \cdot A_{61} \cdot A_{47} - A_{32} \cdot A_{43} \cdot A_{61} \cdot A_{29} + A_{32} \cdot A_{61} \cdot A_{27} \cdot A_{45} + A_{41} \cdot A_{33} \cdot A_{26} \cdot A_{65} - \\
& - A_{41} \cdot A_{33} \cdot A_{62} \cdot A_{29} - A_{41} \cdot A_{25} \cdot A_{62} \cdot A_{37} + A_{41} \cdot A_{25} \cdot A_{36} \cdot A_{63} - A_{41} \cdot A_{26} \cdot A_{35} \cdot A_{63} + \\
& + A_{41} \cdot A_{35} \cdot A_{62} \cdot A_{27} + A_{33} \cdot A_{42} \cdot A_{61} \cdot A_{29} - A_{33} \cdot A_{61} \cdot A_{26} \cdot A_{45} + A_{42} \cdot A_{25} \cdot A_{61} \cdot A_{37} - \\
& - A_{42} \cdot A_{61} \cdot A_{35} \cdot A_{27} - A_{25} \cdot A_{43} \cdot A_{61} \cdot A_{36} + A_{43} \cdot A_{61} \cdot A_{26} \cdot A_{35}\,, \\
C_2 = {} & A_{21} \cdot A_{62} \cdot A_{39} \cdot A_{49} - A_{21} \cdot A_{62} \cdot A_{47} \cdot A_{39} - A_{21} \cdot A_{36} \cdot A_{63} \cdot A_{49} + A_{21} \cdot A_{36} \cdot A_{47} \cdot A_{65} - \\
& - A_{22} \cdot A_{61} \cdot A_{37} \cdot A_{49} + A_{22} \cdot A_{61} \cdot A_{47} \cdot A_{39} + A_{31} \cdot A_{26} \cdot A_{63} \cdot A_{49} - A_{31} \cdot A_{26} \cdot A_{47} \cdot A_{65} - \\
& - A_{31} \cdot A_{62} \cdot A_{27} \cdot A_{49} + A_{31} \cdot A_{62} \cdot A_{29} \cdot A_{47} + A_{23} \cdot A_{61} \cdot A_{36} \cdot A_{49} + A_{32} \cdot A_{61} \cdot A_{27} \cdot A_{49} - \\
& - A_{32} \cdot A_{61} \cdot A_{29} \cdot A_{47} - A_{41} \cdot A_{26} \cdot A_{63} \cdot A_{39} + A_{41} \cdot A_{26} \cdot A_{37} \cdot A_{65} + A_{41} \cdot A_{62} \cdot A_{27} \cdot A_{39} - \\
& - A_{41} \cdot A_{62} \cdot A_{37} \cdot A_{29} - A_{41} \cdot A_{27} \cdot A_{36} \cdot A_{65} + A_{41} \cdot A_{36} \cdot A_{63} \cdot A_{29} - A_{33} \cdot A_{61} \cdot A_{26} \cdot A_{49} - \\
& - A_{42} \cdot A_{61} \cdot A_{27} \cdot A_{39} + A_{42} \cdot A_{61} \cdot A_{37} \cdot A_{29} - A_{25} \cdot A_{61} \cdot A_{36} \cdot A_{47} + A_{43} \cdot A_{61} \cdot A_{26} \cdot A_{39} - \\
& - A_{43} \cdot A_{61} \cdot A_{36} \cdot A_{29} + A_{61} \cdot A_{26} \cdot A_{35} \cdot A_{47} - A_{61} \cdot A_{26} \cdot A_{45} \cdot A_{37} + A_{61} \cdot A_{27} \cdot A_{36} \cdot A_{45}\,, \\
C_0 = {} & A_{61} \cdot A_{26} \cdot A_{47} \cdot A_{39} - A_{61} \cdot A_{26} \cdot A_{37} \cdot A_{49} + A_{61} \cdot A_{27} \cdot A_{36} \cdot A_{49} - A_{61} \cdot A_{36} \cdot A_{29} \cdot A_{47}\,.
\end{aligned}
$$

The denominator of the transfer function (21), which represents the natural oscillations of the system via its determinant *D*, has two zero roots. And it indicates unequivocally that the non-isolated dynamic system under consideration (i.e. the combined tractor-implement unit) is unstable. Therefore, it makes no sense to discuss the stability criteria of Routh-Hurwitz, Mikhailov or Nyquist. Only after complementing the system of differential equations of motion of the said system (19) with a mathematical model of the driver, the stability of its motion can be taken into consideration.

The analysis of the controllability of motion of the studied tractor-implement unit will be carried out with the use of the following algorithm. Basing on the transfer function (21) and using the generally accepted methods of the dynamic system self-control theory, the respective characteristics of the amplitude-frequency (AFR) and phase-frequency (PFR) response to control inputs by the fertilising and sowing tractor-implement unit under consideration can be calculated. The former describes the rate of amplification of the input signal by the dynamic system, the latter represents the lag of its response to the said signal.

Since the examined tractor-implement unit, regarding its physical nature, is effectively a dynamic servo-system, its desirable (ideal) amplitude-frequency response (AFR) and phase-frequency response (PFR) are known a priori. Provided that the system responds to the oscillating control input within the working range of its frequencies, the mentioned characteristics must be as follows:

$$AFR = 1$$
$$PFR = 0$$

It has been shown by the previous fundamental scientific research that the working range of control input frequencies in case of agricultural tractor-implement units as dynamic servo-systems (designated ω) usually does not exceed 0.5 Hz (or 3.14 s^{-1}). Hence, the desirable (ideal) amplitude-frequency response of the tractor-implement unit must be equal to 1, when the frequency of oscillations of the angular displacement of the tractor's steering wheels stays within a range of up to 3.14 s^{-1}, and it must be equal to 0 outside that range. Physically, this implies that the heading angle of the power unit (as a response to the input control action) must be equal to the angular displacement of its steering wheels, i.e. $\varphi = \alpha$, when the frequency of oscillations of the input parameter α changes from $\omega = 0$ to $\omega = 3.14$ s^{-1}. In case of $\varphi > \alpha$ or $\varphi < \alpha$ we have, accordingly, the overcontrol or undercontrol of the dynamic system by the input signal, both of which are equally undesirable.

It is to be noted that the real amplitude-frequency response in most instances can be different from the desirable (ideal) one. But, the algorithm of mathematical modelling in those instances remains unequivocal and invariable. That is to say the diagrammatical design of the tractor-implement unit or the design-and-process property value, which delivers the actual amplitude-frequency response and phase-frequency response that are close to the ideal ones, will prevail.

With the use of the analytical mathematical model of the plane parallel motion of the combined fertilising and sowing tractor-implement unit developed by us, the controllability of the combined unit's motion can be estimated with regard to the influence of any if its parameters contained in the coefficients K and A_{ij} of the system of equations (19). But, at this stage of research the following parameters will be examined:

- coefficient of rolling resistance f of the running gear of the combine tractor as well as the fertiliser distributor and the grain drill. In the analytical mathematical model of the plane parallel motion of the combined fertilising and sowing tractor-implement unit the mentioned coefficient represents the forces that resist the rolling of its members: F'_{rf1}, F_{rf1}, F_{rf2} and F_{rf4};
- α_2, α_4– distances from the hitch points of the fertiliser distributor and the grain drill to their centres of mass (Figs 4, 6, 5);
- l_2, l_4 – lengths of the hitch frames of the fertiliser distributor and the grain drill.

As the masses of the towed implements (fertiliser distributor and grain drill) m_2 and m_4 are correlated with the traction force category of the employed tractor (in the considered case it is traction force category 1.4; Nadykto et al., 2015), this phase of research does not provide for the assessment of the effect that the change of these parameters has on the controllability of motion of the combined tractor-implement unit.

The analysis of the obtained phase-frequency response characteristics of the studied dynamic system has shown that the system's response lagging behind the control action is constant and equal to -180° or -3.14 rad (Fig. 2).

In general, such behaviour of the phase of the response to the control action is characteristic of conservative dynamic systems with virtually absent dissipative processes. Formally, the dynamic system under consideration is just such kind of system, since the effect of dissipative forces on it has been assumed to be insignificant.

The analysis of the obtained amplitude-frequency response calculation results proves the following. At the same control action oscillation frequency, the higher the coefficient of rolling resistance *f* is, the greater the rate of amplification of the said control input by the dynamic system will be (Fig. 3).

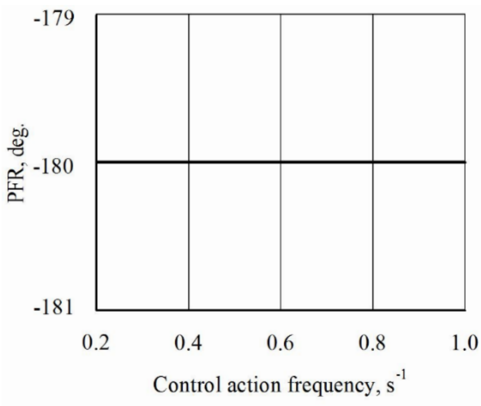

Figure 2. Phase-frequency characteristic of dynamic system's response to control action.

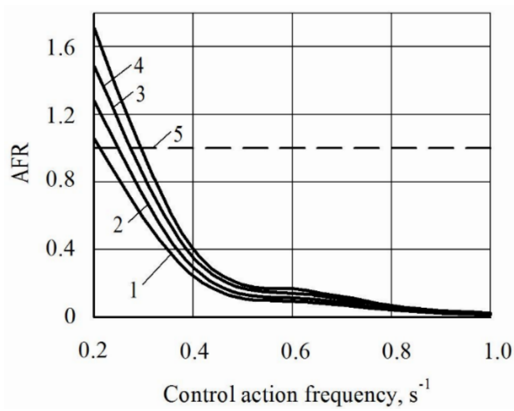

Figure 3. Amplitude-frequency characteristic of dynamic system's response to control action at different values of coefficient of rolling resistance: 1) 0.10; 2) 0.12; 3) 0.14; 4) 0.16; 5) desirable (ideal) amplitude-frequency characteristic.

For instance, when the combined fertilising and sowing tractor-implement unit advances on relatively firm agricultural background ($f = 0.10$, Graph 1 in Fig. 3), the angular displacement of the tractor's front steering wheels with a frequency of 0.2 s^{-1} gives rise to its response in the form of the heading angle change with a gain rate of 1.1. Meanwhile, when the tractor-implement unit in question operates on broken background ($f = 0.16$, Graph 4, Fig. 3, the rate of amplification of the examined input signal that has the same frequency (i.e. 0.2 s^{-1}) by the dynamic system (tractor) increases to a level of 1.7, thus more and more departing from the ideal state (Graph 5, Fig. 3).

With the increase of the frequency of angular displacement of the combine tractor steering wheels, the influence of the agricultural background, on which the combined tractor-implement unit travels, decreases. Under a condition of $\omega > 0.3$ s^{-1} the actual amplitude-frequency characteristics become lower than 1. The dynamic system under consideration shifts to the input signal undercontrol mode, which is undesirable.

At the same time, for each condition of the agricultural background represented by its value of the coefficient of rolling resistance *f*, such a desirable frequency of angular displacement of the combine tractor steering wheels (ω_0) exists, which provides for an actual amplitude-frequency characteristic meeting the requirements to the ideal one. The graphical interpretation of this relation is shown in Fig. 4.

It can be seen from the analysis of the graphically derived function ω_0 = f(*f*) that the control action oscillation frequency will vary within a range of 0.210…0.295 s^{-1}, depending on the agricultural background. It is to be stressed that the lower limit of the range (i.e. 0.21 s^{-1}) coincides with the frequency of angular displacement recommended by the researchers for the steering wheels of the combine tractor in the agricultural tractor-implement unit during its travel on the headland.

Obviously, it is rather problematic to maintain the required frequency ω_0 under the real practical conditions, if operating in the manual mode of power unit (tractor) control. At the present time, it is more reasonable to apply a GPS-navigator complete with an automatic manoeuvring system of the UniDrive type or some other one.

As it was already pointed out earlier, the controllability of motion of the combined tractor-implement unit under consideration can be to a certain extent influenced by its such design parameters as α_2 and l_2 (Figs 5, 4, 3). The first of them is essentially the length of the hitch frame, provided that the centre of mass of hitched fertiliser distributor 2 is situated close to its running gear axle. The second one defines the longitudinal coordinate of the point of connection of grain drill 4 to the combine tractor (Figs 1, 2, 3, 4).

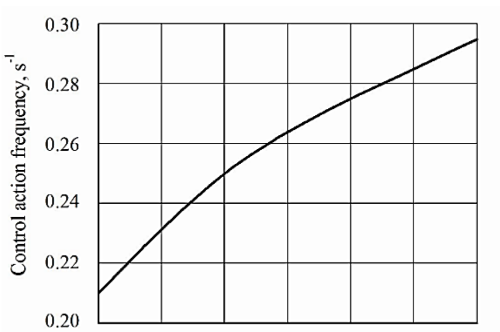

Figure 4. Relation between the desirable frequency of angular displacement of steering wheels of combine tractor in combined fertilising and sowing tractor-implement unit and the conditions of its motion (coefficient of rolling resistance *f*).

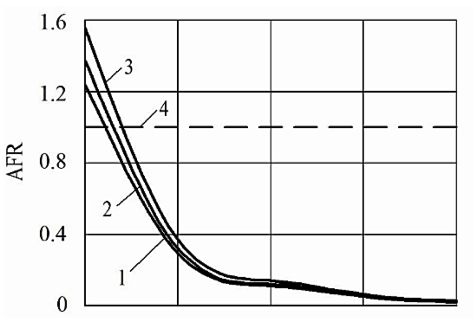

Figure 5. Amplitude-frequency characteristic of dynamic system's response to control action at different values of the design parameter α_2: 1) 1.15 m; 2) 2.15 m; 3) 3.15 m; 4) desirable (ideal) amplitude-frequency characteristic.

It is known from the towed machine dynamics theory that the best stability of the machine's plane parallel motion in the horizontal plane is achieved, when the parameters α_2 and l_2 are as great as possible. At the same time, the accordingly increased kinematic length of the combined unit implies the growth of the unit's non-productive time consumption during its manoeuvring on the headland. Taking that into account, a compromise solution with regard to the parameters α_2 and l_2 can be arrived at only following the assessment of their influence on the controllability of motion of the studied combined fertilising and sowing tractor-implement unit.

The analysis of the mathematical modelling results proves that the rise of the parameter α_2 from 1.15 m to 3.15 m produces: at control action oscillation frequencies of $\omega < 0.24$ s^{-1} – desirable, but at frequencies of $\omega \geq 0.3$ s^{-1} – undesirable decrease of the actual amplitude-frequency response (Fig. 5).

Thus, at $\omega = 0.2$ s^{-1} and $\alpha_2 = 3.15$ m the amplitude-frequency characteristic of the dynamic system's response to the control action is equal to 1.58 (Graph 1, Fig. 2). In practice this means that the heading angle β_1 of the tractor in the combined fertilising and sowing tractor-implement unit under consideration (Figs 2, 3, 4) will change with respect to the angular displacement α of its steering wheels with a gain rate of 1.58. In other words, the dynamic system will operate with an over-response to (i.e. excessive amplification of) the input signal at a surplus of 58%, which is also undesirable, as is known from the theory of dynamic servo-system self-control.

On the other hand, after reducing the parameter α_2 to 1.15 m, the indicated undesirable over-response will become more than two times smaller, as the amplitude-frequency characteristic of the dynamic system under consideration decreases to a level of 1.23 (Graph 3, Fig. 5).

When the frequency of oscillation of the angular displacement of the steering wheels of the power unit (tractor) is set at a level of $\omega = 0.3$ s^{-1}, the amplitude-frequency characteristic of the tractor-implement unit's response to the control action at $\alpha_2 = 1.15$ m is altogether ideal, i.e. equal to 1 (Graph 1, Fig. 5). Increasing the design parameter under consideration α_2 to 3.15 m at the same frequency ω will decrease the amplitude frequency characteristic to a level of 0.7 (Graph 3, Fig. 5). In this case the dynamic system replicates the control action with an under-response at a deficit of 30%, which is undesirable as well.

Only for the combine tractor steering wheel angular displacement oscillation frequencies ω in a range from 0.24 s^{-1} to 0.30 s^{-1} (Fig. 5) it is possible to select such a value of the design parameter α_2, which will facilitate the virtually ideal controllability of motion of the combined fertilising and sowing tractor-implement unit under consideration.

A similar, by its nature, conclusion can be reached with respect to the selection of the design parameter l_2 as well. What will be different is that the control action oscillation frequency range, within which the actual amplitude frequency response characteristics of the dynamic system (i.e. the combined fertilising and sowing tractor-implement unit under consideration) match the ideal ones, will be narrower. Analysing the curves in Fig. 6, it is possible to conclude that this range will span approximately from 0.23 to 0.26 s^{-1}.

While the increase of the design parameter α_2 results in the uniform behaviour of the respective amplitude frequency response characteristics of the dynamic system under consideration, the consequences of the same variation of the parameter l_2 are different. Thus, at a frequency of $\omega = 0.2\ s^{-1}$, for example, the amplitude frequency response characteristic f(α_2) is inversely correlating and almost linear (Graph 1, Fig. 7).

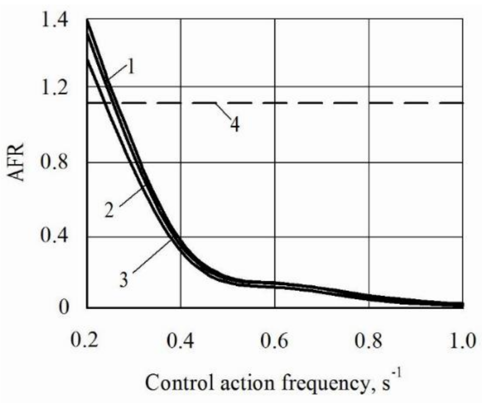

Figure 6. Amplitude-frequency characteristic of dynamic system's response to control action at different values of the design parameter l_2: 1) 3.15 m; 2) 2.15 m; 3) 4.15 m; 4) desirable (ideal) amplitude-frequency characteristic.

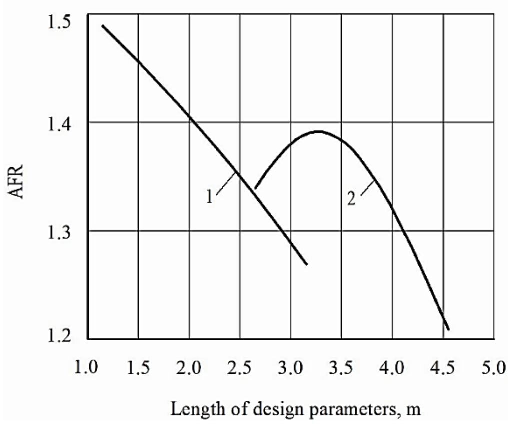

Figure 7. Amplitude-frequency characteristics of dynamic system's response to control action at a frequency of 0.2 s^{-1} at different values of the design parameters α_2 (1) and l_2 (2).

At the same time, the amplitude frequency response function f(l_2) at a frequency of $\omega = 0.2\ s^{-1}$ is curvilinear and to a certain extent approximates a parabolic curve (Graph 2, Fig. 7). This type of relation between the amplitude frequency response and the parameter l_2 continues, as it follows from the analysis of Fig. 6, with the increase of the combine tractor steering wheel angular displacement oscillation frequency until it reaches a level of at least 0.5 s^{-1}.

The behaviour of Graph 2 (Fig. 7) suggests that the preference in the selection of the parameter l_2 should be given to its greater values. In that event, the values of the actual amplitude frequency response of the dynamic system are closer to 1.

At the same time, the increased parameter l_2 results in the turn of grain drill 4 (Fig. 1) about fertiliser distributor 2 (Figs 1, 2, 3, 5) without their collision, when the combined tractor-implement unit travels on the headland. That eventually implies that raising the parameter l_2 is limited by the values that ensure the accident-free turning ability of the said combined tractor-implement unit.

Following the analysis of the results obtained by modelling the controlled motion of the combined fertilising and sowing tractor-implement unit in a horizontal plane, it becomes evident that the effect the design parameters α_4 and l_4 have on this process (Figs 2, 3, 4) is similar, in terms of both quality and quantity, to that of the parameters α_2 and l_2.

CONCLUSIONS

Thereby, after solving the obtained system of differential equations of the plane parallel motion of the combined fertilising and sowing tractor-implement unit with the use of the PC, the following final conclusions have been reached:

1. Depending on the cultivated field surface condition, the oscillation frequency of the control action, i.e. the angular displacement of the steering wheels of the combined tractor-implement unit under consideration, has to stay within a range of $\omega = 0.210 \ldots 0.295$ s^{-1}. At the same time, the greater values will be more appropriate for the operation of the tractor-implement unit on a looser agricultural background, the lower ones will better suit firmer backgrounds.

2. In order to provide for the better controllability of motion of the combined fertilising and sowing tractor-implement unit, the preference has to be given to greater values of the design parameters α_2, l_2 and l_4 (Figs 2, 3, 4). The limits for these values are stipulated by the requirement to ensure the accident-free turning ability of the fertiliser distributor with respect to both the combine tractor and the hitched grain drill.

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Theoretical research into the stability of motion of the ploughing tractor-implement unit operating on the 'push-pull' principle

V. Bulgakov[1], V. Adamchuk[2], V. Nadykto[3], O. Kistechok[3] and J. Olt[4,*]

[1]National University of Life and Environmental Sciences of Ukraine, 15, Heroyiv Oborony Str., UA 03041 Kyiv, Ukraine
[2]National Scientific Centre, Institute for Agricultural Engineering and Electrification, 11, Vokzalna Str., Glevaкha-1, Vasylkiv District, UA 08631 Kiev Region, Ukraine
[3]Tavria State Agrotechnological University, 18, B. Khmelnytsky Ave., UA 72312 Melitopol, Zaporozhye region, Ukraine
[4]Estonian University of Life Sciences, Institute of Technology, Kreutzwaldi 56, EE51014 Tartu, Estonia
[*]Correspondence: jyri.olt@emu.ee

Abstract. The reduction of power consumption in the ploughing operations can be achieved by way of improving the grip properties of the implement-carrying tractors, which is facilitated by setting up ploughing units for operation on the 'push-pull' principle. The aim of the current research is to substantiate the set-up and parameters of the ploughing unit with a front-mounted plough basing on the theoretical investigation of the stability of its motion in the horizontal plane. The methods of research include obtaining the amplitude- and phase-frequency response characteristics of the dynamic system in order to analyse the stability of its motion under the action of external statistically random perturbations. Also, the methods of software development and PC-based numerical computation are applied. The results of the study prove that the increase of the ploughing unit's travel speed results in the considerable rise of the gain of the amplitude of the tractor's heading angle oscillation in response to the oscillation of the angular displacement of the front-mounted plough in the horizontal plane. The phase-frequency response displays the same behaviour, changing substantially together with the unit's travel speed. Raising the coefficient of resistance to tyre slip of the tractor's rear wheels from 100 to 130 kPa and the front wheels from 140 to 175 kPa results in a minor decrease of the amplitude of oscillation of the tractor's heading angle φ. The ploughing unit has the best response to the input effect, i.e. the oscillation of the front-mounted plough's angular displacement β_p, when it operates using the 1+5 combination. The increase of the number of front-mounted plough bodies from 1 to 3 results in the substantial growth of the tractor's heading angle oscillation amplitude. Taking into account the way, in which the ploughing unit as a dynamic system responds to the input perturbance, the increase of its travel speed can be restricted not by the condition of its motion stability, but solely by the agrotechnical requirements applied to such a process operation as ploughing. The ploughing unit's motion stability substantially improves in case of higher air pressure in the tyres on the tractor's front and rear wheels. This effect is especially pronounced in the perturbance oscillation frequency range (0...1.5 s^{-1}) that covers the main part of its dispersion.

Key words: tractor, plough, push–pull, dynamic system, stability of motion.

INTRODUCTION

Ploughing as the main operation in the process of soil preparation requires considerable inputs of power, which stipulates the active search for ways to reduce them (Macmillan, 2002; Gil-Sierra et al., 2007; Mircea & Nicolae, 2014; Bulgakov et al., 2015; Nadykto et al., 2015). One of the steps towards this aim is the improvement of the combine tractor's grip properties by increasing its weight as part of the ploughing unit (hitched weight).

The numerous theoretical and experimental studies have shown that the needed increase of weight can be achieved, when setting up the ploughing tractor-implement unit, by combining ploughs with the tractor on the 'push-pull' principle. It has been found in the theoretical studies that the vertical component of the front-mounted plough's tractive resistance increases the weight acting on the front wheels, which means that the hitched weight of the tractor also increases. That results in the certain decrease of its wheel slipping as well as the reduction of the specific fuel consumption of the overall ploughing unit (Kopiks & Viesturs, 2010; Li et al., 2015; Xu et al., 2015; Bulgakov et al., 2016).

At the same time, the incorrect attachment of the front-mounted plough to the power unit can result in the situation, when instead of additionally loading the tractor's front wheels they will be partially released from load, leading to the inevitable loss of controllability and stability of the motion of the whole ploughing tractor-implement unit. It has been established by the theoretical studies (Kasymov & Zolotarev, 1988) that such a negative effect can be avoided, in case of a tractor with a nominal tractive effort rating of 30–32 kN, by using the front-mounted plough with two bodies and the rear-mounted plough with three bodies ('2+3' set-up). In this pattern, the tractor's right wheels roll in the furrow, the front-mounted plough is attached to the tractor in the horizontal plane and the carrier wheel of the ploughing implement is placed outside the furrow.

The ploughing tractor-implement unit under investigation operating on the 'push-pull' principle comprises a Class 3 combine tractor, a front-mounted two-body plough and a rear-mounted three-body plough (Fig. 1).

Figure 1. Tractor-implement unit operating on the 'push-pull' principle.

From among the possible alternatives for attaching the front-mounted ploughing implement to the wheeled combine tractor, the following two are taken into consideration: rigid and articulated attachment. For the analytical investigation we have chosen the second of the mentioned options. The preference for such a design solution can be explained by the fact that it allows the front-mounted ploughing implement to deflect aside in case of encountering a mechanical obstruction and thus prevent its damage. At the same time, in order to ensure the stable motion of the front-mounted implement, the instantaneous centre of turn of the combine tractor's front mounting mechanism shall be situated forward of the ploughing implement suspension axis (Bulgakov et al., 2016).

In this study, the physical object of investigation is a ploughing unit operating on the 'push-pull' principle with a front-mounted plough. Despite the fact that the motion of the combine tractor is performed with its right side wheels in the furrow, the articulated attachment of the ploughing implement at the front can cause stability problems not only with regard to its motion in the horizontal plane, but also to the ploughing tractor-implement unit overall (Larson et al., 1976; Molari et al., 2012; Kyurchev, 2014).

The paper is aimed at assessing the effect that the design and process parameters and the mode of operation of a ploughing tractor-implement unit operating on the 'push-pull' principle have on the stability of its motion just in case of the articulated attachment of the front-mounted plough to the combine tractor.

MATERIALS AND METHODS

The first step is the development of a mathematical model of functioning of the ploughing tractor-implement unit as a dynamic system, which will describe its response (reaction of the tractor's heading angle) to the input perturbing action. In the ploughing tractor-implement unit under consideration the said input is produced by the front-mounted plough, which deflects from the unit's line of travel through a certain angle, when it moves performing the work process of ploughing (Bulgakov et al., 2016).

For this purpose, at first an equivalent schematic model of the considered tractor-implement unit has to be developed. It is to be noted that the analytical mathematical model of a ploughing tractor-implement unit operating on the 'push-pull' principle, even if its linear version is assumed, will be represented by a system of rather complicated differential equations. For that reason, the following assumptions are made in order to simplify the generation of differential equations of motion for such a tractor-implement unit:

1) The field surface is horizontal, the ploughing unit has no fore-and-aft trim.

2) The redistribution of the vertical load between the sides of the combine tractor due to its tilt caused by the motion of its right wheels in the furrow is ignored.

3) The variation of the longitudinal components of the tractive resistance of the ploughing unit's front- and rear-mounted ploughs does not have any essential effect on its translational velocity, therefore, it is assumed constant.

4) The tyre slip angles of the combine tractor wheels situated on the same geometrical axis as well as the lateral forces applied to them are assumed sufficiently small.

5) It is supposed that the angular displacements of the combine tractor's steerable wheels are small enough to regard them as equal to each other.

Also, it is necessary to specify at the beginning the conditions of attachment of the front-mounted plough to the combine tractor. It is assumed that the front-mounted plough has an articulated connection to the tractor following the schematic model shown in Fig. 2. In this case, the 'Centre of Resistance' of the front-mounted ploughing implement is at point π, at which its tractive resistance force R_{pp} is also concentrated.

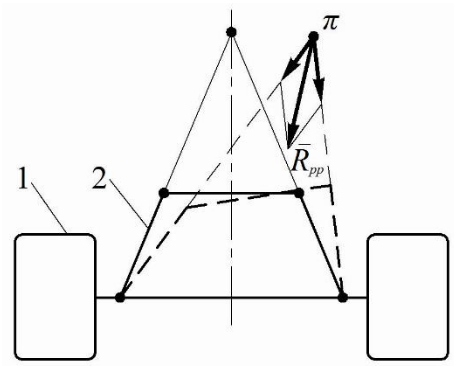


Figure 2. Schematic model of attachment of front-mounted plough to combine tractor: 1 – tractor's front axle; 2 – tractor's front mounting mechanism.

Taking into consideration the above-mentioned allowances, it is assumed that the ploughing tractor-implement unit performs uniform translational motion in the fixed plane $X_1O_1Y_1$ of the field surface at a velocity of V_o. The combine tractor's centre of mass (point S_T) is assigned the role of the origin for the moving frame of reference XOY. With respect to this frame, the power unit together with the ploughs mounted at its front and rear performs independent motions in the form of the translational displacement X_{S_T} and the course turning through an angle of φ.

The next step is to model the external forces acting on the ploughing tractor-implement unit under consideration in the horizontal plane. Apart from the already mentioned front-mounted plough resistance force R_{pp} deflected from the tractor's fore-and-aft axis S_TY_T through an angle of β_p, the following forces also act:

- The moving force F_B of the combine tractor's rear wheels applied at point B and making with its longitudinal symmetry axis a slip angle of δ_B;
- The moving force F_A of the power unit's front wheels applied at point A and deflected from the front running gear's direction of travel through a slip angle of δ_A;
- The lateral forces P_{BA} and P_{BB} applied at points A and B respectively;
- The rear-mounted plough resistance force R_{pz} deflected from the tractor's centreline through an angle of β_z.

Taking into account the above-stated considerations, the equivalent schematic model can be set up as shown in Fig. 3.

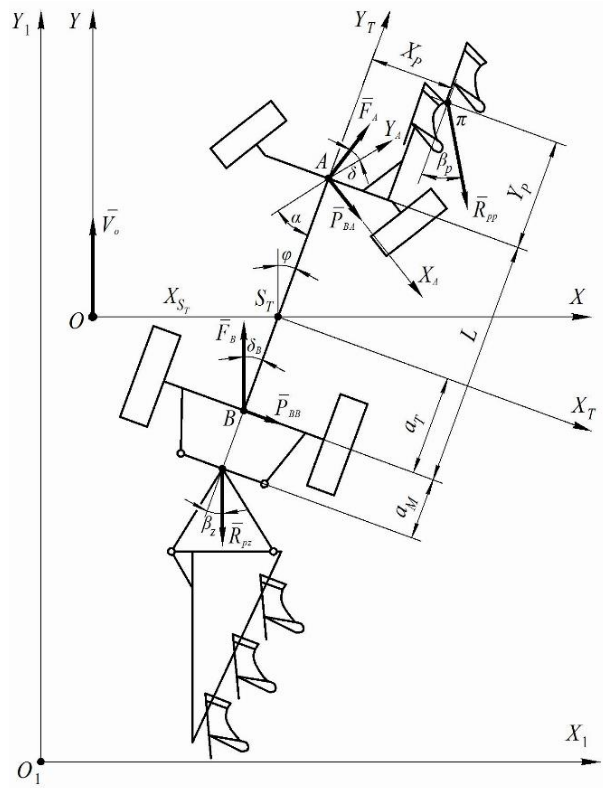


Figure 3. Equivalent schematic model of motion of ploughing tractor-implement unit operating on the 'push-pull' principle in the horizontal plane: S_T – mass centre of the combibe tractor; L – distance between S_T and A; a_T – distance between S_T and B; a_M – distance between B and hitching point.

In order to generate the differential equations of motion of the dynamic system under consideration, the original equations in the form of the Lagrange equations of the second kind are used in accordance with the assumed generalized coordinates X_{S_T} and φ. The result is as follows:

$$\left.\begin{aligned} \frac{d}{dt}\frac{\partial T_T}{\partial \dot{X}_{S_T}} - \frac{\partial T_T}{\partial X_{S_T}} = Q_{X_{S_T}}, \\ \frac{d}{dt}\frac{\partial T_T}{\partial \dot{\varphi}} - \frac{\partial T_T}{\partial \varphi} = Q_{\varphi}, \end{aligned}\right\} \quad (1)$$

where T_T – combine tractor's kinetic energy; $Q_{X_{S_T}}$, Q_{φ} – generalized forces on the respective generalized coordinates X_{S_T} and φ.

After determining the required values for the system (1), performing the necessary transformations and reductions, the analytical mathematical model of motion of a ploughing tractor-implement unit operating on the 'push-pull' principle in the horizontal plane becomes represented by the following system of two nonlinear differential equations:

$$\left.\begin{aligned} &A_{11}\cdot\ddot{X}_{S_T}+A_{12}\cdot\dot{X}_{S_T}+A_{13}\cdot\dot{\varphi}+A_{14}\cdot\varphi=f_{11}\cdot\alpha+f_{12}\cdot\beta_p+f_{13}\cdot\beta_z,\\ &A_{21}\cdot\ddot{\varphi}+A_{22}\cdot\dot{\varphi}+A_{23}\cdot\varphi+A_{24}\cdot\dot{X}_{S_T}=f_{21}\cdot\alpha+f_{22}\cdot\beta_p+f_{23}\cdot\beta_z+f_{24},\end{aligned}\right\}\qquad(2)$$

where

$A_{11}=M_A;$ $\quad f_{12(A,B)}=n_p\cdot b_k\cdot k_o\cdot h;$

$A_{12}=(k_A+k_B-F_A-F_B)\cdot V_o^{-1};$ $\quad f_{12(C)}=0;$

$A_{13}=[(k_A-F_A)\cdot(L-a_T)-(k_B-F_B)\cdot a_T]\cdot V_o^{-1};$ $\quad f_{13}=n_z\cdot b_k\cdot k_o\cdot h;$

$A_{14}=-A_{12}\cdot V_o;$ $\quad f_{21}=(L-a_T)\cdot k_A;$

$A_{21}=J_a;$ $\quad f_{22(A)}=n_p\cdot b_k\cdot k_o\cdot h\cdot(L-a_T+Y_P);$

$A_{22}=[(k_A-F_A)\cdot(L-a_T)^2+(k_B-F_B)\cdot a_T{}^2]\cdot V_o^{-1};$ $\quad f_{22(B)}=n_p\cdot b_k\cdot k_o\cdot h\cdot(L-a_T-Y_P);$

$A_{23}=-A_{13}\cdot V_o;$ $\quad f_{22(C)}=0;$

$A_{24}=A_{13};$ $\quad f_{23}=-n_z\cdot b_k\cdot k_o\cdot h\cdot(a_M+a_T);$

$f_{11}=k_A;$ $\quad f_{24}=n_p\cdot b_k\cdot k_o\cdot h\cdot X_P$

The following designations have been assigned in the system of differential equations (2): α – angle of turn of the combine tractor's steerable wheels, rad; M_A – mass of the unit, kg; k_A, k_B – coefficients of resistance to tyre slip of the combine tractor's front and rear wheels respectively, kN rad^{-1}; J_a – tractor-implement unit's moment of inertia about the vertical axis that passes through the point S_T, Nm s^2; n_p, n_z – number of bodies in the front- and rear-mounted ploughs respectively; b_k – width of plough body, m; k_o – coefficient of specific resistance of the ploughing unit, kN m^{-2}; h – ploughing depth, m; X_p, Y_p – coordinates of the front-mounted plough's centre of resistance, m; L, a_T, a_M – design parameters, m (Fig. 3).

One of the perturbations for the straight-line motion of the ploughing tractor-implement unit is the front-mounted plough's angular displacement β_p. Response of the dynamic system to the said perturbation is assumed to be represented by the change of the combine tractor's heading angle φ.

In order to simplify the solution of the differential equation system (2) with the use of a PC, the Laplace transformations are used, which imply changing from the original function to its respective transforms by introducing the special operator $p=\frac{d}{dt}$. That enables switching from the complex system of differential equations to a relatively simple system of algebraic equations.

In this particular case, after performing the described transformations, the differential equation system (2), i.e. the analytical mathematical model of the ploughing tractor-implement unit operating on the 'push-pull' principle, in the operator format will appear as follows:

$$\left.\begin{aligned} K_{11} \cdot X_{S_T}(p) + K_{12} \cdot \varphi(p) = F_{11} \cdot \alpha(p) + F_{12} \cdot \beta_p(p) + F_{13} \cdot \beta_z(p) + F_{14} \cdot 1(p), \\ K_{21} \cdot X_{S_T}(p) + K_{22} \cdot \varphi(p) = F_{21} \cdot \alpha(p) + F_{22} \cdot \beta_p(p) + F_{23} \cdot \beta_z(p) + F_{24} \cdot 1(p), \end{aligned}\right\} \quad (3)$$

where $K_{11} = A_{11} \cdot p^2 + A_{12} \cdot p$; $K_{12} = A_{13} \cdot p + A_{14}$; $K_{21} = A_{24} \cdot p$; $K_{22} = A_{21} \cdot p^2 + A_{22} \cdot p + A_{23}$; $F_{11} = f_{11}$; $F_{12} = f_{12}$; $F_{13} = f_{13}$; $F_{14} = 0$; $F_{21} = f_{21}$ $F_{22} = f_{22}$; $F_{23} = f_{23}$; $F_{24} = f_{24}$; $1(p)$ – unit step transform of the input parameter.

The following parameters act as the input variables in the system of equations (3):

– control input in the form of the combine tractor steerable wheel's turn angle (α);
– angular displacement β_p of front-mounted plough in the horizontal plane;
– angular displacement β_z of rear-mounted plough in the horizontal plane;
– turn-around moment $R_{pp} \cdot X_p$, represented by factor f_{24} in the differential equation system (2).

The following are the output parameters of functioning of the dynamic system under consideration, i.e. the discussed tractor-implement unit:

– transverse offset X_{S_T} of the combine tractor's centre of mass;
– combine tractor's heading angle φ.

For the analytical investigation of the dynamic system under consideration, i.e. the studied tractor-implement unit operating on the 'push-pull' principle, when it performs the work process of ploughing, the most important issue is the system's behaviour in the presence (or absence) of variation of the angular displacement (β_p) of the front-mounted plough in the horizontal plane.

Therefore, in order to analyse the variation of the mentioned angular displacement (β_p), it is necessary to generate the corresponding transfer function. In order to generate the mentioned transfer function, use will be made of the polynomial known from the automatic control theory, which in its most general form appears as follows:

$$W(p) = \frac{F_m \cdot p^m + F_{m-1} \cdot p^{m-1} + \ldots + F_1 \cdot p + F_o}{C_n \cdot p^n + C_{n-1} \cdot p^{n-1} + \ldots + C_1 \cdot p + C_o} \quad (4)$$

where F_m, C_n – factors of the numerator and denominator of the transfer function defined by the kinematic and design parameters of automatic control system under study; m and n – indexes of the equations.

Later, when using the expression (4), the coefficients F_m and C_n will be derived from the analytical mathematical model of the ploughing tractor-implement unit under examination.

In order to assess the stability of motion of the ploughing tractor-implement unit operating on the 'push-pull' principle, the transfer function $W_{\beta p}(p)$ can be used, which represents the ratio between the front-mounted plough's angular displacement β_p and the combine tractor's heading angle φ. Expressly:

$$W_{\beta p}(p) = \frac{D_{\beta p}}{D} \quad (5)$$

where $D_{\beta p}$ – determinant that defines the angular displacement β_p of the front-mounted plough in the horizontal plane; D – general determinant of the system of equations (3).

The components of the expression (5) have to be found. The determinants are obtained in the form of 2×2 matrices, which appear as follows:

$$D_{\beta p} = \begin{vmatrix} K_{11} & F_{12} \\ K_{21} & F_{22} \end{vmatrix} \tag{6}$$

$$D = \begin{vmatrix} K_{11} & K_{12} \\ K_{21} & K_{22} \end{vmatrix} \tag{7}$$

The elements of the determinants (6) and (7) are constituents of the system of equations (3). In this context, the determinant $D_{\beta p}$ defined by the expression (6) is obtained by replacing the column of the coefficients K_{12} and K_{22} related to the output variable φ with the column of the coefficients F_{12} and F_{22} related to the input variable β_p – angular displacement of the front-mounted plough in the horizontal plane. The determinant D defined by the expression (7) is composed of the coefficients in the left-hand side of the system of equations (3).

After expanding the determinants (6) and (7) and substituting their values into (5), the final representation of the transfer function $[W_{\beta p}(p)]$ is obtained:

$$W_{\beta p}(p) = \frac{F_1 \cdot p + F_o}{p\left(C_2 \cdot p^2 + C_1 \cdot p + C_o\right)}, \tag{8}$$

where $F_1 = f_{22} \cdot A_{11}$; $F_o = f_{22} \cdot A_{12} - f_{12} \cdot A_{24}$; $C_2 = A_{11} \cdot A_{21}$; $C_1 = A_{12} \cdot A_{21} + A_{11} \cdot A_{22}$; $C_o = A_{12} \cdot A_{22} + A_{11} \cdot A_{23} - A_{13} \cdot A_{24}$; p – differentiation operator.

The next step is to determine the perturbations in the form of a unit step function. For this purpose, it is necessary to form its transfer function $W_1(p)$, and, in order to achieve that, again, the initial expression (4) will be used. In the discussed case the transfer function $W_1(p)$ is a representation of the sudden and instantaneous change of the turn-around moment created by the front-mounted plough's resistance force R_{pp}. The analysis will be based on the conditions of the said turn-around moment's effect on the combine tractor's heading angle φ. The transfer function in this case appears as follows:

$$W_1(p) = \frac{D_M}{D}. \tag{9}$$

where

$$D_M = \begin{vmatrix} K_{11} & 0 \\ K_{21} & F_{24} \end{vmatrix} \tag{10}$$

And the determinant D that appears in the expression (9) is the determinant defined by the expression (7). After expanding the determinant (10), applying and expanding the determinant (7) and substituting their values into (9), the final representation of the transfer function $W_1(p)$ of the following form is obtained:

$$W_1(p) = \frac{F_1 \cdot p + F_o}{C_2 \cdot p^2 + C_1 \cdot p + C_o}. \tag{11}$$

Meanwhile, it is to be noted that the automatic control theory states that the dynamic system responds to the input action in the form of a unit step function as a simple amplifying circuit. Since $p = i \cdot \varpi = 0$ in this case, then the final result is the transfer function of perturbations $W_1(p)$ of the following appearance:

$$W_1(p) = \frac{F_o'}{C_o}, \tag{12}$$

where $F_o' = f_{24} \cdot A_{12}$; $C_o = A_{12} \cdot A_{22} + A_{11} \cdot A_{23} - A_{13} \cdot A_{24}$.

Meanwhile, F_0' is the solution of the determinant D_M, which was defined by the expression (10). The next phase is the determining of the respective amplitude-frequency response and phase-frequency response characteristics. If in (8) the value $i \cdot \omega$ (where $i = \sqrt{-1}$ and ω – frequency of the perturbing action) is substituted for the differentiation operator *p*, then it becomes possible to obtain expressions for the real and imaginary frequency responses of the dynamic system under consideration. That is:

$$U(\omega) = \frac{M \cdot M_1 + N \cdot N_1}{M_1^2 + N_1^2} = R_e, \tag{13}$$

$$V(\omega) = \frac{M_1 \cdot N - M \cdot N_1}{M_1^2 + N_1^2} = I_m, \tag{14}$$

where $M = F_o - F_2 \cdot \omega^2 + F_4 \cdot \omega^4 - ....$; $N = F_1 \cdot \omega - F_3 \cdot \omega^3 + F_5 \cdot \omega^5 - ....$;

$M_1 = C_o - C_2 \cdot \omega^2 + C_4 \cdot \omega^4 - ....$; $N_1 = C_1 \cdot \omega - C_3 \cdot \omega^3 + C_5 \cdot \omega^5 - .....$

The coefficients of the real and imaginary components of the transfer function *M*, *N* and M_1, N_1 are presented in their general form. The specific values of these coefficients are determined after expanding the transfer functions (8) and (12).

In the case of the ploughing tractor-implement unit under study, the mentioned coefficients for the transfer function (8) are as follows: $M = F_o - F_2 \cdot \omega^2$; $N = F_1 \cdot \omega - F_3 \cdot \omega^3$; $M_1 = C_o - C_2 \cdot \omega^2$; $N_1 = C_1 \cdot \omega - C_3 \cdot \omega^3$. For the transfer function (12) the coefficients have the following values: $M = F_o$; $N = 0$; $M_1 = C_o$; $N_1 = 0$. Hence, the imaginary part of the frequency response (12) is equal to null.

At the same time, the values F_o, F_1, F_3, C_o, C_1, C_2 and C_3 represent in this expression the combination of the coefficients appearing in the transfer function (8) and found from the system of equations (3).

Thus, the desired amplitude-frequency response characteristic can be found from the following expression:

$$A(\omega) = \left[U(\omega)^2 + V(\omega)^2\right]^{\frac{1}{2}}. \tag{15}$$

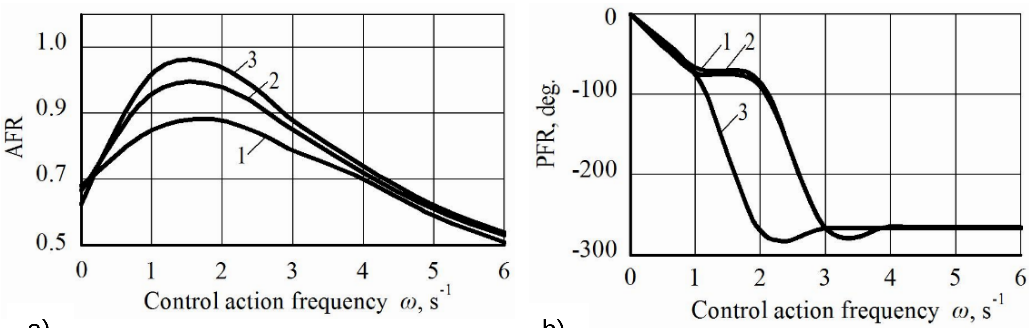
Applying the expression (15) with the use of the standard computer programmes on a PC, the computation of the amplitude-frequency response characteristics of the ploughing tractor-implement unit under consideration has been performed.

The phase-frequency response characteristic can be estimated using the methods described in (Klujev, 1986). It should be noted that this analytical study analyses the response of the dynamic system, i.e. the ploughing tractor-implement unit, to the perturbing actions. In accordance with the automatic control theory, the most desirable amplitude-frequency response in the case under consideration is the smallest possible response. On the other hand, the phase shift or else phase-frequency response has to have as high a value as possible. Ideally, the phase-frequency response characteristic has to go to infinity.

RESULTS AND DISCUSSION

The assessed indices of the motion stability of the dynamic system under consideration, i.e. the ploughing tractor-implement unit, are the characteristics of its amplitude- and phase-frequency response to the external perturbing action (amplitude of oscillation of the angle β_p) obtained from the numerical calculations carried out by us with the use of a PC.

The analysis of the derived amplitude-frequency response characteristics shows that the increase of the velocity V_o of the working motion of the ploughing tractor-implement unit is followed by a significant rise of the factor of the power unit heading angle φ oscillation amplitude gain under the effect of the oscillation of the angular displacement β_p of the front-mounted ploughing implement in the horizontal plane, which is undesirable. Moreover, this rise becomes more intensive at $V_o = 2.0$ m s^{-1} (Fig. 4).



a) b)

Figure 4. Amplitude- (AFR) – a) and phase- (PFR) – b) frequency response of dynamic system to oscillation of angular displacement β_p of front-mounted plough at different velocities V_o of working motion of ploughing tractor-implement unit: 1) 1.5 m s^{-1}; 2) 2.0 m s^{-1}; 3) 2.5 m s^{-1}.

The same intensity of change in relation to the velocity V_o of the ploughing unit's working motion is also observed in the phase-frequency response characteristics of the dynamic system. Only at $V_o = 2.5$ m s^{-1} they are completely different from those obtained for the velocity ratings up to 2.0 m s^{-1} (Fig. 4).

On the other hand, this difference is observed only within a very limited range of frequencies of the perturbing action: 1...3 s^{-1}. Moreover, when a follow-up dynamic system (the dynamic system under consideration falls exactly into that category of systems) responds to a perturbation, it is more important how it responds to the amplitude of the input action rather than to its phase. Analysing the obtained amplitude-frequency response characteristics from that point of view, it can be concluded that the undesirable increase of the amplitude of the combine tractor's heading angle φ takes place in the same range of perturbation frequencies: 1...3 s^{-1}. The following analysis will show, whether the growth of the amplitude-frequency response is substantial or not.

The process velocity of the working motion of up-to-date ploughing tractor-implement units reaches 2.0...2.5 m s^{-1}. It can be seen from the diagrams in Fig. 4 that, when V_o increases from 2.0 to 2.5 m s^{-1}, the amplitude-frequency response of the ploughing unit to the perturbing action rises maximum by mere 5% at $\omega = 1.5$ s^{-1}.

Generally, such a rise is insignificant, therefore, the increase of the travel speed V_o of the ploughing unit under consideration may be restricted not by the requirements of its motion stability, but solely by the agrotechnical requirements applied to such a process operation as ploughing.

The following issue to be analysed is how the amplitude-frequency response and phase-frequency response of the dynamic system depend on the air pressure in the combine tractor's tyres. The calculations show that the increase of this parameter in the power unit's rear running gear from 100 to 130 kPa, in the front running gear – from 140 to 175 kPa results in the reduction of its heading angle (φ) oscillation amplitude. The effect is especially pronounced in a perturbation frequency range of 0...1.5 s^{-1} (Fig. 5). According to the data obtained by us earlier, this is exactly the range of frequencies (0.5...1.5 s^{-1}), where the major part of the ploughs' angular displacement oscillation dispersion is concentrated.

The reached result is explained by the fact that the increase of the air pressure in the tyres results in the higher values of their slip resistance coefficients. That means that the tyres on the running wheels become stiffer and more resistant to the action of lateral forces.

The mentioned range of ω (i.e. 0...1.5 s^{-1}) features also the desirable behaviour of the phase-frequency response in case of increasing the parameters ρ_{sA} and ρ_{sB}. Moreover, when the tyre air pressure is maximum, the dynamic system under consideration changes from a minimum-phase element into a nonminimum-phase element, which follows from the appearance of its phase-frequency response characteristic (Curve 2, Fig. 5). The causes of such a result need a separate investigation.

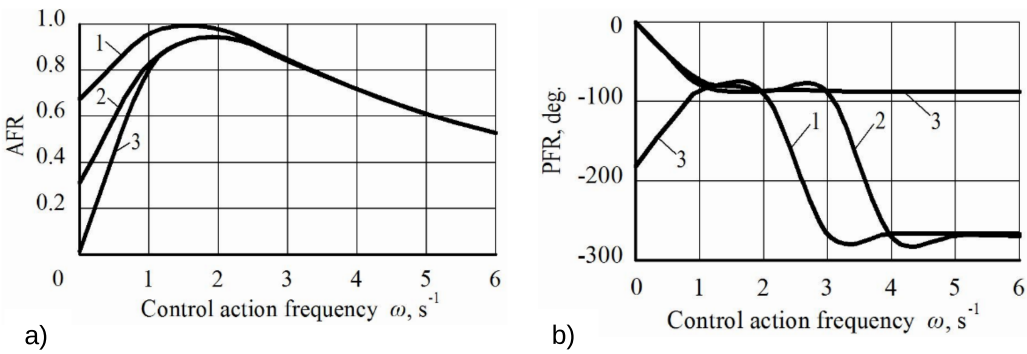


Figure 5. Amplitude- (AFR) – a) and phase- (PFR) – b) frequency response of dynamic system to oscillation of angular displacement of front-mounted plough at different pressures in front (ρ_{sB}) and rear (ρ_{sA}) wheel tyres of tractor: 1) ρ_{sB} = 100 kPa; ρ_{sA} = 140 kPa; 2) ρ_{sB} = 115 kPa; ρ_{sA} = 155 kPa; 3) ρ_{sB} = 130 kPa; ρ_{sA} = 175 kPa.

All the analysis above is concerned with the stability of motion of a ploughing tractor-implement unit under the condition of combining a front-mounted plough with two bodies (n_p = 2). A logical question arises, how the dynamic system's response to the perturbing action will change in case of n_p = 1 and n_z = 3.

The analysis of the mathematical modelling data shows that the ploughing tractor-implement unit has the best response to the input effect, i.e. the oscillation of the front-mounted plough's angular displacement β_ρ, when the combination pattern is '1+5'. The worst amplitude-frequency response is observed, when implementing the tractor-implement unit that operates with the use of the pattern ‘3+3’. The increase of the number of front-mounted ploughing implement bodies from 1 to 3 results in the significant growth of the amplitude of oscillation of the combine tractor’s heading angle φ. Thus, at a frequency of ω = 1.5 s^{-1} the perturbing action gain shows undesirable growth, increasing almost seven-fold (Curves 1 and 3, Fig. 6).

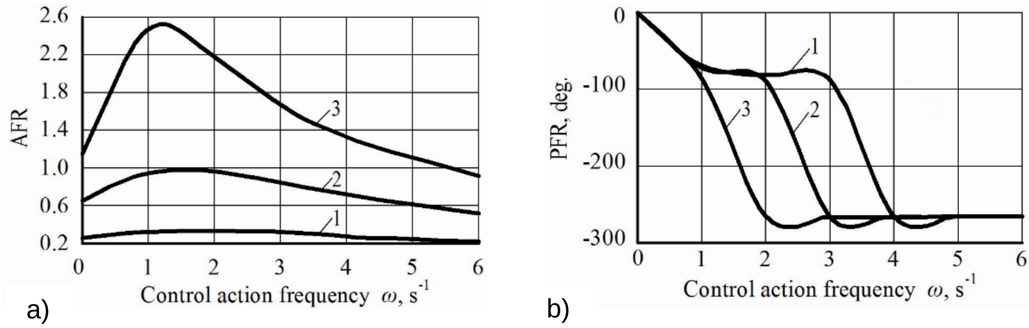


Figure 6. Amplitude- (AFR) – a) and phase- (PFR) – b) frequency response of dynamic system to oscillation of angular displacement of front-mounted plough at different combination patterns of plough bodies in front-mounted and rear-mounted ploughing implements: 1) ‘1+5’; 2) ‘2+4’; 3) ‘3+3’.

At the same time, in case of the ploughing unit that operates on the pattern ‘2+4’, the gain of the dynamic system responding to the input perturbation within the whole range of its oscillation does not exceed unity (Curve 2, Fig. 6), which can be quite acceptable.

The phase-frequency response characteristics closest to the desirable ones have been found in the case of the ploughing tractor-implement unit that operates using the pattern ‘3+3’. But, firstly, that takes place only in a relatively narrow range of frequencies: 1.2 ... 2.8 s^{-1}. Secondly, the said range of frequencies contains an insignificant fraction of the dispersion of such a perturbing action as the plough’s angular displacement in the horizontal plane. Overall, that indicates unequivocally the inexpediency of implementing a ploughing unit that operates on the pattern ‘3+3’.

CONCLUSIONS

When the velocity of motion of a ploughing unit, in which the instantaneous centre of turn of the tractor’s front mounting mechanism is offset forward, increases, the amplitude frequency response of the dynamic system to the perturbing action represented by the front-mounted plough’s angular displacement in the horizontal plane deteriorates, but the phase frequency response, contrarily, improves. However, since the undesirable change of the amplitude frequency response, in terms of quantity, is inessential, then the increase of the travel speed of the ploughing tractor-implement unit under consideration can be restricted not by the condition of its motion stability, but solely by the agrotechnical requirements to the performance of such a process operation as ploughing.

The stability of motion of the ploughing tractor-implement unit substantially improves, when the air pressure in the tyres on the combine tractor's front and rear running gear is made higher. This effect is especially pronounced in the perturbing action oscillation frequency range (0...1.5 s^{-1}) that covers the main part of its dispersion.

The increase of the number of bodies in the front-mounted plough from 1 to 3 causes the substantial growth of the amplitude of the combine tractor heading angle oscillation. That said, the implementation of a ploughing unit set up on the pattern '2+4' results in the dynamic system that responds to the input perturbing action within the whole range of its oscillation at a gain not exceeding 1, which is totally acceptable.

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Influence of shape of cutting tool on pressure conditions in workspace of mulcher with vertical axis of rotation

J. Čedík[1,*], J. Chyba[2], M. Pexa[1] and S. Petrásek[2]

[1]Czech University of Life Sciences, Faculty of Engineering, Department for Quality and Dependability of Machines, Kamýcká 129, CZ16521, Prague 6, Czech Republic
[2]Czech University of Life Sciences, Faculty of Engineering, Department of Agricultural Machines, Kamýcká 129, CZ16521, Prague 6, Czech Republic
[*]Correspondence: cedikj@tf.czu.cz

Abstract. Nowadays there is laid great insistence on work efficiency improvement. This effort also affects the construction of mowers such as mulchers. Mulching with a vertical axis of rotation is very energy demanding work operation mainly, due to high energy losses. These energy losses, but also the quality of work, are influenced by the airflow and associated conditions of pressure inside the workspace of mulcher. Airflow in the workspace ensures repetitious contact of the truncated forage crops with the cutting edge tool and thus ensures crushing of aboveground parts of plants. The paper deals with the influence of the cutting tool shape on the mulcher's inside workspace pressure conditions with the vertical axis of rotation. The influence of the trailing edge angle and rake angle on the pressure profile in the mulcher's workspace with dependence on the rotor speed was examined. Measurements were performed on a laboratory single rotor mulcher model. It was found that in the mulcher's workspace the vacuum is formed by virtue of the rotary movement of the cutting tools wherein the vacuum increases with rotor speed. The maximum measured vacuum was about 2.4 kPa and from the centre of the rotor towards its circumference almost linearly decreases. Furthermore, it was found that with decreasing trailing edge angle and with increasing rake angle the maximum vacuum decreases. When reducing the angle of the trailing edge from 45° to 25° led to reduction of vacuum of about 0.3 kPa (12.6%).

Key words: mulcher, pressure, airflow, cutting tool.

INTRODUCTION

Mulching is a technological process during which crushed plant residues are left on the soil surface. It is primarily used for cutting and crushing green plant residues, old grass on permanent grasslands and for treatment of fallow lands. Mulching can also be used for crushing crop residues on the arable land (Mayer & Vlášková, 2007; Syrový et al., 2013).

Mulchers with vertical axis of rotation in its principle rank among rotational mowers. Power requirement of rotational mowers can be dependent according to work conditions, method of use and its construction. Literature deals with power requirement in range of 3.53.5–23 kW m^{-1} (kW per meter of the working width of the machine) (McRandal & McNulty, 1978; Tuck et al., 1991; Srivastava et al., 2006; Syrový et al., 2008; ASABE D497.7, 2011; Čedík et al., 2015; Kumhála et al., 2016) while the mulchers reach a very high values of power requirement. Air flow and associated pressure conditions inside the workspace of mulcher (ie. ventilation effect) is very important for the energy demands and quality of work of mulcher (Chon et al., 1999a; 1999b). Direction and speed of air flow have an influence on relative speed of air and tool and thus influences aerodynamic resistance and also repeated contact of plant matter with tool, which lead to the perfect crushing of plant matter. Air flow and pressure conditions in workspace of mulcher also influence uniform dispersion of crushed plant matter in the whole working width of machine (Čedík, 2016; Čedík et al., 2016a; 2016b).

Direction and speed of the air flow are influenced by cutting speed. The mower's cutting speed is normally in range of 71–84 m s^{-1} (O'Dogherty, 1982; Jun et al., 2006). Srivastava et al. (2006) stated that in dependence on the cutting tool sharpness the cutting speed should be in the range of 50–75 m s^{-1} for reliable function. From the results of other authors (Hosseini & Shamsi, 2012; Kakahy et al., 2014) it is evident that the optimization of the cutting speed and the cutting tool shape can significantly reduce the power consumption.

The cutting tool shape, primarily the trailing edge angle (Fig. 1), is important factor influencing the pressure conditions and air flow inside the mulcher's workspace. Chon & Amano (2004) with the aid of a mathematical model found that high pressure is formed in the space above the cutting tool, whereas low pressure is formed in the area below the cutting tool. The highest pressure is then generated on the front edge of the cutting tool. Steady flow in the workspace and reduced power consumption can be achieved by optimization of cutting tool in terms of aerodynamics (Zu et al., 2011). Jun et al. (2008) concluded that for reliable function of side-discharge of mower is required a minimum trailing edge angle of 20°. Hagen et al. (2002) stated that the shape of the cutting tool has equal importance as the shape of the covering of mulcher in terms of air flow. Another important parameter of the cutting tool shape is the rake angle. In the literature the rake angle have been studied mainly from viewpoint of its effect on energy of cut in the range 0–50°. The most effective cut was found within the range 15°–30° (O'Dogherty & Gale, 1986; O'Dogherty & Gale, 1991; Kakahy et al., 2012; Kakahy et al., 2013). McRandal & McNulty (1980) states that the blade rake angle is significant for the resistance to penetration of both stem and leaf. Hoseinzadeh et al. (2009) reached the lowest shearing energy of wheat with the rake angle of 25°.

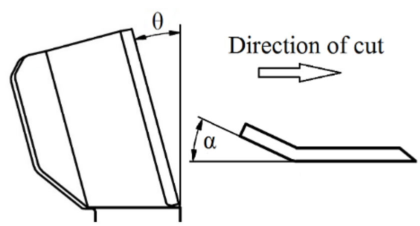

Figure 1. Schematically ilustrated angles on the cutting tool – rake angle (θ) and trailing edge angle (α).

The aim of this paper is to experimentally determine the effect of the cutting tool shape, in particular, the rake angle and the trailing edge angle on the pressure conditions inside the workspace of mulcher with vertical axis of rotation.

MATERIALS AND METHODS

The measurement was carried out under laboratory conditions at the Department of Agricultural Machines at Czech University of Life Sciences Prague. In order to determine the influence of the cutting tool shape on the pressure conditions inside the workspace of the mulcher, a laboratory model of a single mulcher rotor was used. This model was based on the working mechanism of three-rotor mulchers MZ 6000 produced by the BEDNAR FMT, Ltd company. The working speed of the mulcher's MZ 6000 rotors is 1,000 rpm. To drive the rotor with a diameter of 2 m an asynchronous electromotor MEZ with output of 22 kW was used. The speed of the electromotor was controlled by a frequency converter (Siemens). The laboratory model of the mulcher is shown in Fig. 2.

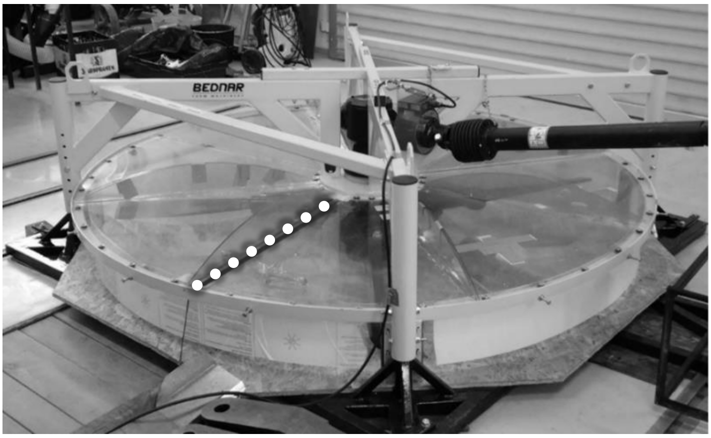

Figure 2. Laboratory model of one mulcher rotor with highlited position of the pressure sensors by dotted line.

In order to determine the influence of cutting tool shape, tools with different rake angles of 0°, 15° and 25° (Fig. 3) and a trailing edge angle of 35° and 25° were produced. The values of the rake angle were chosen based on the literature review. The values of trailing edge angles were chosen lower than original in order to lower aerodynamics resistance of the tools (Čedík et al, 2016b). Tools were made of carbon steel. As a reference, the original cutting tool (rake angle = 0°, the trailing edge angle = 45°) was used. Tools are referred to as rake angle X trailing edge angle (e.g 15X25 – rake angle of 15° and a trailing edge angle of 25°).

To measure the pressure conditions in the workspace of mulcher the strain gauge pressure sensors were used. The sensors in the form of strips were installed radially to the axis of rotation on the upper covering of mulcher model (Figs 2 and 4). On the strips the individual measuring elements are located with spacing of 10 mm. The sensors were produced by Association for Research and Education, Ltd. Three strips placed in series were used for measurement. Parameters of the sensors, provided by the manufacturer, are shown in Table 1. Data from the pressure sensors were stored on the PC's hard drive with a frequency of 2.5 Hz. Between the measurements the zeroing of the sensors was done by means of external pressure sensor, provided by manufacturer.

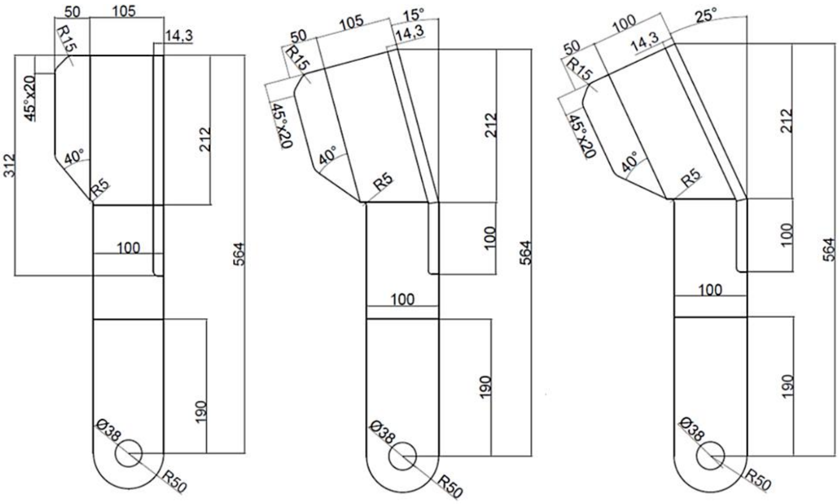

Figure 3. Proposed cutting tools with different rake angle (from left: 0°, 15°, 25°; dimensions in mm).

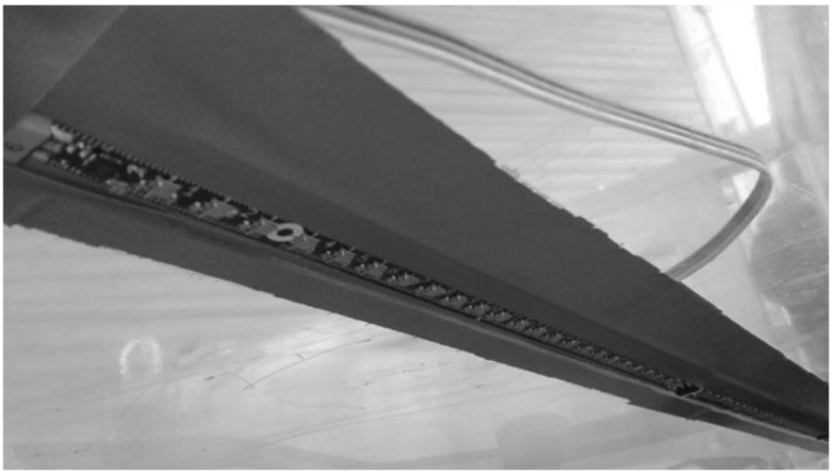

Figure 4. Pressure sensors in the form of strips.

Measurements were carried out at rotor speeds of 200, 400, 600, 800 and 1,000 rpm which correspond to cutting speeds of 21, 42, 63, 84 and 105 m s^{-1} respectively. For safety reasons it was not possible to reach 1,000 rpm (105 m s^{-1}) for all measured variants because the vibration acceleration of the frame's central part of the rotor reached up to 12 g.

Table 1. Parameters of the used pressure sensors

Pressure range	93–107 kPa
Temperature range	15–40 °C
Sampling frequency	10 Hz
Accuracy	< 10 Pa
Nonlinearity and hysteresis	< 8 Pa
Noise	± 5 Pa

RESULTS AND DISCUSSION

Fig. 5 shows the dependence of the average values of the pressure inside the workspace of mulcher on the distance from the rotation axis of the rotor for the original cutting tools (0X45).

From Fig. 5 it is clear that the pressure in dependence on speed decreases from the periphery towards the centre of the rotor almost linearly. This phenomenon occurs most likely due to centrifugal forces of the rotating air volume. The pressure values may also to some extent be influenced by the position of the sensors, which are always on the inside of the top cover. Chon & Amano (2004) also measured the lowest pressure at the centre of the rotor of municipal mower, caused by centrifugal forces. This result also agrees with Chon & Amano (2003) who stated that the air flow velocity increases from the rotor centre to its periphery.

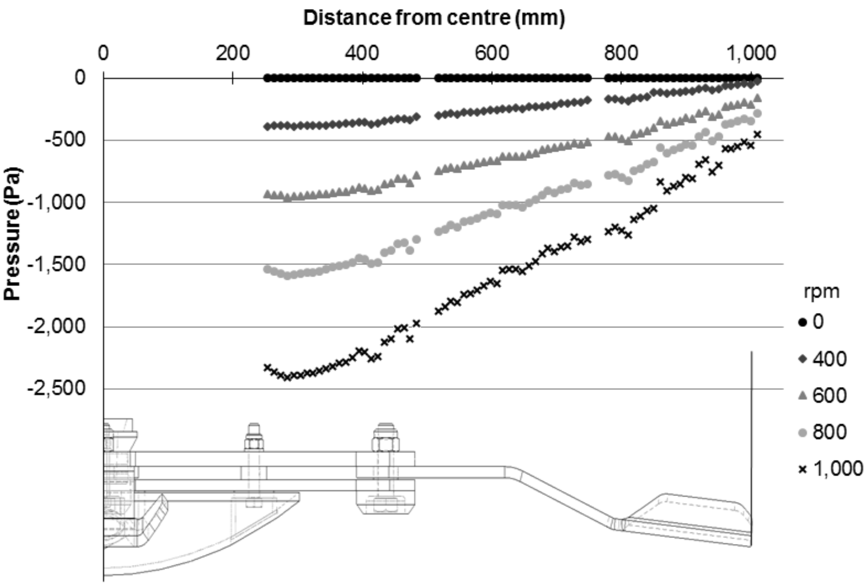

Figure 5. The course of pressure inside the workspace for original cutting tool (0X45).

When comparing the pressure curves with the drawing of cutting tool disposed below the graph it is possible to see the influence of various elements of the cutting tool on the course of pressure, e.g., cranked parts of the tool, trailing edge, retaining screw, etc. Further, it can be seen that the shape of the average pressure curves for each rotation speed are for the same cutting tool very similar and differ only in absolute pressure. Fig. 6 shows the course of pressure in the workspace of model of mulcher for different rotation speed of rotor with 0X25 cutting tool.

The course of pressure of the individual cutting tools are very similar as can be seen in Figs 5 and 6. For all the measured tools the highest vacuum was always measured by a sensor positioned of 284 mm from the centre of the rotor. Further from the centre of rotation (about 414–424 mm) it is evident the effect of retaining screw of the cutting tool which is similar for all variants. Pressure then increases linearly up to cranked part of the cutting tool, which was the same for all variants. Here, the noticeable pressure stagnation ranged between values of 627–657 mm from the centre of rotation can be seen. Further, significant deviation from linearity occurs at the second cranked part of the cutting tools, its trailing edge and rake angle. Despite differences in the shape of the tip of the cutting tools the pressure trends between 780 mm and 1,010 mm from the centre were again very similar to each other. At 810 mm a pressure drop occurred which was followed by its increase between 860–870 mm from the axis of rotation. This effect was stronger for the proposed cutting tools with zero rake angles 0X25 and 0X35. The trend of pressure around the tip of the blade is in good agreement with Chon & Amano (2005). They claimed that in the area around the tip of the blade the level of turbulent kinetic energy is higher than in the rest of the workspace.

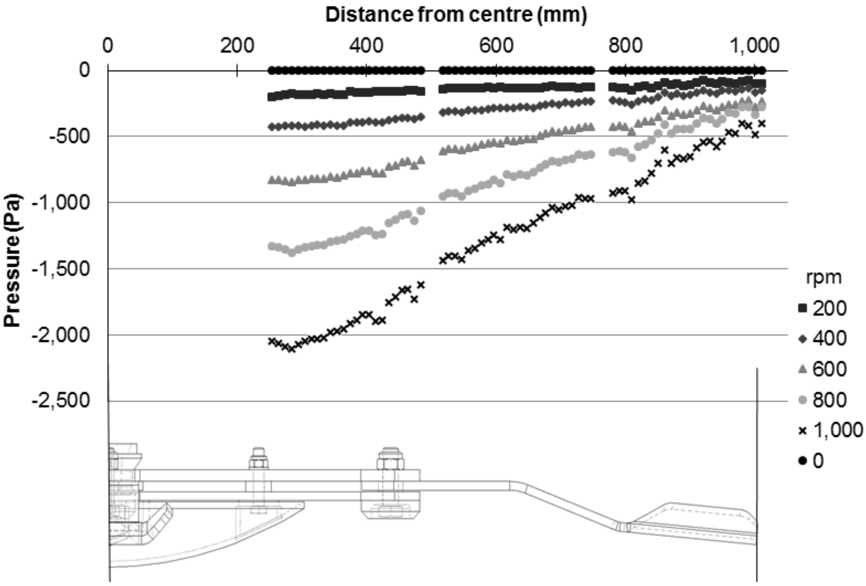

Figure 6. The course of pressure inside the workspace for cutting tool 0X25.

Since the pressure profile for all variations was very similar and under given conditions of measurement the differences were at the limit of the measurement accuracy the main criterion of comparison was the absolute value of achieved vacuum. Fig. 7 shows the maximum vacuum achieved in the workspace due to movement of the cutting tools. The maximum measured vacuum was 2.41 kPa and it was achieved with the original cutting tools. The analysis of variance of measured maximum vacuum values showed the statistically significant difference among all measured tool shapes at 800 min^{-1} and 1,000 min^{-1} at significance level $\alpha = 0.05$. The analysis of variance for 1,000 min^{-1}, complemented with Tukey HSD post-hoc test is shown in the Table 2. From Fig. 7 it is evident that at the zero rake angle of the cutting tool the decreasing value of achieved maximum vacuum can be observed as a result of the decreasing cutting tool's trailing edge angle. This effect is evident both at 800 min^{-1} for instruments 0X45, 0X35 and 0X25, and at 1,000 min^{-1} for instruments and 0X45 0X25. Decrease of the trailing edge angle from 45° to 25° can reduce maximum reached vacuum at 1,000 min^{-1} by approx. 0.3 kPa (12.6%). Further, it may be noted that when rake angle is reaching a non-zero values the increase of the maximum vacuum in the workspace can be observed as a result of decreasing trailing edge angle. This effect was reflected for both rake angle of 15° (15X35 and 15X25) and 25° (25X35 and 25X25) at the rotation speed of 800 min^{-1}. For the rake angle of 15° and 25° the decrease of the pressure at 800 min^{-1} was approx. 0.15 kPa (10.2%). This effect requires further analysis based on the air flow velocities measurement in the workspace by means of Laser Doppler Velocimetry.

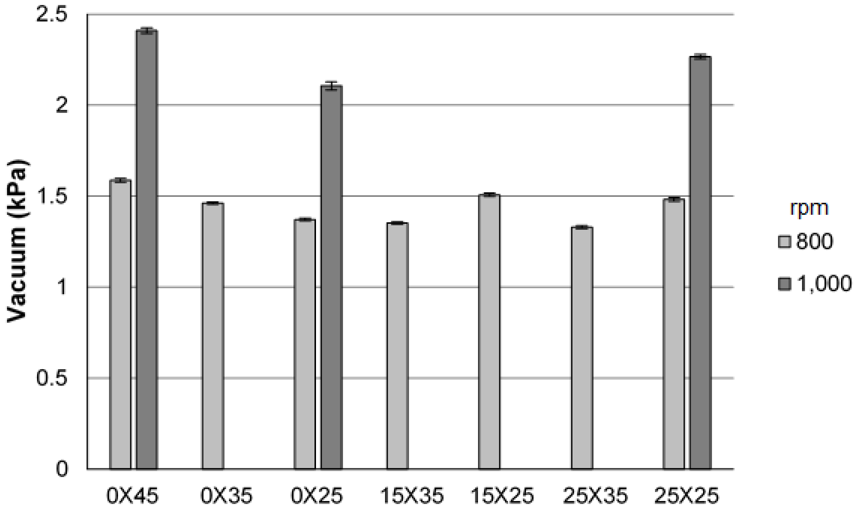

Figure 7. The maximum reached underpressure with original and proposed tools.

Table 2. Analysis of variance, complemented with Tukey post-hoc test for different tools at 1,000 min-1 (105 m s^{-1})

ANOVA				
α = 0.05	Sum of squares	Degrees of freedom	Variance	F
Between groups	8.6411	2	4.3205	16,872.185
Within groups	0.1857	725	0.0003	
Total	8.8267	727		
Tukey HSD Post-hoc Test				
Group 1 vs Group 2: Diff = -0.3043, 95%CI = -0.3083 to -0.3003, p = 0.0000				
Group 1 vs Group 3: Diff = -0.1445, 95%CI = -0.1502 to -0.1388, p = 0.0000				
Group 2 vs Group 3: Diff = 0.1598, 95%CI = 0.1532 to 0.1664, p = 0.0000				

The difference between maximal and minimal pressure values is also important in the terms of quality of work. According to Chon & Amano (2004) the low pressure near to the centre of the rotor helps to create better air circulation and higher upward velocity at the tip of the blade. On the contrary, Čedík et al. (2016a) and Čedík (2016) claims that vacuum in the centre of rotor could cause a suction of higher quantity of grass matter under the rotor centre and thus it can reduce the work quality. Table 3 gives the values of maximum pressure difference measured for individual cutting tools. It is obvious that the highest difference (approx. of 2 kPa) was achieved with the original cutting tools.

The lowest difference was achieved, as expected, with the cutting tools 0X25. As an interesting cutting tool appears variant 25X35 which has shown the second lowest difference in pressure, but in field trials, conducted by Čedík (2016), showed the best work quality from the proposed instruments. However, due to unfavourable measuring conditions these results are not fully conclusive and require additional measurements.

Table 3. Pressure differences

Cutting speed ($m\ s^{-1}$)	Pressure difference (kPa)						
	0X45	0X35	0X25	15X35	15X25	25X35	25X25
84	1.31	1.18	1.10	1.15	1.24	1.13	1.24
105	1.95	-	1.71	-	-	-	1.91

Chon & Amano (2005) performed measurement with a double-blade mower with side-discharge and co-rotating blades. They reached the maximum pressure difference of 3 kPa at a cutting speed of 82 $m\ s^{-1}$, but at 2,700 rpm, which produces a higher centrifugal force and therefore the higher pressure difference.

CONCLUSIONS

During the measurement of the pressure conditions inside the mulcher's workspace the following conclusions were made:

- The movement of cutting tools creates the vacuum (under pressure) within the workspace. This vacuum decreases almost linearly from the centre of the rotor towards to its periphery. Maximum reached vacuum was 2.41 kPa with original shape of cutting tools. Other sources (Chon & Amano, 2003; Chon & Amano, 2005) with use of mathematical model also found the highest vacuum in the centre of rotor of municipal mower.
- The maximum pressure difference in the workspace was measured 1.95 kPa at cutting speed 105 $m\ s^{-1}$. Chon & Amano (2005) reported the pressure difference 3 kPa at municipal double rotor mower with rotor diameter approx. 0.6 m with cutting speed 82 $m\ s^{-1}$.
- Proposed shapes of the cutting tools generally lowered the maximum reached vacuum in comparison with the original cutting tool. Also, proposed shapes of the cutting tools have only a negligible effect on the course of pressure.
- At zero rake angle of cutting tool the maximum achieved vacuum was reduced by decreased trailing edge angle. For the rake angle of 15° and 25° it was found that decrease of the trailing edge angle conversely increases the maximum vacuum.

Lower vacuum has resulted in a smaller power requirements for creating and maintaining of vacuum. But too low vacuum could significantly impair the quality of mulcher work since there would be no sufficient disruption of the plants structure by repeated contact with blades of the cutting tools.

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Effect of rake angle and cutting speed on energy demands of mulcher with vertical axis of rotation

J. Čedík[1,*], M. Pexa[1] and R. Pražan[2]

[1]Czech University of Life Sciences Prague, Faculty of Engineering, Department for Quality and Dependability of Machines, Kamýcká 129, CZ165 21, Prague 6, Czech Republic
[2]Research Institute of Agriculture Engineering, Drnovská 507, CZ161 01, Prague 6, Czech Republic
[*]Correspondence: cedikj@tf.czu.cz

Abstract. The contribution deals with the reduction of agriculture energy demands. For maintenance and treatment of permanent grassland areas, areas left fallow and put to rest the mulching in combination with other workflows (mowing, grazing) is advantageous procedure. As conventional impact grass cutting and chopping is energy demanding procedure, it is proper to reduce the energy demands of such device. In the paper the effect of shape of cutting tool, particularly the rake angle, on energy demands of mulcher with vertical axis of rotation is studied. The effect of cutting speed on energy demands is also verified. The measurement was performed using mulcher MZ 6000 made by Bednar FMT Ltd. with working width of 6 m and three rotors. During the measurement the test rides using the cutting tools with different rake angle and cutting speeds of 105m s^{-1}, 89 m s^{-1} and 79 m s^{-1} were performed. The rake angle of cutting tools were chosen 0°, 15° and 25°. The test area was pasture with permanent grassland. During the measurement the torque and power, transferred through PTO to the machine, fuel consumption and GPS coordinates were measured. From each test ride the samples of grass matter were taken in order to determine the yield and moisture content. It was found that increase of the rake angle up to 25° and decrease of the cutting speed resulted in decrease of the power requirement of the mulcher.

Key words: mulcher, permanent grassland, energy demands, cutting tool, rake angle, cutting speed.

INTRODUCTION

At the present time there is put ever increasing emphasis on reducing the energy demands of individual operations in agriculture. Mulching with vertical axis of rotation belongs to the energy demanding agricultural operations. Mulching with use of vertical axis of rotation causes the impact cutting, which is in principle much more energy demanding than mowing with a support.

For the rotary mowers, to which belong also a mulcher with vertical axis of rotation, the sources of scientific literature mention very different values of energy demands (Table 1).

Table 1. Results of energy demands of rotation mowers, measured at different conditions

Source	Performance requirement (kW m^{-1})	Conditions
Čedík et al. (2015)	10–23	Mulcher working with mass performance of 10–35 t h^{-1}
	5	Mower
	8	Mower with conditioner
	6.67	Mower with the average mass performance 120 t h^{-1} and blunt blades
	5.67	Mower with the average mass performance 120 t h^{-1} and sharp blades
Srivastava et al. (2006)	11–16	Mower at a speed of 15 km h^{-1}
	8–10	Mower with sharp blade
	10–12	Mower with worn blade
	5	Mower
	3.5–6.5	Mower with conditioner

During the impact cutting the reaction to the cutting force is represented by structural stiffness or inertia of plants. From this reason a plant can be cut only in case, when these resistance forces of plant exceed the force delivered by tool (Johnson, 2012). It is obvious, that the stiffness and mass of plant stem represent very important factor, to which must be adapted cutting conditions, in particular cutting speed. Therefore, cutting speed plays very important role in terms of energy demands and quality of work. The effect of cutting speed on cutting parameters of mowers has been examined in numerous studies (McRandal & McNulty, 1978a; O'Dogherty & Gale, 1991a; Tuck et al., 1991b; Chattopadhyay & Pandey, 1999; Chattopadhyay & Pandey, 2001; Hagen et al., 2002; Yiljep & Mohammed, 2005; Hosseini & Shamsi, 2012; Kakahy et al., 2012; Kakahy et al., 2013; Kakahy et al., 2014). The results of most of these studies mention the lowest energy needed for impact cutting at cutting speeds in the range of 60–90 m s^{-1}. O'Dogherty (1982) mentions typical cutting speed for disc and rotary mowers in range of 71–84 m s^{-1}.

Species and the condition of processed plants, especially its moisture, has also a significant effect on energy demands during the mowing (Chen et al., 2004; Shahbazi et al., 2011; Kronbergs et al., 2013).

Another important factor related to the energy demands is the geometry of tool, sharpening angle and rake angle (Fig. 1). In case of sharpening angle the sources of scientific literature mention the most advantageous range of values from 20° up to 30° (O'Dogherty & Gale, 1991b; Tuck et al., 1991b; Chattopadhyay & Pandey, 2001; Hoseinzadeh et al., 2009). Owing to the higher degree of wear of cutting blades during the mulching as a result of repeated contact of cutting tool with material and soil, the rake angle of tool appears as more significant.

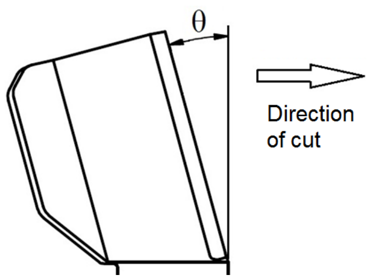

Figure 1. Schematically illustrated rake angle θ.

In the literature the rake angle have been studied in the range 0–50°. The most effective cut was found within the range 15°–30° (O'Dogherty & Gale, 1986; O'Dogherty & Gale, 1991b; Kakahy et al., 2012; Kakahy et al., 2013). McRandal & McNulty (1980) states that the blade rake angle is significant for the resistance to penetration of both stem and leaf. Hoseinzadeh et al. (2009) reached the lowest shearing energy of wheat with the rake angle of 25°.

The disruption of plant structure by repeated contact with tool blade is important when mulching with vertical axis of rotation in order to facilitate the decomposition of the plants and as well as its distribution in the entire width of machine. Fulfillment of this requirement ensures ventilation effect and the associated negative pressure in the workspace (Čedík et al., 2016a). This fact however means considerably higher losses due to the air resistance.

Identified energy losses of rotary mowers are the following: acceleration of the material to the output speed, overcoming friction forces between the material and the cover of the mower mechanism while the material is still pressed by the cutting device, overcoming friction forces between the blade and the stubble/soil, continuous movement of the air in the cut area (so called ventilation effect), overcoming mechanical friction forces of the drive mechanism and other parasitic losses. Total losses may be greater than the real cutting performance (Persson, 1987; O'Dogherty & Gale, 1991b). The experiments with mowing machines with vertical axis of rotation proved that 50% of the input energy is used for 'transport' of the plants while only 3% of the input energy is used for cutting the plant stems (McRandal & McNulty, 1978a).

This contribution is aimed at determination of effect of the changes of cutting tool rake angle and cutting speed on energy demands of mulcher with a vertical axis of rotation in field conditions.

MATERIALS AND METHODS

For the measurement the mulcher with vertical axis of rotation Mulcher MZ 6000 produced by the company Bednar FMT, Ltd. in the set with tractor FENDT 818 were used (Fig. 2). Both machines were rented from collective farm Agro Liboměřice, joint-stock company. The area, on which the mentioned mulcher was used during the period of its operation didn´t exceed 200 ha.

Figure 2. Working set – tractor Fendt 818 with connected Mulcher MZ 6000.

In order to verify the effect of change of rake angle there have been designed and manufactured the tools with rake angle 0°, 15° a 25° from carbon steel. The values of the rake angle were chosen based on the literature review. Sharpening angle of the blades was 40° according to the original cutting tools. The drawings of semifinished tools are shown in the Fig. 3.

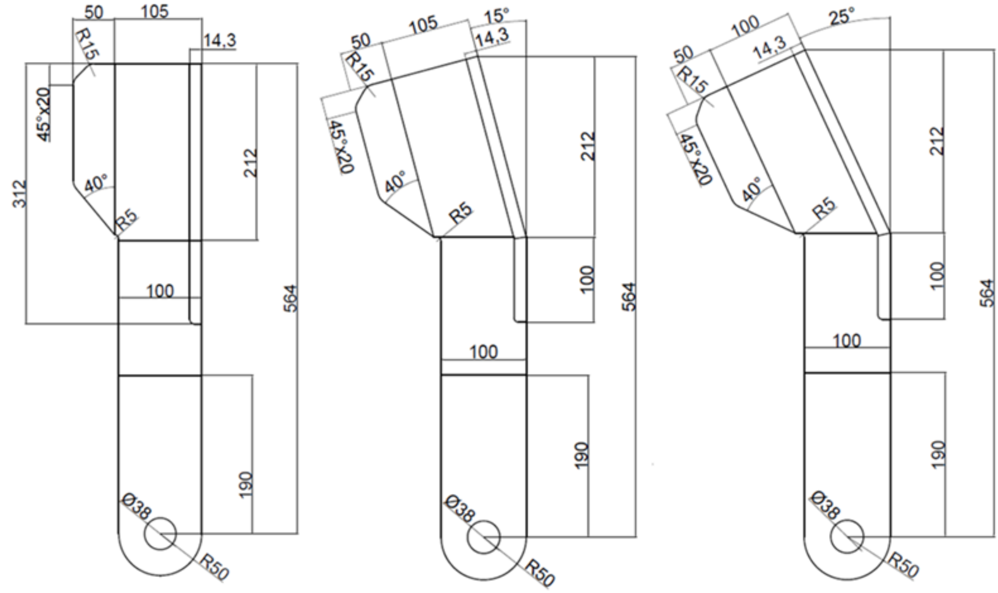

Figure 3. Cutting tools with different rake angle.

In order to determine the energy demands a torque sensor Manner Mfi 2500Nm_2000U min^{-1} (accuracy 0.25%), mounted on the tractor PTO shaft was used and for the determination of position of the working set and its speed the GPS receiver Qstarz BT-Q1000XT was placed on the tractor roof. All sensors were connected by means of analog-digital converter LabJack U6 (resolution 18 bit) to the measuring computer HP mini 5103, which was placed in tractor cab. Data were recorded at frequency of 2 Hz.

On the measuring plot there have been carried out the test drives with designed tools at the PTO 1,000 rpm (cutting speed 105 m s^{-1}), 850 rpm (cutting speed 89 m s^{-1}) and 750 rpm (cutting speed 79 m s^{-1}). The speed of set was chosen 9 km h^{-1}. For each shape of the tool and cutting speed there were carried out two drives. In order to evaluate and compare the energy demands there were used only these drives, at which the comparable mass performance was achieved. As there was already published (Čedík et al., 2015; Kumhála et al., 2016), energy demands and efficiency of mulcher itself depend strongly on achieved mass performance.

The measuring plot was pasture area at village of Bojanov, near to Chrudim in the Czech Republic (49.430567°N, 15.7102258°E). This plot is flat and it is situated approximately 420 m above sea level. Mulched plant stand has been mostly formed by grasses (cocksfoot, perennial ryegrass) with dry undergrowth, where the faded stalks of sorrel were represented to the greatest extent.

For the determination of measurement conditions two samples were taken for each shape of cutting tool blades in order to determine the proportion of moisture content. The moisture content had average value 67%w.b. with standard deviation 7.3%w.b. The data has been also used to determine the average yield of grass matter from each measuring section by means of a laboratory scales Vibra AJ 6200 (range 6,200 g, resolution 0.01 g, accuracy 0.1 g).

The power requirement and specific energy consumption were evaluated parameters of energy demands. Specific energy consumption is energy needed to process 1 ton of the material and thus reflects the efficiency of the machine. The power requirement was calculated according to Eq. (1) and the specific energy consumption was calculated according to Eq. 2:

$$PR = \frac{\overline{P}}{B} \tag{1}$$

where PR – power requirement (kW m^{-1}), P – mean input power of the mulcher for the test ride (kW); B – working width of mulcher (m)

$$SEC = \frac{\sum_{i=1}^{n}(P_i \cdot t_i)}{360 \cdot \omega \cdot L \cdot B} \tag{2}$$

where SEC – specific energy consumption (kWh t^{-1}); P_i – measured input power of the mulcher at i index of data-set (kW); t_i – measuring interval of i index of data-set (ms); ω – yield per hectare of grass cover (t ha^{-1}); L – length of test ride (m); B – working width of mulcher (m)

RESULTS AND DISCUSSION

From the measured data only drives with comparable mass performance were selected for the comparison. For determination of the effect of rake angle there have been selected drives, in which it was attained mass performance approx. 7–8 t h^{-1} (Fig. 4). In order to determine the effect of cutting speed there were chosen the drives with achieved mass performance approx. 3–4 t h^{-1} (Fig. 5).

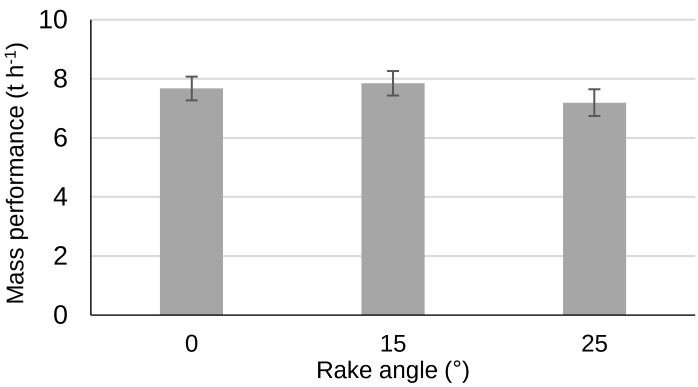

Figure 4. Achieved mass performance for tools with different rake angle.

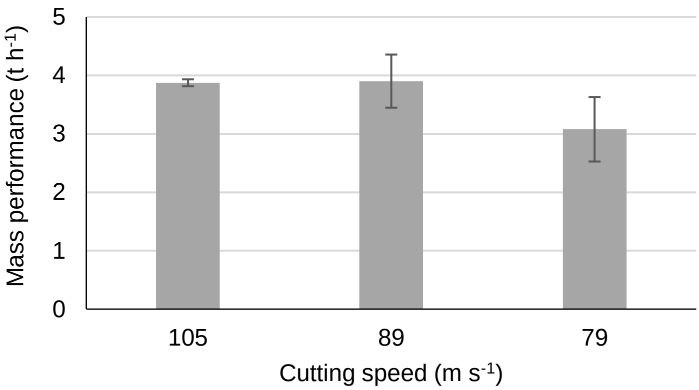

Figure 5. Achieved mass performance for different cutting speeds (rake angle = 0°).

Determination of rake angle effect

The Fig. 6 shows the effect of rake angle on power requirement and specific energy consumption. As can be seen from the figure, increasing rake angle results in a reduction of energy demands of mulcher during the working operation in the field conditions. By increase the rake angle from 0° to 25° the specific energy consumption has been reduced by 21.4% and power requirement by 26.3%. The results of this measurement have a high explanatory value, because during the measurement it was achieved very similar mass performance in all drives. Such a finding is consistent with other publications (Hoseinzadeh et al. 2009; Kakahy et al., 2012; Kakahy et al., 2013), however other sources (Chattopadhyay & Pandey, 2001) mention, that the lowest level of consumed energy is reached with a significantly higher rake angle (40°).

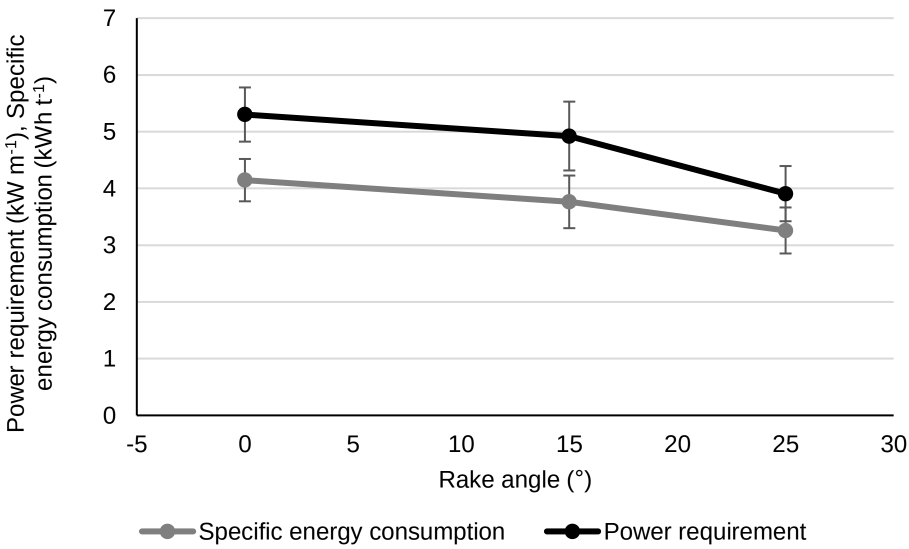

Figure 6. Power requirement and specific energy consumption for tools with different rake angle.

In the Table 2 there is shown an analysis of variance of measured values destined for evaluation of the effect of rake angle on power requirement, complemented with Tukey HSD post-hoc test. The results show, that among all the variants there is statistically significant difference at significance level α = 0.05.

Table 2. Power requirement analysis of variance, complemented with Tukey post-hoc test for tools with different rake angle

ANOVA				
α = 0.05	Sum of squares	Degrees of freedom	Variance	F
Between groups	92.9084	2	46.4542	42.3345
Within groups	297.3718	271	1.0973	
Total	390.2802	273		
Tukey HSD Post-hoc Test				
Group 1 vs Group 2: Diff = -0.3790, 95%CI=-0.7372 to -0.0208, p = 0.0352				
Group 1 vs Group 3: Diff = -1.3938, 95%CI = -1.7568 to -1.0308, p = 0.0000				
Group 2 vs Group 3: Diff = -1.0148, 95%CI = -1.3958 to -0.6338, p = 0.0000				

Determination of cutting speed effect

In the Fig. 7 the power requirement and specific energy consumption for various cutting speeds when using the tool with zero rake angle is shown. It is evident, that with decreasing cutting speed the power requirement also decreases and the greatest difference can be seen between 105 m s^{-1} and 89 m s^{-1}.

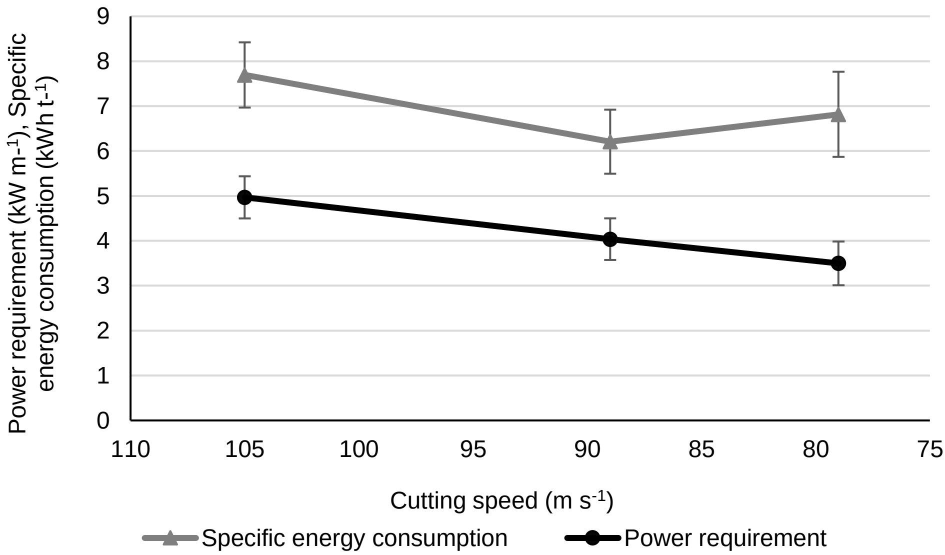

Figure 7. Power requirement and specific energy consumption for different cutting speeds (rake angle = 0°).

By reduction of cutting speed from 105 m s^{-1} to 89 m s^{-1} it is possible to decrease the specific energy consumption by 19.3% and power requirement by 18.7%. By reducing the cutting speed from 105 m s^{-1} to 79 m s^{-1} it was achieved the decrease of specific energy consumption by 11.4% and power requirement by 29.6%. This reduction was achieved mainly due to lower aerodynamic losses of the cutting tools in the workspace, which is in good agreement with previous results (Čedík et al., 2016a; 2016b). The value of specific energy consumption for cutting speed of 79 m s^{-1} was affected by lower mass performance achieved in the measuring section.

In the Table 3 there is analysis of variance of the measured values complemented by Tukey HSD post-hoc test in order to compare the influence of cutting speed on power requirement. From the results it is obvious, that among all variants there is statistically significant difference at significance level $\alpha = 0.05$.

Table 3. Power requirement analysis of variance, complemented with Tukey post-hoc test for different cutting speeds

ANOVA				
$\alpha = 0.05$	Sum of squares	Degrees of freedom	Variance	F
Between groups	104.1988	2	52.0994	58.2416
Within groups	229.8965	257	0.8945	
Total	334.0953	259		
Tukey HSD Post-hoc Test				
Group 1 vs Group 2: Diff = -0.9313, 95%CI = -1.2688 to -0.5937, p = 0.0000				
Group 1 vs Group 3: Diff = -1.4703, 95%CI = -1.8010 to -1.1396, p = 0.0000				
Group 2 vs Group 3: Diff = -0.5391, 95%CI = -0.9070 to -0.1711, p = 0.0018				

CONCLUSIONS

From the measurement results it is obvious, that by increasing the rake angle of cutting tool up to 25° the power requirement was reduced by more than a quarter. This result is in good agreement with results of other authors obtained with mowers of lower dimensions in different cutting speed (Kakahy et al., 2012; Kakahy et al., 2013) or in laboratory conditions (Hoseinzadeh et al., 2009; O'Dogherty & Gale, 1986). On the contrary O'Dogherty & Gale (1991b) reported statistically insignificant lowest cutting energy at rake angle of 15°.

The decrease of energy demands is above all caused by lower energy of cut, because it has been already previously demonstrated in laboratory and field conditions (Čedík et al., 2016b), that the rake angle has only minimal effect on energy losses of mulcher. These losses occur mainly due to the air resistance.

By reducing the cutting speed to the value of 79 m s^{-1} it was achieved the decrease of power requirement almost by 30%. This result is in good agreement with results of other authors, achieved in different conditions (O'Dogherty, 1982; Chattopadhyay & Pandey, 1999; Kakahy et al., 2013; Tuck et al., 1991b).

The decrease of energy demands was reached mainly due to lower aerodynamic losses of mulcher blades, because the cutting speed highly influences relative speed of cutting tool and airflow inside the mulcher workspace (Čedík 2016a, 2016b). The energy losses of the mulcher can consume most of the energy supplied depending on conditions.

However, the reduction of cutting speed has also a negative influence on ventilation effect, which ensures good quality of machine work. Cutting speed must be high enough so that the movement of machinery had as a consequence sufficient number of repeated contacts of cut plant matter with cutting edges of cutting tools and the structure of plant matter was disrupted, which enables its easier decomposition.

Increase of rake angle influences as well as the pressure conditions and air flow in workspace of mulcher. This phenomenon will be further studied.

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Evaluation of nutritional and physical values of pellets based on pea and lupine with added yeast in chickens fattening

L. Chladek[1,*], V. Plachy[2], P. Vaculik[1] and P. Brany[1]

[1]Czech University of Life Sciences Prague (CULS), Faculty of Engineering, Kamýcká 129, CZ165 21 Prague – Suchdol, Czech Republic
[2]Czech University of Life Sciences Prague, Faculty of Agrobiology, Food and Natural Resources, Department of Microbiology, Nutrition and Dietetics, Kamýcká 129, CZ165 21 Prague – Suchdol, Czech Republic
[*]Correspondence: chladekl@tf.czu.cz

Abstract. The article is focused on the development of the new type of broiler chicken feed, based on pea (*Pisum sativum L.*) and blue lupine (*Lupinus angustifolius L*), enriched with used dried brewer´s yeast. This composition eliminates use of soybean meal (PES) that was yet a traditional component in chicken feed. The main reason for its elimination was the using of genetically modified varieties of soybean and its relatively high price around 0.5 €uro kg^{-1} in Czech Republic. For milling of pea or blue lupine was used vertical (hammer) mill type Taurus, supplied by company TAURUS, for drying of used brewer´s yeast had been used drier Memmert UFE 800, final dry matter of the yeast was 88%. For pellets production were used two devices, press type JGE 120-6110 and Testmer. For the determination of physical properties of manufactured pellets (the weight of 1,000 pieces, bulk density, abrasiveness and pellet durability index PDI) were used following laboratory devices, Pellet Tester Holmen NHP and Testmer 200. Experimental activities had shown that the best results were reached using pellets manufactured on base blue lupine enriched by dried brewer´s yeast (6%).

Key words: broiler chicken, feeding, blue lupine (*Lupinus angustifolius*), pea (*Pisum sativum*), used dried brewery yeast, pellets, mechanical properties, weight of 1,000 pellets, bulk density, abrasiveness, pellet durability index (PDI).

INTRODUCTION

The global poultry industry has greatly expanded due to an increase in demand for chicken meat and eggs. Growth of the industry was followed by progress in research which resulted in improved growth rate, feed efficiency, health status, and reduced carriage of pathogens. However, major research focus was improvement in productivity. It is possible to manipulate feed formulations to improve the feed conversion ratio (FCR), which results in a lower feed requirement to achieve market weight. For improving of feed quality are used additives, which are ingredient or combination of ingredients added to the basic feed mix or parts thereof to fulfil a specific need. The problem of supplemental fats in broiler chickens feed discusses in his article V. Ravindran (Ravindran et al., 2006). Fats and oils possess the highest caloric density of all known nutrients. In recent years, because of the ever-increasing energy costs, there is greater interest in maximizing the use supplemental fats as nutritionists strive to increase the dietary energy density to meet the requirements of high-performing contemporary birds. To maximize their energy yielding potential, there is a need to better understand the physiological basis and factors affecting fat digestion. Compared to other macronutrients, the digestion and absorption of fats is a complex process and involve sequence of physicochemical events requiring breakdown to fat droplets, emulsification, lipolysis and micelle formation. Current knowledge of the principles of fat digestion and absorption in poultry is reviewed, along with factors influencing available energy content of supplemental fats (Cowieson, 2016). The supplemental fats are one of the most difficult ingredients to evaluate in terms of available energy. Important variables influencing the energy content of fats include age of the birds, degree of fat saturation, chain length, free fatty acids and fat inclusion level. Potential strategies to improve fat utilization in poultry diets are also examined (Gangadoo, 2016; Ravindran, 2016). Used brewery yeast is a waste from main fermentation of wort to get so called 'green beer' before lager process. From one hl of fermenting wort will be generated two liters of used yeast, but only one liter is possible to reuse it for next fermentation cycle. The brewery yeast has a stimulating effect, supports the immune system of animals, improving the digestibility of protein, eliminate diarrhea, improve skin development quality, also improve reproduction. The high biological value is determined by the favorable B-group vitamins, particularly thiamine (vitamin B1), riboflavin (vitamin B2), pyridoxine (vitamin B6) and pantothenic acid (vitamin B3), as well as the content of minerals and trace elements , especially P, K, Fe, Cu, Zn. Dried brewer's yeast are particularly suitable as feed in feed mixtures for high-animals, young animals (piglets, calves, chickens, small animals of all kinds), and recovering animals (Kunze, 2010). Brewer's yeast composition of its stimulating effect and supports the immune system of animals. On brewer's yeast must be regarded not only in terms of price in relation to nitrogen substances, but must also include significant content of vitamin B (Kunze, 2010). The possible use of RNA from brewery spent yeast for enrichment of cattle feed described Chládek et al. (2007).

MATERIAL AND METHODS

During the experimental work had been used in the assembly of complete feed mixtures prepared on the basis of the nutrient needs of fattened chickens created under wheat, pulses and dried brewer's yeast. As test animals used were chicken broiler ROSS 308, split into three groups of 100 pieces (two experimental groups and a third group that was fed conventional feed). The first mix was used as the basis blue lupine (*Lupinus angustifolius L.*) with the addition of 6% of dry yeast to increase the levels of nitrogen compounds, second group of broilers fed diets, whose foundation was pea (*Pisum sativum L.*) as a main proteinaceous component and to reach match levels of nitrogen compounds have been used 6% (mas) of dry yeast (Plavnik & Sklan, 1995; Elwinger et al., 2016). All chickens were fattened till the age of 46 days. The extension of the fattening period was chosen because of the use of the procedure in organic farming. Further combinations lupine or pea and yeast were not able to meet the nutritional needs of the protein for classical fattening.

Chickens fed with the addition of dry yeast into both types of feed were compared with a control group of comparable weight. Due to the content of the natural sources of amino acids, vitamins, especially B group and minerals in both groups fed yeast was detected yeasty taste adulteration meat quality without any symptom of the yeast taste. The results showed a possibility of substituting soybean meal by pea or lupine to get the same quality of meat produced by feeding soya bean.

For the preparation of broiler chicken feed had been as a raw material used blue lupine, pea and used dried brewer´s yeast. As test chicken for experimental activities had been used chicken broilers ROSS 308, split into two groups of 100 pieces, one group was fed with pea enriched by supplement of 6% dried yeast and second one was fed in similarly way by blue lupine enriched by 6% of dried yeast (Rutkowski, 2015). In the initial version of the article was published a wrong information about third group of fattening, this part of the article was deleted. (For this mistake we are sorry and thank to reviewer for his kind remind). Pea and blue lupine for feeding purposes had been harvested in School farm of CULS. For the milling of pea and lupine was used Vertical hammer mill type Taurus (Fig. 1), supplied by company TAURUS LTD Chrudim (Czech Republic) is the machine determined for milling of cereals. Material is milled by eight hammers as well as by friction between sieve and milled materials. The capacity of the mill is 200 kg h^{-1}. For the experimental activities was used sieve No. 3, giving on the base of previous trials the best results.

Spent yeast for pellets manufacturing had been provided by Tutorial and Research Brewery of the Czech University of Living Sciences (CULS) in Prague. The fresh yeast, type W96, was supplied by Research Institute of Malting and Brewing (RIBM) in Prague.

For the manufacture of pellets had been used pellet press JGE 120-6110 (Figs 2, 3 and 4) (capacity 100 kg h^{-1}), flowsheet capacity 200 kg h^{-1}. The used matrix had whole diameter 3 mm, the length of pellets was 6.5 mm. The second pellet press type Testmer 200 (Fig. 5) was equipped with the same matrix. For spent brewer´s yeast drying had been used drier type Memmert UFE 800, initial dry matter appr. 7%, final dry matter 93%.

Figure 1. Vertical hammer mill type TAURUS.

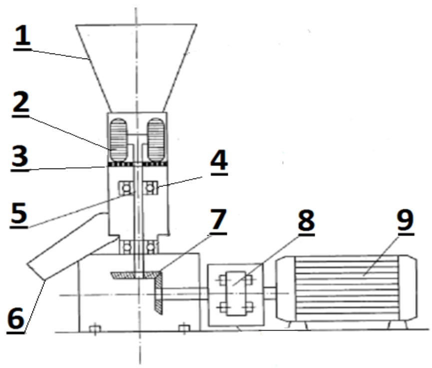

Figure 2. Flowsheet of pellet press JGE 120-6110. Explanatory notes: 1 – hopper, 2 – rollers, 3 – matrix, 4 – bearing, 5 – shaft, 6 – outlet of pellets, 7 – bevel gearing, 8 – flange coupling, 9 – electric motor.

Figure 3. Pictures of pellet press JGE 120-6110.

Figure 4. Matrix of pellet press JGE 120-6110 with wholes diameter 3 mm and 8 mm.

Figure 5. Picture of pellet press type Testmer 200, using the same matrix (wholes 3 mm).

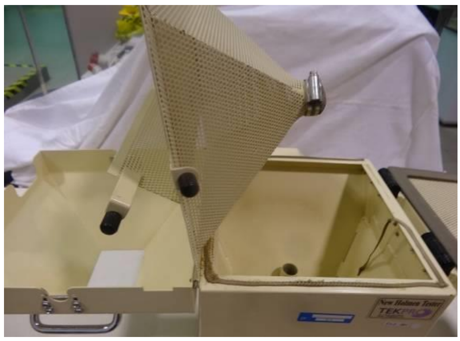

Figure 6. Picture of device for abrasiveness measurement New Holmen Tester TEK (general view).

Figure 7. Picture of device for abrasiveness measurement New Holmen Tester TEK (detail).

For the measurement of the weight of 1,000 pellets, made from pea and from blue lupine had been used the balance type KERN 440-43, weighing range 0–400 g, accuracy ± 0.5 g (Fig. 12). For the measurement of abrasiveness and of mechanical durability index of developed chicken feed have been used two different laboratory devices. First one was Ligno-Tester LT II, designed according Austrian standard ÖNORM M7135, manufactured and supplied by Company Borregaard Lignotech, (Fig. 8).

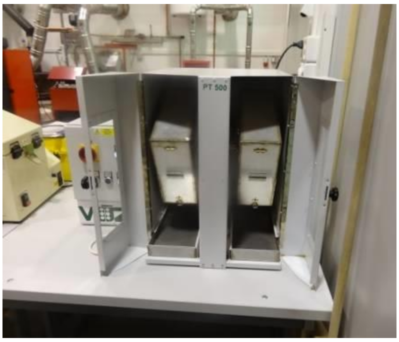

Figure 8. Picture of device type PT for pellets durability index measurement (PDI).

The flow sheet of this device is shown on the Fig. 11. The device consists of the housing with a pyramid sieve (tip down) in that is put before measurement weighed sample of the pellets. On the down part of sieve there is located an inlet of pressed air and the fan and outlet of tested pellets. The air passes through the layer of pellets generating their movement that causes their abrasiveness.

The weight of pellets after this process was weight of pellets again tested. The way of abrasiveness measurement was following: the mass 100 g ± 0.5 g of pellets was put into pyramid sieve in apparatus and let it blowing through the layer of pellets for 60 seconds by the air at pressure 70 mbar from the fan installed in apparatus. The final value of the pellets abrasiveness was calculated using following equation:

$$A = \frac{(mE - mA)}{mE} \cdot 100 \qquad (1)$$

where A – abrasiveness (%); mE – initial weight of pellets before measurement (g); mA – final weight of pellets after measurement (g).

The second used device was designed according Czech standard ČSN EN 15210-1 ‘Determination of mechanical durability of pellets’. The picture of this device is shown on Fig. 11. The design of the device is following: it consists of two square or hexagonal boxes fixed on the rotating shaft. At the beginning of measurement every box will be filled with 500 g ± 10 g.

After closing the box starts to rotate at speed of fifty revolutions per minute. After 500 revolutions (appr. 10 minutes) content of every box will be sieved to separate generated dust, the remaining pellets will be weighed. The measured durability will be calculated according next equation:

$$PDI = \frac{mA}{mE} \cdot 100 \qquad (2)$$

where PDI – Pellet Durability index (%); mE – initial weight of pellets before measurement (g); mA – final weight of sieved pellets after measurement (g).

The ratio between abrasiveness (Eq. 1) and PDI (Eq. 2) is following:

$$PDI = 100 - A \qquad (3)$$

RESULTS AND DISCUSSION

Comparison of results using pea, lupine and yeasts for chicken feeding

The course of 46 days chicken feeding using feed blue lupine and pea without dried yeast is ilustrated in Fig. 9.

Fig. 9 illustrates average results from 10 trials showing increase in weight of living chicken during course of 46 days. With an exception of first 10 and 32 days better result have been reached using lupine (Table 1).

Table 1. Live weight of chicken

Feed		Lupine (g)	Pea (g)	Lupine (%)	Pea (%)
	10 days	176	185	95.14	100
	20 days	433	347	124.78	100
	32 days	718	710	101.13	100
	46 days	2223	2177	103.91	100

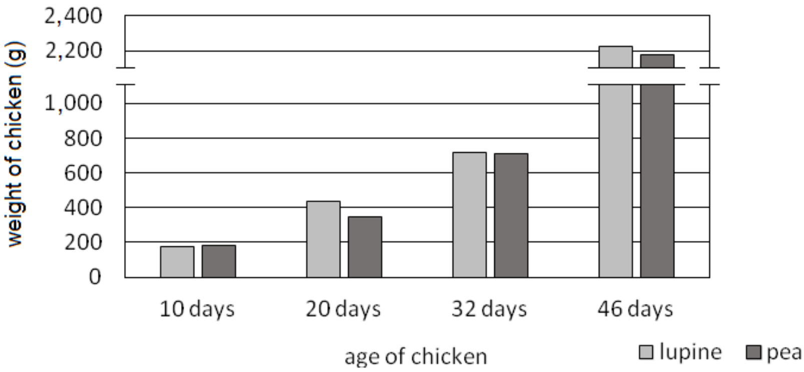

Figure 9. Increase in weight of chicken (g), fed blue lupine and pea (without dried yeast).

Fig. 10 illustrates feed conversion of broiler chickens using blue lupine or pea enriched by 6% of dried yeast (feed conversion means feed consumption (kg)/1 kg of increase in weight) (Table 2).

Table 2. Feed conversion (1–46 days)

		Lupine	Pea
Weight	(g)	1,846	1,900
	(%)	97.15	100

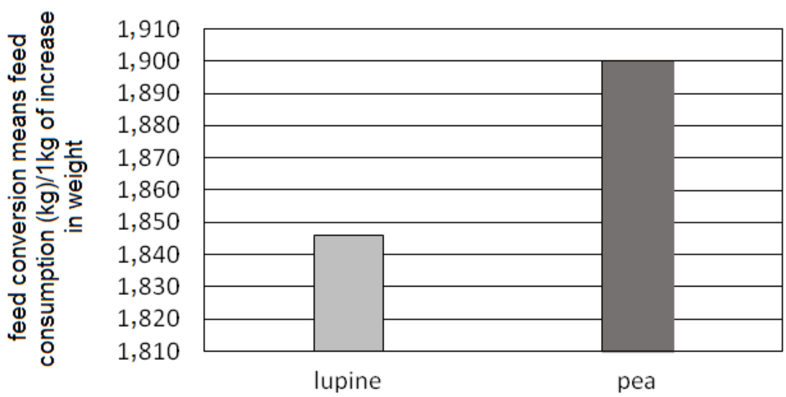

Figure 10. Feed conversion using supplement 6% of dried yeast.

Measurement of 1,000 pellets weight

The weighing of 1,000 pellets**,** made from pea and 6% dried yeasts, diameter 3 mm, lengths 6.5 mm.

Figure 11. Weighing of 1,000 pellets made from pea with addition of 6% dried yeast.

Figure 12. The weighing of 1,000 pellets, made from pea with addition of 6% dried yeast, diameter 3 mm, lengths 6,5 mm.

The average weight of 1,000 pcs lupine pellets was in the range 25.0–25.9 g, average mass of pea pellets was in the range the 27.9–28.1 g (Table 3 and 4). The difference in weight of pea and lupine pellets was caused by different content of fiber.

Table 3. Weight of 1,000 pieces of lupine pellets with addition of 6% dried yeast

Nr.	1	2	3	4	5	6	7	8	9	10
1	26.2	25.9	26.1	26.0	26.2	25.9	25.0	26.0	26.2	26.1
2	24.4	25.8	24.7	25.8	25.5	25.8	25.5	25.4	24.0	24.7
3	25.8	25.9	25.8	24.4	25.5	25.9	26.0	25.3	26.0	24.8
4	26.1	26.0	25.9	26.2	25.7	24.9	25.7	26.3	26.0	24.9
5	25.9	25.5	25.0	25.5	25.8	25.4	25.8	25.4	25.0	24.0
6	25.7	25.2	25.5	26.0	26.1	26.2	26.1	26.2	25.7	25.5
7	25.4	25.4	25.5	25.1	26.2	25.4	26.0	25.4	26.0	25.5
8	25.9	24.8	25.7	26.4	25.9	24.1	25.9	25.9	25.9	25.0
9	25.9	25.8	24.0	24.0	25.8	25.8	25.8	25.8	26.1	25.9
10	25.3	25.9	26.6	26.1	26.3	25.9	25.8	25.9	25.3	24.0
∑	256.6	256.2	254.8	255.5	259	262.1	264.6	265.6	265.2	260.4
Average	25.7	25.6	25.5	25.6	25.9	25.6	25.8	25.8	25.6	25.0
St. Error	1.93	1.44	2.77	2.99	1.06	1.64	1.17	1.34	2.53	2.72
St. Dev	0.50	0.37	0.71	0.76	0.28	0.42	0.30	0.34	0.65	0.68

Table 4. Weight of 1 000 pieces of pea pellets with addition of 6% dried yeast

Nr.	1	2	3	4	5	6	7	8	9	10
1	28.2	28.0	28.2	28.2	28.2	28.2	29.0	28.1	27.0	28.1
2	28.1	27.9	27.1	28.1	29.0	28.1	28.1	27.9	27.9	27.9
3	28.9	28.0	28.3	28.3	27.3	28.3	28.3	28.0	28.0	28.0
4	28.5	28.2	28.5	27.5	28.5	28.5	28.5	27.2	28.2	27.2
5	27.7	28.5	27.3	26.7	27.2	27.7	27.7	27.9	28.6	27.5
6	27.3	28.4	27.6	27.6	27.6	27.6	27.6	28.4	28.4	27.4
7	27.7	27.9	27.7	27.7	27.7	27.7	27.7	27.9	27.9	27.9
8	29.0	27.8	28.0	28.0	28.0	28.0	28.0	28.8	29.0	28.8
9	27.8	28.2	27.8	27.8	27.8	27.8	27.8	28.2	28.2	28.2
10	28.2	28.1	28.2	28.2	29.0	27.3	28.2	28.1	27.6	28.1
∑	281.4	281	278.7	278.1	280.3	279.2	280.9	280.5	280.8	279.1
Average	28.1	28.1	27.9	27.8	28.0	27.9	28.1	28.1	28.1	27.9
St. error	1.83	0.76	1.54	1.63	2.17	1.24	1.46	1.38	1.86	1.56
St. dev	0.52	0.21	0.43	0.45	0.61	0.35	0.41	0.39	0.52	0.43

Results of measurement of bulk density of pea and lupine pellets with 6% dried yeast

For measurement of bulk density of pea and lupine was used graduated cylinder volume 0.5 liter. The bulk density of lupine pellets with 6% dried yeast was measured in the range 346.2–351.2 g 0.5 L (692.4 g L^{-1}). The bulk density of pea pellets with 6% dried yeast was determined again from 10 trials in the range 356.2 g 0.5 L^{-1} – 372.3 g 0.5 L^{-1} (712.4 g L^{-1} – 744.6 g L^{-1}).

Results of measurement of abrasiveness and PDI of pea and lupine pellets with 6% dried yeast

The results of abrasiveness and PDI of pea and lupine pellets with 6% dried yeast are shown in the Table 5 and Table 6.

Table 5. Abrasiveness of lupine pellets and pea pellets (device New Holmen Tester TEK– Figs 6 and 7)

	Lupine pellets			Pea pellets		
Nr.	mA (g)	mE (g)	A (%)	mA (g)	mE (g)	A (%)
1	100	71.7	28.3	100	74.5	25.5
2	100	71.9	28.1	100	75.1	24.9
3	100	72.9	27.1	100	75.2	24.8
4	100	72.4	27.6	100	75.6	24.4
5	100	72.9	27.1	100	75.8	24.2
6	100	71.4	28.6	100	75.4	24.6
7	100	72.0	28.0	100	75.1	24.9
8	100	72.1	27.9	100	75.8	24.2
9	100	72.4	27.6	100	75.1	24.9
10	100	72.2	27.8	100	75.2	24.8
∑	1,000	721.9	278.1	1,000	752.8	247.2
Average	100	72.2	27.8	100	75.2	24.8

Table 6. PDI of lupine pellets and pea pellets (device PT)

Nr.	Lupine pellets			Pea pellets		
	mA (g)	mE (g)	PDI (%)	mA (g)	mE (g)	PDI (%)
1	500	358.5	71.7	500	370.5	74.1
2	500	359.5	71.9	500	376.0	75.2
3	500	364.5	72.9	500	376.5	75.3
4	500	362.0	72.4	500	380.5	76.1
5	500	364.5	72.9	500	385.5	77.1
6	500	357.0	71.4	500	387.5	77.5
7	500	360.0	72.0	500	384.0	76.8
8	500	360.5	72.1	500	381.0	76.2
9	500	362.0	72.4	500	380.5	76.1
10	500	361.0	72.2	500	381.0	76.2
∑	5,000	3,609.5	721.9	5,000	3803	760.6
Average	500	361.0	72.1	500	361.0	76.1

CONCLUSION

The combination of pulses and dried yeast can be used as a substitute for soybean meal, especially in cases of chicken production in a sustainable and organic agriculture. Compared combination lupine x yeast and yeast games x indicates better performance of fattening in favor of lupine.

Unlike the bulk density of the tested compounds (pea - lupine) was due to a higher proportion of fiber in the case of lupine. There was a fairly good agreement in the measurement of abrasiveness and PDI of pea and lupine pellets enriched with dried yeast.

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Performance analysis of biodegradable municipal solid waste collection in the Czech Republic

O. Chotovinský* and V. Altmann

Department of Machinery Utilization, Faculty of Engineering, Czech University of Life Sciences in Prague, Kamycká 129, CZ165 21 Prague 6 – Suchdol, Czech Republic
*Correspondence: chotovinsky@tf.czu.cz

Abstract. The article deals with the issues of biodegradable municipal solid waste management system, focusing on its separate collection. The two basic locations are compared – rural area and urban area. The emphasis is put on evaluation of individual biodegradable municipal solid waste collections development from 2012 to 2015. Individual technological performances of collection are also observed and evaluated (e.g. biodegradable municipal solid waste production, development of container quantity and collection frequency). The observed data also verify the efficiency of biodegradable municipal solid waste management compared to relative representation of this waste in rest municipal solid waste, which is produced in both locations. Also referential locations without separate biodegradable municipal solid waste collection are observed for evaluation. There are one locality of an urban area and one rural area too. The decrease of biodegradable municipal solid waste in rest of municipal solid waste at the basic rural researched area indicates that the directive on landfills could be followed with well-chosen technological parameters of separate biodegradable municipal solid waste collection at a given site. A statistically significant impact of separate biodegradable municipal solid waste production on relative amount of the biodegradable part in rest municipal solid waste has been demonstrated at the side of this basic rural area.

Key words: municipal solid waste, rest municipal solid waste, biodegradable municipal solid waste, biodegradable municipal solid waste collection, material analysis.

INTRODUCTION

Biodegradable municipal solid waste (BMSW) or the biodegradable part of rest municipal solid waste (RMSW) is considered a potential source of perennial bioenergy (Greg, 2010). According to the aggregated indicator ‘Global human-appropriated biomass’, it was estimated that up to one fifth of the total primary production is returned to the global ecosystem as a biodegradable component of municipal solid waste (MSW) (Vitousek et al., 1986; Imhoff et al., 2004). Most of the BMSW is collected and aggregated in population centers with high energy demands. This waste of biological origin produced at a municipal area is quantitatively very important category of waste and the way how it is treated can both positively and negatively influences environmental components. BMSW accumulation affects the anthropogenic greenhouse effect and the climatic change of the planet. The greenhouse gases production during BMSW decay at landfills contributes to global greenhouse gases emissions with approximately

4% (Papageorgiou et al., 2009). Nevertheless, technologies using this type of BMSW are increasing and gradually displacing fossil energy. As a consequence, the formation of methane during storage of BMSW at dump areas can be reduced (Consonni et al., 2005). This may also decrease the need for waste dumps located near urban areas (Porteous, 2005). A directive which has a crucial value from this perspective and which is fully integrated with Czech legislation is called Council Directive on the landfill 1999/31/EC. The directive's requirement determines gradual decrease of BMSW stored at landfill to 2020. In 2010 there could be 75% of the whole BMSW mass produced in 1995 stored at landfill, in 2013 50% of this amount and by the year 2020 only 35% of BMSW from 1995. In the Czech Republic, there were 1,530,000 tons of BMSW produced in 1995 and in 2010 there were 1.5 million tons of BMSW stored at landfill instead of admissible 1.15 million tons. The precautions of the directive should cover material and energetic use of the waste from the perspective of BMSW management system (Vehlow et al., 2007). The most common technological method of material utilizing is composting. Composting is highest form of recycling. Compost can improve soil conditions and plant growth, and reduce the potential for erosion, runoff, and non-source pollutions. Compost is an organic matter resource. Properly produced compost aids humus to soil (Epstein, 1997). The BMSW can also be processed by the anaerobic digestion method that produces biogas and organic fertilizer as well.

Any type of BMSW is capable of aerobic and anaerobic decomposition. This in particular applies to the part of MSW composed of grass clippings, leaves, twigs, branches, and garden refuse. The decomposable part also includes separately collected biodegradable waste from residential areas, commercial establishments (e.g., restaurants) and institutions (e.g., schools), as well as waste paper (paper and paperboard products), wood, natural textiles and clothing made from these (Vrbová & Balner, 2009). Table 1 shows an overview of BMSW types and the biological component ratio in each type of waste (Kotoulová, 2001).

Table 1. Summary of biodegradable municipal solid waste - according to legislation in the Czech Republic

Type no.	Name of the Type of Waste	Ratio
20 01 01	Paper and cardboard with the exception of highly glossing paper and the wallpaper waste	1.00
20 01 08	Cafeteria biodegradable waste	1.00
20 01 10	Clothing	0.60
20 01 11	Textiles	0.50
20 01 38	Wood not included in 20 01 37	1.00
20 02 01	Biodegradable waste	1.00
20 03 01	Rest municipal solid waste	0.54
20 03 02	Marketplace waste	0.80
20 03 07	Bulky waste	0.50

Note: Ratio – the biological component proportion in each type of waste.
Type no. – the code for each type of waste by the Waste Catalogue of the Czech Republic.

Waste collection is probably one of the most conspicuous activities in a waste management system and one that the public comprehend highly. The service of waste collection is defined as a combination of a certain technology and a human labour (Bilitewsky et al., 1997). This action corresponds not only with the waste collection from certain type of source, but includes the transport of this waste to the places where the waste management lorries are loaded (Tchobanoglous et al, 2002). The method of BMSW collection and its organization significantly affect the quality and quantity of the obtained material and have an impact on the technical equipment requirements for collected BMSW treatment during subsequent processing (Tchobanoglous et al., 1993).

1. Kerbside collection using conventional and specially designed collection vehicles.
2. Incidental kerbside collection by charitable organizations.
3. Delivery by residents to drop-off centers.

Waste collection for separating the biodegradable part from municipal solid waste could be analysed according to their performance in terms of costs (Teerioja et al., 2012; Rogge & De Jaeger, 2013), environmental impacts (Powell, 1996; Maimoun et al., 2013; Teixeira et al., 2014; Yildiz-Geyhan et al., 2016), recycling/collection rates (Wilson & Williams, 2007), and public participation and behavior (Oskamp et al., 1996; Wang et al., 1997; Bolaane, 2006; Martin et al., 2006; Shaw et al., 2006).

The goal is put on evaluation of separate BMSW collections, focusing on the issue of their performances which can make BMSW diversion from landfill more effective. The first part of this paper is evaluation of separate BMSW collection at sites A and B (rural and urban areas with separate BMSW collection) in period of time 2012–2015. The work is further based on assessing the effectiveness of separation in terms of relative BMSW representation in RMSW in monitored years of above mentioned areas and the values of relative BMSW representation in RMSW are available for referential sites C and D (without separate BMSW collection). BMSW production of the same period in one researched area with an effective separation is also analysed and compared to its significant impact on relative amount of BMSW in RMSW.

MATERIALS AND METHODS

Basic rural area A and urban area B, biodegradable municipal solid waste production data

The built-up rural area A spans 18 hectares with 19 hectares of gardens. 627 permanent residents live in 233 family houses and 10 blocks of flats. Most houses use gas as the heating energy. Separate collection of BMSW can be considered fully developed, with good access throughout the territory of village. The collection here is applied as combination of drop-off and pick-up systems. Both systems are applied 0.12 m^3 and 0.24 m^3 containers and large volume containers (18 m^3).

The built-up urban area B spans 48 hectares with 53 hectares of gardens. 4,955 permanent residents live in 862 family houses and 52 blocks of flats in this town. Gas is the most common heating medium. Separate collection of BMSW is fully developed in the whole territory. Both drop-off and pick-up systems are applied. 0.77 m^3 containers and 0.24 m^3 containers (previously used), as well as large volume containers (18 m^3) are placed in the municipality.

Table 2 specify, on a month-by-month basis, the BMSW production in rural area A and urban area B in 2012 and 2015 (peripheral input data). These tables summarize also the real number of containers/month, available per collection drive.

Table 2. Biodegradable municipal solid waste production (20 02 01) in the rural area A and the urban area B 2012 –2015

Month	Production [t]		Collected containers [pcs.month^{-1}]			Collections [drives.month^{-1}]		
	C_{BMSW} 0.24 m^3	LSC 18 m^3	C_{BMSW} 0.24 m^3*	C_{BMSW} 0.12 m^3	LSC 18 m^3	C_{BMSW} 0.24 m^3	C_{BMSW} 0.12 m^3	LSC 18 m^3
Area A			**2012**					
April	2.20	9.84	33	5	4	2	2	1
May	1.30	-	33	5	-	2	2	-
June	2.92	13.08	33	5	4	2	2	1
July	4.40	8.98	33	5	4	3	3	1
August	3.14	18.34	33	5	4	2	2	1
September	4.30	-	33	5	-	2	2	-
October	1.89	18.41	33	5	4	2	2	1
November	1.60	-	33	5	-	2	2	-
Area A			**2015**					
April	2.08	15.45	71	5	4	1	1	1
May	5.18	10.67	71	5	4	2	2	1
June	11.11	23.43	81	5	4	3	3	1
July	5.98	2.43	81	5	4	2	2	1
August	10.44	23.49	86	5	4	2	2	1
September	10.72	-	86	5	-	2	2	-
October	9.01	36.56	86	5	4	3	3	1
Area B			**2012**					
April	2.06	-	80	-	-	1	-	-
May	8.69	-	80	-	-	4	-	-
June	7.99	14.24	80	-	1	4	-	3
July	10.77	9.53	80	-	1	5	-	2
August	10.93	4.03	80	-	1	4	-	1
September	8.25	8.02	80	-	1	4	-	2
October	12.66	4.07	80	-	1	5	-	1
Area B			**2015**					
March	7.96	3.57	34		1	3	-	3
April	16.07	3.84	34	-	1	5	-	3
May	13.84	3.59	34	-	1	4	-	2
June	12.44	-	34	-	-	4	-	-
July	16.20	-	34	-	-	4	-	-
August	19.16	-	34	-	-	5	-	-
September	11.62	-	34	-	-	3	-	-
October	3.93	-	34	-	-	1	-	-

**- C_{BMSW} containers (volumes of 0.24 m^3) were changed for C_{BMSW} containers with volumes of 0.77 m^3 in Náměšť nad Oslavou in 2012.*

Source: research ESKO-T s.r.o.

RMSW analysis data – Sites A, B, C, D

The values given in Tables 3–6 were provided by collection company (ESKO-T s.r.o.), which perform regular RMSW (Type no. 20 03 01) analysis at monthly intervals in the region. Substance analysis of RMSW have been performed since 2012. For the purpose of evaluating total amount of BMSW in RMSW data from January to December of each year is used. Values for the amount of individual types of municipal waste are in

2012–2015 and all the sites are listed in merged tables 3–6, where the total amount of each RMSW sample is presented in tons. For all basic and referential sites only BMSW with the specific Type no. 20 02 01 (Biodegradable waste) is listed in merged tables.

Table 3. RMSW analysis of the basic rural area A in 2012 and 2015

Month in 2012	1. 2.49 [t]	2. 2.56 [t]	3. 2.48 [t]	Month in 2015	10. 5.08 [t]	11. 4.82 [t]	12. 5.02 [t]
Type no.	[kg]	[kg]	[kg]	Type no.	[kg]	[kg]	[kg]
…				…			
20 02 01	17.6	7.2	12.8	20 02 01	2.2	0.6	3.6
…	84.4	103.4	94.2	…	80.6	83.6	88.4
Total				Total			

Table 4. RMSW analysis of the basic urban area B in 2012 and 2015

Month in 2012	1. 8.24 [t]	2. 8.28 [t]	3. 7.26 [t]	Month in 2015	10. 9.08 [t]	11. 11.3 [t]	12. 5.71 [t]
Type no.	[kg]	[kg]	[kg]	Type no.	[kg]	[kg]	[kg]
…				…			
20 02 01	2.2	12.6	12.8	20 02 01	12.2	4.2	7
…				…			
Total	93.0	95.6	107.8	Total	101.6	96.0	97.4

Table 5. RMSW analysis of the referential rural area C in 2012 and 2015

Month in 2012	1. 1.49 [t]	2. 1.28 [t]	3. 1.31 [t]	Month in 2015	10. 1.89 [t]	11. 1.42 [t]	12. 2.15 [t]
Type no.	[kg]	[kg]	[kg]	Type no.	[kg]	[kg]	[kg]
…				…			
20 02 01	14.0	0.8	0.4	20 02 01	5.8	2.6	0.8
…				…			
Total	81.4	59.0	72.2	Total	87.0	84.8	82.6

Table 6. RMSW analysis of the referential urban area D in 2012 and 2015

Month in 2012	1. 7.96 [t]	2. 6.98 [t]	3. 7.26 [t]	Month in 2015	10. 7.55 [t]	11. 7.15 [t]	12. 6.45 [t]
Type no.	[kg]	[kg]	[kg]	Type no.	[kg]	[kg]	[kg]
…				…			
20 02 01	7.4	20.4	12.8	20 02 01	8.8	5.8	2.2
…				…			
Total	91.0	129.4	107.8	Total	98.6	99.0	87.8

Determining the average value of the RMSW composition in terms of BMSW distribution - Methodology

The determination of the amount of BMSW in RMSW is based on the results of composition analysis (Tables 3–6). Average values of the content of individual RMSW components are calculated by derived relation (1), where is adjusted formula for arithmetic mean from progressively performed RMSW analysis in 2012 and 2015. For the considered calculations, the methodology also allow for relation (3) determining the relative amount of BMSW in RMSW.

Average relative content of type of waste in RMSW [%]

$$\bar{p}_D = \frac{\sum_{i=1}^{n}(\frac{m_{Di}}{m_{Ci}})}{\text{n}} \cdot 100 \quad (1)$$

where $\bar{p}_D$ – Average relative content of type of waste in RMSW [%]; m_{Di} – content mass of type of waste in one RMSW sample [kg]; m_{Ci} – one whole RMSW sample mass [kg]; n – number of performed RMSW analyse [-].

Relative amount of BMSW in RMSW [%]

$$P_{BMSW} = \frac{m_{BMSW}}{m_{sample}} \cdot 100 \quad (2)$$

where p_{BMSW} – Relative amount of BMSW in RMSW [%]; m_{BMSW} – content mass of type of waste in one RMSW sample [kg]; m_{sample} – one whole RMSW sample mass [kg].

Also methodology for descriptive statistics was used to process the RMSW composition results – standard deviation and coefficient of variation.

Standard transformation for correlation, regression model and analysis of variance – Methodology

In order to obtain a more precise interpretation, a standardized transformation has been applied. This model, which is more suitable for handling winter months without BMSW (20 02 01) collection in the municipality, is depicted in Table 7. The program STATISTICA 8 was used to analyse the data and obtain the necessary characteristics of correlation, simple regression and analyse of variance (*F*-test in regression).

Table 7. Standard transformation

Year	Quarter	Relative amount of BMSW in RMSW [%]	Average monthly BMSW production [t]
2012	1Q	$\frac{c_1 + c_2 + c_3}{3}$	$\frac{1}{3}(\sum_{i=1}^{n} x_{i(0.12;\,0.24)} + \sum_{i=1}^{n} x_{i(0.12;\,0.24)} + \sum_{i=1}^{n} x_{i(0.12;\,0,.24)})$
…	…	…	…
2015	4Q	…	…

Note: x_i = the amount of BMSW in C_{Bmsw} containers (0.12 and 0.24 m^3) per one drive of collection; n = the number of collection (drive of collection); c_1, c_2 and c_3 = monthly relative amount of BMSW in RMSW [%].

RESULTS AND DISCUSSION

The overall success evaluation of BMSW collection is shown in Fig. 1. Fig. 1. shows that in all the researched areas, with the exception of the site A, the percentage of BMSW in RMSW is steady and it has more likely increasing or an equal tendency. Table 8 show the value of individual calculations of descriptive statistics (standard deviation and coefficient of variation) relating to average checked values of BMSW in RMSW.

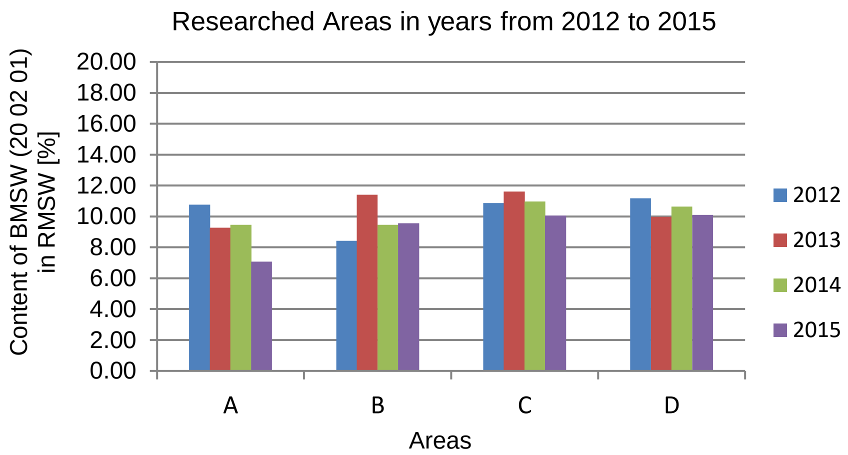

Figure 1. Graphical representation of the relative amount of BMSW in RMSW [%] at the side of all researched areas.

Table 8. Standard deviations (s) and coefficients of variation (V) of the sites A, B, C and D (BMSW values 20 02 01)

Year	A		B		C		D	
	s [-]	*V* [-]	*s* [-]	*V* [-]	*s* [-]	*V* [-]	*s* [-]	*V* [-]
2012	4.93	36.82	3.81	34.99	4.04	41.98	3.02	27.03
2013	2.68	43.15	3.89	34.11	5.40	53.76	3.15	32.52
2014	4.12	45.89	4.15	47.72	4.24	38.14	3.51	33.00
2015	2.59	60.73	4.43	39.49	5.11	56.09	4.70	49.49

The sites with introduced separate collection of BMSW placed four types of BMSW containers in the both built-up area. Their usage is as follows:

- C_{BMSW} containers 0.12 m^3, 0.24 m^3 and 0.77 m^3 – BMSW from residences,
- LSC containers 18 m^3–BMSW from public green areas.

The year-by-year development of the number of BMSW containers and their collection at the sides A and B is presented in Table 9 below.

Table 9. Number of total biodegradable municipal solid waste containers and number of collected containers per month at the areas A and B

Year	C_{BMSW} 0.12 m^3	C_{BMSW} 0.24 m^3	C_{BMSW} 0.77 m^3	LSC 18 m^3
Area A*				
2012	5/11	33/70	-	4/4
2013	5/11	45/88	-	4/4
2014	5/10	86/170	-	4/4
2015	5/11	86/170	-	4/4
Area B*				
2012	-	88/330	-	1/2.7
2013	-	88/310	-	1/3.8
2014	-	-	33/137	1/1.5
2015	-	-	34/123	1/2.3

**-total of containers/collected containers per month (C_{BMSW} – adjusted BMSW containers; LSC -large-sized containers).*

Increasing the number of CBMSW 0.24 m^3 containers (and the associated increase of the number of participating residences) influenced the total volume of collected BMSW between 2012 and 2015 at the side of rural area A with effective separation. This trend, recalculated to average monthly BMSW production by individual drive of collection, is presented in Table 10. Table 10 is also complemented by appropriate values of relative amount of BMSW in RMSW in percent. This table represents the standard data transformation for mentioned statistical methods in the chapter Materials and Methods.

Table 10. Average values from data obtained for individual quarters of the years 2012–2015 (Standard transformation)

Quarter\year	2012	2013	2014	2015
1Q	0	0	0	0
2Q	13.00	5.00	8.00	12.00
3Q	16.00	11.00	16.00	9.00
4Q	7.00	9.00	8.00	2.00
1Q	0	0	0	0
2Q	2.14	2.38	4.61	6.13
3Q	3.95	5.49	7.73	9.09
4Q	1.16	3.36	4.11	3

**-collection of C_{BMSW} containers (0.12 and 0.24 m^3).*

The first of result of the analysis by STATISTICA 8 is focused on determining the correlation coefficient (the Correlations matrices function) in Table 11. The simple regression summary is presented in Table 12. The Coefficient of Determination R^2 can be considered as a percentage of the total variability of the response variable, as explained by the regression model. However, use of the Adjusted Coefficient of Determination R^2 is recommended (Šmilaur, 2007).

'*F* statistics', resulting from the analysis of the variance regression model, was carried out as an intermediate step of the selected regression function (Table 13).

Values of the Mean Squares in Table 10 were used for testing the significance of the regression model, whereas the key value used was the ratio of the model mean square and the residual mean square. In the case of the null hypothesis, the value of this ratio should be relatively close to 1 (i.e., the explained and unexplained variability should be of a similar size). More precisely (for this particular model), it should originate from the F disturbance with a parameter value of 1.14 (for the presented model). Nevertheless, the probability that the true value of this ratio, i.e. the *F* statistic (with a value of 15.01014), originates from this F disturbance is less than 0.000001 or equal to 0^6, as confirmed by the values in the '*p*-level' column. Hence H_0 can be rejected with this probability of a Type I error (at the concerned level of significance).

Table 11. Result of correlation values

	Correlations (Table 10) Marked correlations are significant at $p < 0.05000$ $N = 16$ (Case deletion of missing data)
Variable	[t]
[%]	0.7193 $p = 0.000$

Table 12. Results of regression for Average The development of biodegradable municipal solid waste production per one collection drive

	Regression summary for Dependent Variable: [%] (Table 10) R = 0.71931223 R^2 = 0.51741008 Adjusted R^2 = 0.48293937 F(1.14)=15.01014 p < 0.00168 Std.Error of estimate: 0.04019					
N = 16	Beta	Std.Err. of Beta	B	Std.Err. of B	t(14)	p-level
Intercept			0.024204	0.015839	1.528144	0.148751
[%]	0.719312	0.185663	0.014296	0.003690	3.874292	0.001685

Note: The R field contains the coefficient of correlation, which is the positive square root of R-square;
The R^2 field contains the coefficient of determination, which measures the reduction in the total variation of the dependent variable due to the independent variable;
The Adjusted R^2 is interpreted similarly to the R^2 value except the adjusted R^2 takes into consideration the number of degrees of freedom;
The F-value, df and resulting p-value is used as an overall F-test of the relationship between the dependent variable and the set in independent variables;
The Standard error of estimate measures the dispersion of the observed values about the regression line. The Intercept field contains the intercept value if you selected to include the intercept in the model on the Model Definition - Advanced;
The Std. error field contains the standard error of the intercept;
The t-value with the resulting of p-value are used to test the hypothesis that the intercept is equal to 0; The beta coefficients are the regression coefficients you would have obtained had you first standardized all of your variables to a mean of 0 and a standard deviation of 1;
The N is total number of observations.

Table 13. ANOVA results

	Analysis of Variance; *DV*: [%] (Table 10)				
N = 16	Sums of Squares	*df*	Mean Squares	*F*	p-level
Regress	0.024245	1	0.024245	15.01014	0.001685
Residual	0.022614	14	0.001615		
Total	0.046859				

Note: The N is total number of observations.

We present below a graphical representation of the regression line, (Fig. 2).

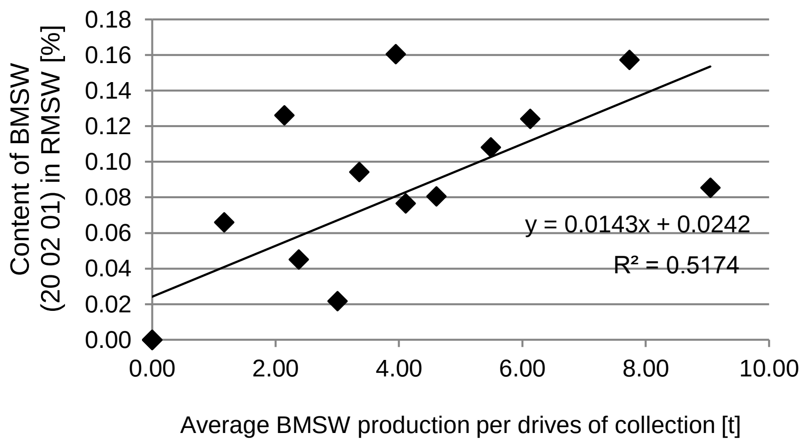

Figure 2. Graphical representation of regression.

According to Fig. 1. in more detail, there is a decrease of relative content of BMSW 20 02 01 in RMSW approximately from 10.77% to 7.08% here in monitored years 2012–2015 and these values remain in the site A. This state is achieved by providing a sufficient number of containers and with probably consequently shortening the delivery distance. On the other hand there was no reflection of separate BMSW collection in RMSW composition at the site B. The representation of BMSW in RMSW still remains about 10% in monitored period. Stable values were also observed at the referential sites C and D and without separate BMSW collection. At the site B, where separate system of BMSW collection has also been introduced, the collection did not have a positive effect, probably there was an increased number of 24 m^3 C_{BMSW} containers in exchange for a decrease in 0.77 m^3 C_{BMSW} container numbers. Thus the delivery distance could have extended above the tolerable limit which means higher efficiency of BMSW collection system. In the view of comparison of these both sites through the use indicator of Waste generation per capita per year (Teixeira et al. 2014 and CML et al. 2014) is also evident a difference in the achieved value 122 kg·person^{-1} year^{-1} (site A) and 20 kg person^{-1} year^{-1} (site B) in the last year of measurement 2015.

An assessment of the mean values of input data (site A) further proves a statistically significant relation between the relative amount of BMSW in RMSW and the average monthly BMSW production (r = 0.7193, α = 0.05, n = 16). In other words, the Relative amount of BMSW in the rural area A depends on the average monthly BMSW production by settings of collection parameters, from the perspective of the overall size of this site. The positive relationship was furthermore enriched by regression analysis; however this does not necessarily reflect a causal relation (in fact, only non-manipulated areas were observed). Thus, the relative amount of BMSW in RMSW is influenced by non-measured factors. Furthermore, as the distribution of regression residuals around the x-axis shows, there exist some differences between the real (observed) and predicted (fitted by the regression model) values of the variables in the regression equation. An increasing number of C_{BMSW} 0.24 m^3 containers was influence the analysed components and additionally a families participating at least once per month in separating/total number of families also could play a certain role like as another factor with the possible influence. (Martinho, G., et al., 2017).

CONCLUSIONS

The principal objective of the present study was an evaluation of BMSW collection in sites A, B, C and D in the period of 2012–2015. The authors also studied the influence of the average monthly BMSW production on the relative amount of BMSW in RMSW at the side of rural area with effective collection.

The study proves that the average monthly BMSW production influence the relative amount of BMSW in RMSW and mathematically defines this dependence. Available data for individual quarters of 2012–2015 confirm the following regression compensation straight line of the average monthly BMSW production **p** and the relative amount of BMSW in RMSW **T** in rural area A: T = 0.0242 + 0.0143.p.

The decrease of BMSW in RMSW at site A indicates that the directive on landfills can be followed with well-chosen technological parameters of separate BMSW collection at a given site. It confirms the statistically significant relation. Improperly adjusted technological parameters at site B indicate that this site has total monitored results parallel to referential areas without separate collection. It means then, that the municipality has only an increase in costs for BMSW disposal without concrete positive effects of separate BMSW collection and on the environment.

Hence it is necessary to continually analyse the collection data, rigorously evaluate and carry out immediate remedial measures and optimize the biodegradable municipal solid waste technological parameters at given sites with separate collection.

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Skeletal muscle tone and motor performance characteristics in dentists as compared to controls

J. Ereline[1,*], K. Pärenson[2], D. Vahtrik[1], M. Pääsuke[1] and H. Gapeyeva[1]

[1]University of Tartu, Faculty of Medicine, Institute of Sport Sciences and Physiotherapy, 5 Jakobi Street, EE51014 Tartu, Estonia
[2]Selfdiagnostics GmbH OÜ, Rävala pst 3/Kuke 2, EE10143 Tallinn, Estonia
[*]Correspondence: jaan.ereline@ut.ee

Abstract. The daily work tasks of dentists are associated with repeated movements and static load during the treatment of patients. Dentists' profession includes manual dexterity and maintaining the occupational posture for a long time. Previously it has been noted that dentists have increased muscle stress in neck, shoulder and lower back regions. The aim of the present study was to compare the muscle tone and motor performance characteristics of neck and shoulder region in dentists and representatives of other professions who do not have similar static load of long-time duration (as controls). Twenty women aged 34–55 years participated in the study: ten dentists with the age (mean and SE) of 40.2 ± 3.9 years and ten controls (bookkeepers, security guards, office workers, printing house workers, laundry and dry cleaning workers) with the age of 40.9 ± 2.4 years; working period was on the average 14 years in both groups. The tone characteristics of *m. trapezius* and *m. extensor carpi radialis* were investigated by device Myoton-2 (Müomeetria Ltd, Estonia) at rest and at maximal voluntary contraction (MVC) in sitting position at the workplace of participants. The cervical range of motion (CROM) and the handgrip strength were measured. Significantly higher ($P < 0.05$) tone and elasticity characteristics of *m. extensor carpi radialis* and lower ($P < 0.05$) tone and elasticity characteristics of *m. trapezius* at rest were noted in dentists compared to controls. At MVC, no significant differences were found in the studied characteristics between body sides in the measured groups. Dentists had lower ($P < 0.05$) CROM of flexion and rotation than controls. In dentists emerged significant difference in muscle elasticity characteristics for the right body side, this is related with stretching for dentistry instruments.

Key words: muscle tone, muscle elasticity, handgrip strength, range of motion, dentists.

INTRODUCTION

The daily work tasks of dentists are associated with repeated movements and static load during the treatment of patients. Dentists' profession includes manual dexterity and maintaining the occupational posture for a long time. Previously it has been noted that dentists have increased muscle stress in neck, shoulder and lower back regions (Hope-Ross & Corcoran, 1985). A recent study, where three dentists' work postures were analyzed by the Rapid Upper Limb Assessment Quick Exposure Check in videoanalysis, also indicated that the risk of developing musculoskeletal disease was greater in the lower back and neck area (Park et al., 2015). The dentist works in a very limited area (the patient's mouth), where they have to use the treatment tools with great accuracy. This kind of work includes both static and dynamic movements that can cause a variety of musculoskeletal ailments (Pope-Ford & Jiang, 2015; Ohlendorf et al., 2016). For dentist the sitting position is good for attaining sufficient support in work operations requiring great precision, but it is not suitable in terms of the range of movement and implementing strength. Therefore, compromises and solutions have to be found to make the posture during work comfortable and efficient (Micholt, 1990).

The working position is partly conditioned by the requirements of the surrounding factors and the necessity of using force, the other part depends on the fitness of the person and his/her command of specific movement skills, including the application of force, as well as the ability to relax between work operations. Consequently, the profession requires a good general working position, establishing suitable individual positions for conducting different procedures, experience and knowing one's body (Micholt, 1990). The study of Ohlendorf et al. (2016) showed that for the most part, dentist is working with the head bent from 45° to 90° (58–83% of the total work time). Tilting one's head down increases the forces necessary for maintaining the position of the shoulders and neck and for the contraction of the respective muscles (Micholt, 1990). In review article of Gupta et al. (2013) it was concluded that repetitive motion, exertion, extreme posture evoke muscle fatigue and imbalance, which could lead to changes in musculoskeletal system (increase of tension, compression, tears probability, as well as laxity, constraint and instability in joints) and to microtrauma, and in some cases to cumulative trauma disorder. Less attention in the literature has been paid to the evaluation of shoulder and neck muscle tone in dentists.

The aim of the present study was to compare the muscle tone and motor performance characteristics of neck and shoulder region in dentists and representatives of other professions who do not have similar static load of long-time duration (as control group).

MATERIAL AND METHODS

Participants

Twenty women aged 34–55 years participated in the study: ten dentists and ten non–dentists as controls (bookkeepers, security guards, office workers, printing house workers, laundry and dry cleaning workers). The dentists had been working on the average for 14 years and at least 8 hours per day. Control group participants had the similar mean duration of work. The selection criterion was 8-hour work daily during the period of 10 or more years. The following exclusion criteria were accepted: cardiac illnesses, neurological illnesses or any other illness which could interfere with motor functions, arterial blood pressure higher than 140/90 mm/Hg and lower than 110/70 mm/Hg; obesity (body mass index (BMI) greater than 30 kg m^{-2}) or being underweight (BMI lower than 18 kg m^{-2}), history of cerebrovascular disease; acute febrile illness within the previous month; significant emotional distress or depression within the previous year; and upper limb arthritis or joint replacements other reason for inability to perform maximal contractions of upper limbs without severe pain.

Age and anthropometric data of participants are presented in Table 1. All participants were right-handed.

Table 1. Age and anthropometric data of participants

Characteristics	Dentists (n = 10)	Controls (n = 10)
Age (year)	40.2 ± 3.9	40.9 ± 2.4
Body height (cm)	165.7 ± 1.2	164.6 ± 1.5
Body mass (kg)	66.7 ± 2.7	67.8 ± 2.9
BMI ($kg \cdot m^{-2}$)	25.1 ± 1.7	26.5 ± 1.1

Note: BMI – body mass index. Data are mean and standard error (SE); difference between dentists and controls is not significant ($P > 0.05$).

The persons were asked to avoid caffeine consumption for 24 h before the experiment and avoid participation in any sports activity one day before the testing. The direct ergogenic effect of caffeine on the skeletal muscle's force and duration of contraction has been shown (Tarnopolsky, 2008; Olorunschola & Achie, 2011). The study was performed at participants' workplace. Before the testing the participants had a rest of about 20 min sitting on the chair with a back support. The room temperature was maintained at 24 °C. All measurements were conducted in the same time of day and their sequence is described below in Methods. All subjects signed a written informed consent for participation in the study.

In the present study, the following parameters were measured: tone characteristics of skeletal muscles, range of motion in cervical part of spine and hand grip strength.

Muscle tone measurements

The tone characteristics of *m. trapezius* and *m. extensor carpi radialis* were measured by device Myoton-2 (Müomeetria Ltd, Estonia) at rest and at maximal voluntary contraction (MVC) for right and left body sides (Fig. 1). This method has been described previously by Vain et al. (2015). Studies have demonstrated that Myoton-2 is a reliable device for measuring muscle tone characteristics (Bizzini & Mannion, 2003; Viir et al., 2006). Measurements of the central part of muscle belly were performed in sitting position on chair without support on back-rest and armrests, and without chair height control. *M. extensor carpi radialis* was tested while the arm was flexed in elbow joint approximately at 90 degrees; for measurement at rest the participant was asked to relax the arm muscle, and for MVC the participant was asked to extend the hand with maximal strength and maintain the contraction during 2–3 s. *M. trapezius* was tested with arm positioned on the thigh, and the participant was asked to relax shoulder girdle and neck muscles; for MVC the participant was asked to maintain the standard load of 2.25 kg in each hand during 2–3 s (straight arm at 90 degrees of adduction). Five measurements in each muscle point were performed using MultiScan mode, and mean data of the following characteristics were used for data analysis: frequency of muscle oscillations (FMO, Hz) – characteristic of muscle tone or stress, and logarithmic decrement of the dampening of muscle oscillations (LDMO) – characteristic of muscle elasticity. Lower LDMO values characterize muscle with better elasticity.

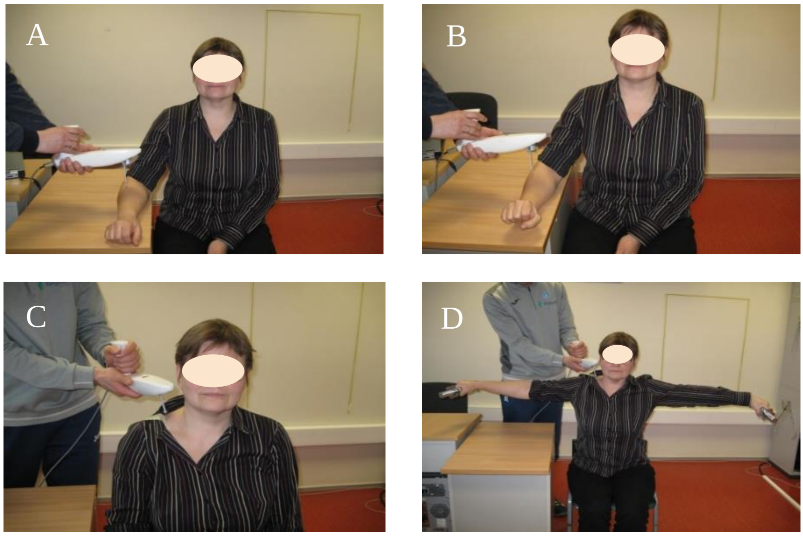

Figure 1. Measurements of tone characteristics at rest and at maximal voluntary contraction in *m. extensor carpi radialis* (A and B, respectively) and in *m. trapezius* (C and D, respectively).

Cervical range of motion measurement

The active cervical range of motion (CROM) was measured by Keno® cervical measurement system (Kuntoväline Oy & David Fitness Medical Ltd, Helsinki, Finland). The device is aligned on the nose and ears and fixed on the head by a velcro belt. Measurements were performed in sitting position. Participants received instruction to incline the head towards the chest as far down as possible (to measure flexion); to incline the head to the right (or to the left) (to measure lateral flexion), and to turn the head to the right and left side as far as possible with keeping the neck stright (to measure rotation). Previously the good reliability of the measurement device has been noted (Peolsson et al., 2000). Three measurements were performed for each head movement and the best result was accepted for data analysis.

Muscle strength measurement

The hand grip strength was recorded for the right and left arm by hand-held dynamometer JAMAR (model J00105, Lafayette Instrument Company, USA). The high reliability of measurements with this device has been shown by Roberts et al. (2011). Three measurements were performed for each hand with the pause of one minute and the best result was accepted for data analysis.

Statistical analysis

Data are means and standard errors of the mean (± SE). Descriptive statistics were calculated using Statistica v.13.0 software. Shapiro-Wilk test was used to analyse normality of data distribution. One-way analysis of variance (ANOVA) followed by Tukey's post hoc comparisons were used to test for differences between groups and between the right and left sides of the body of the all measured characteristics. A level of $P < 0.05$ was selected to indicate statistical significance.

RESULTS AND DISCUSSION

Comparison of measured characteristics between two groups

Age and measured anthropometric characteristics (body mass, height and BMI) did not differ significantly between the groups of dentists and controls (Table 1). In dentists and controls the mean BMI was greater than 25.0 kg m^{-2} (overweight) by 0.4% and by 6.0%, respectively.

The tone characteristic – FMO of the *m. extensor carpi radialis* (Fig. 2, A) at rest was higher ($P < 0.05$) in dentists compared to controls. This characteristic at rest differed ($P < 0.05$) in both groups – dentists and controls – between the right and left side of the body, and in dentists the FMO of the right side was 11% higher than in the left side, whereas in controls it was 5%. Difference of the FMO at MVC was not statistically significant between body sides and between groups.

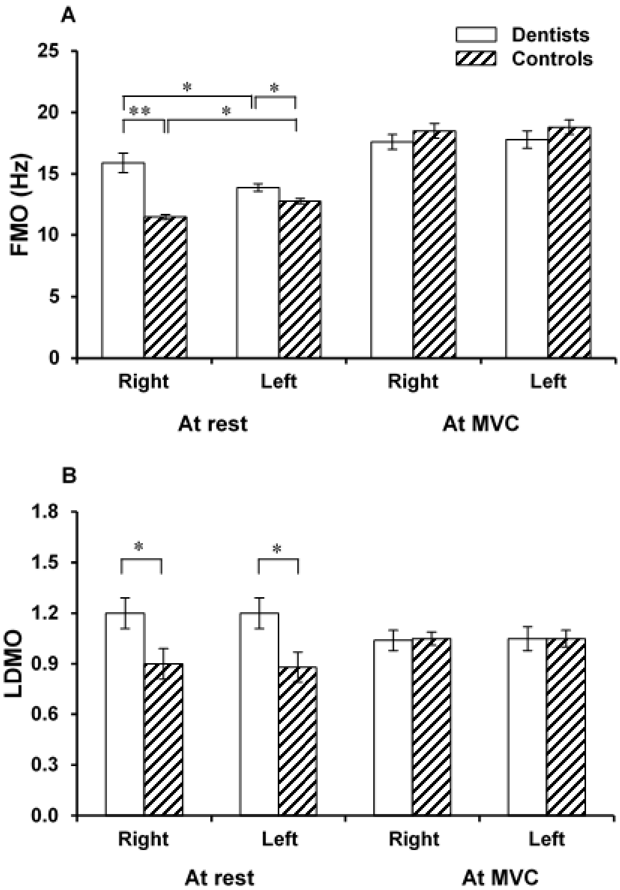

Figure 2. The muscle tone (frequency of muscle oscillation, FMO) (A) and elasticity (logarithmic decrement of the dampening of muscle oscillations, LDMO) (B) characteristics of *m. extensor carpi radialis* for right and left body sides at rest and maximal voluntary contraction (MVC) in dentists (n = 10) and controls (n = 10) (mean ± SE); *: $P < 0.05$.

The elasticity characteristic – LDMO of the *m. extensor carpi radialis* (Fig. 2, B) at rest was greater ($P < 0.05$) on the average by 12% for both body sides in dentists compared to controls. This characteristic at MVC did not differ significantly between dentists and controls.

The FMO of the *m. trapezius* (Fig. 3, A) of the left body side at rest was lower in dentists ($P < 0.05$) as compared to controls. Difference between body sides in FMO was not statistically significant in both groups of participants. This characteristic at MVC was lower in dentists as compared to controls for the right and left body side on the average by 6%, but this difference in controls was not statistically significant.

The LDMO of the *m. trapezius* (Fig. 3, B) at rest was lower in dentists compared to controls on the average by 14%, this difference for the right side of the body was significant ($P < 0.05$). The LDMO at MVC was greater ($P < 0.05$) on the average by 15% in dentists compared to controls.

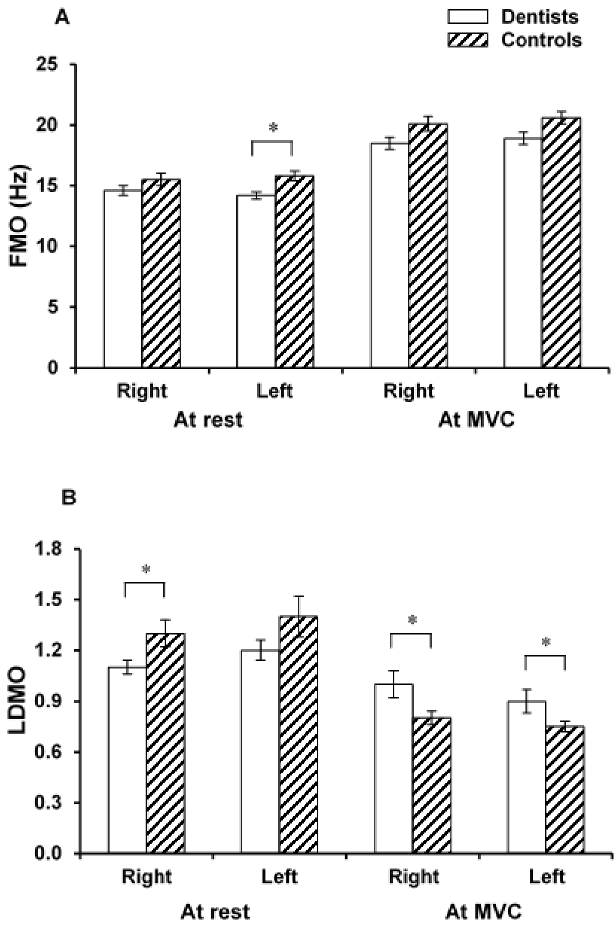

Figure 3. The muscle tone (frequency of muscle oscillation, FMO) (A) and elasticity (logarithmic decrement of the dampening of muscle oscillations, LDMO) (B) characteristics of *m. trapezius* for right and left body sides at rest and maximal voluntary contraction (MVC) in dentists (n = 10) and controls (n = 10) (mean ± SE);. *: $P < 0.05$.

FMO and LDMO of the *m. trapezius* did not differ significantly between the right and left body side in both group participants.

The handgrip strength (Table 2) of the right hand was greater by 8% than in the left hand for both groups and handgrip strength was in dentists greater on the average by 5% as compared to controls, but the difference was not statistically significant. The values of CROM of flexion and rotation (both to the right and to the left) were lower ($P < 0.01$) in dentists compared to controls. Data of CROM of extension and lateral flexion did not differ significantly between the two groups.

Table 2. The motor performance characteristics of dentists and controls

Characteristics	Dentists (n = 10)	Controls (n = 10)
HGS right (kg)	36.4 ± 2.5	31.1 ± 2.6
HGS left (kg)	32.4 ± 1.8	29.1 ± 2.1
CROM of flexion (°)	52.4 ± 3.1**	65.1 ± 3.3
CROM of extension (°)	62.4 ± 3.8	60.1 ± 3.1
CROM of flexion to the right (°)	49.4 ± 1.7	47.4 ± 1.9
CROM of flexion to the left (°)	49.9 ± 2.1	46.3 ± 2.2
CROM of rotation to the right (°)	55.1 ± 1.5**	62.9 ± 2.1
CROM of rotation to the left (°)	56.6 ± 1.4*	61.3 ± 1.6

Note: HGS – hand grip strength; CROM – active cervical range of motion. Data are mean ± SE; *: $P < 0.05$; **: $P < 0.01$ compared to controls. Difference between data of HGS and CROM for the right and left body side were not signficant in both groups of participants ($P > 0.05$).

Comparison of data with previous studies' results

In the present study, the muscle tone characteristics of neck and shoulder region and motor performance characteristics were compared between dentists and control group participants. Participants in both groups were in average slightly overweight, this can be partly explained by prevalence of sitting time during work day. In the present study we did not record the length of time spent sitting and being physically active in participants' work day schedule. In a cross-sectional study of 300 health service providers (HSP) with the mean age of 39.3 years (Iwuala et al., 2015), where 47.7% were medical doctors and dentists, 43.3% were nurses and other categories of HSPs, the authors found that 27.3% of HSPs were obese, 44.7% overweight, and 49.7% had abdominal obesity. Another cross–sectional interview-based questionnaire study of 313 dentists with the mean age of 32.6 years and the prevalence of females (76.6%) revealed that 60.7% of participants were physically active, but professionals aged 41–50 years and those in the teaching field spent more time in sedentary behavior (Srilatha et al., 2016).

We investigated tone and elasticity characteristics of the *m. extensor carpi radialis* and *m.trapezius* using the myotonometry method (Vain et al., 2015). The results of the study showed that in rest both dentists and controls had asymmetry of tone and elasticity characteristics of the right and left body sides of *m. extensor carpi radialis*. Also dentists demonstrated higher muscle tone and lower elasticity (in case of bigger LDMO) of *m. extensor carpi radialis* at rest than controls. Manual asymmetric and mostly right-handed repetitive operations in dentists' work and taking into account the long period of practising – in the current study the average duration of work was fourteen years – lead to muscle fatigue and imbalance. These data are in line with conclusions presented previously (Gupta et al., 2013). It was confirmed that greater muscular activity on one side of the trunk could reduce the right/left symmetry of respiratory kinematics and consequently the self-compensation of their disturbing effect in the coronal plane; it may also disturb the proprioceptive flow of the sensory input displayed by the muscles spindles, which have a prominent role in postural equilibrium maintenance (Roll & Roll, 1988).

In contrary, dentists had lower muscle tone and higher elasticity (in case of lower LDMO) of *m. trapezius* than controls. These results can be explained by the dentists having a repeated static load in a specific working position. Participants in the control group also worked in static position, but their working approaches differ significantly from dentists' techniques (Hagberg & Wegman, 1987; Ardahan & Simsek, 2016). Viir et al. (2007) studied muscle tone and elasticity of *m. trapezius* in 15 healthy right-handed female computer operators with the mean age of 27 years and BMI 19.7 kg m^{-2} in low load bearing (supine position on the examination table) and voluntary uncontracted state (sitting on chair with a back-rest and without armrests); the duration of work was not mentioned. They found that immediate decrease in the tone of the upper part of *m. trapezius* by 20% occurs with a change from a sitting position to a supine position and demonstrates that maintaining the sitting position requires greater tension (the values for FMO of *m. trapezius* of the right and left side decreased from (mean ± SD) 13.1 ± 1.1 Hz to 10.8 ± 0.6 Hz and from 12.9 ± 1.1 Hz to 10.1 ± 0.8 Hz, respectively). Muscle tone values of our study participants for this muscle in sitting position are higher, but they are older and have been working for a long period. Working in sitting position could be one factor influencing muscular stress and postural control. Increased isometric push effort in a sitting position was associated with greater sway path and mean displacement of the center of pressure along the antero–posterior axis (Hamaoui et al., 2007). Moreover, it was suggested that increased muscular tension along the torso induces a more disturbing effect on posture when it is asymmetrical (Hamaoui & Bozec, 2014). Regular brief breaks of simple movements as well as being in the supine position to recover from prolonged sitting have been recommended (Viir et al., 2007).

When comparing the flexibility of the cervical spine between the two groups, we found that dentists had the deficit of neck extension and rotation range of motion compared to controls. This can be explained by the relatively static set of dentists' working postures that cause tension in neck and shoulder muscles and evoke a heavy burden on the flexion and rotation of neck muscles (Kanteshwari et al., 2011; Gaowgzeh et al., 2015; Man-Sig, 2015). In studies on office workers and computer users it has been noted that during long working hours muscles stiffen and the mobility of the neck decreases (Andersen et al., 2013; Ardahan & Simsek, 2016). The duration of work can be one factor influencing neck flexibility and development of postural disorders of the head and neck area. However, a recent study investigated the forward head posture (head is in front of the gravitational line) in 41 dentists (21 women and 20 men), and the mean values of cervical curve in dentists and the control group did not differ significantly. Besides, the authors did not find statistical differences in cervical curve values in dentists working for either 5–8 years or 8–12 years. The mean cervical curve values of men were longer than in women in the dentists' group (Mostamand et al., 2013).

The dentists' handgrip strength of the right and left hand was similar to the related characteristics in the control group. These data are comparable with the study of Fayez (2014), where handgrip strength in dentists with the mean age of 31.3 ± 4.9 years was

33.4 ± 13.1 kg (measured by JAMAR device as in the present study). The results of our study can be explained by the measured groups being comparable in regard to the static and dynamic activities of the working day and, consequently, similar handgrip strength.

The limitation of the present study is that participants were not asked about the intensity of pain in the cervical, thoracal and lumbar parts of spine and in shoulder girdle region. Fayez (2014) study showed high correlation between neck pain intensity and handgrip strength in 25 dentists with chronic neck pain. Also, the work place comfort and ergonomy were not studied. The ergonomic aspects of working place could be the major factor influencing muscle tone and motor performance characteristics in dentists. In the study of 231 dental students the knowledge, practice, and condition of work place regarding ergonomic posture were determined (Munaga et al., 2013). Authors found that 70% of dental students perform torsion of the body and cervical flexion to improve vision and prefer direct vision when working. Only 59% of students reported that they are working with ergonomically designed dental unit and instruments. Most of them reported that the work stool is not comfortable. The knowledge of ergonomic postural requirements and their clinical application among the dental students surveyed were not satisfactory. On base of this study it was suggested that a multifactorial approach that includes preventive education, postural and positioning strategies, proper selection, and use of ergonomic equipment should be employed.

CONCLUSIONS

Significantly higher tone and elasticity characteristics of *m. extensor carpi radialis* and lower tone and elasticity characteristics of *m. trapezius* at rest were noted in dentists compared to controls. Dentists also demonstrated significant differences in the characteristics of muscle tone and elasticity of *m. extensor carpi radialis* between the right and left body side; that can be explained by specific work position and prevalence of right-handed manipulation with dentistry instruments. At maximal voluntary contraction, lower elasticity of *m. trapezius* was noted in dentists as compared to controls.

The active range of motion in neck flexion and rotation of dentists were lower compared to controls. The long (at present case more than ten years) duration of work can influence neck flexibility.

In dentists, handgrip strength of the right and left hand was similar to the respective characteristics of the control group.

Future studies could investigate the immediate influence of 8-hour work and the effect of a long period of employment on muscle tone and motor performance characteristics on dentists with comparison of different ergonomic environments. Additionally, the role of physical activity and occupational physiotherapy in the reduction of asymmetry in muscle function characteristics could be studied. It is recommended that during the work day dentists and office workers have short breaks (5–10 minutes) every hour with performing the set of therapeutic exercises to reduce the load of musculo-skeletal system due to prolonged sitting and fatigue.

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Experimental analysis of hydrotreated vegetable oil (HVO) and commercial diesel fuel blend characteristics using modified CFR engine

M. Gailis[1,2,*], J. Rudzitis[1], J. Kreicbergs[1] and G. Zalcmanis[1]

[1]Riga Technical University, Faculty of Mechanical Engineering, Transport and Aeronautics, Department of Automotive Engineering, Viskalu 36A, LV 1006 Riga, Latvia
[2]Latvia University of Agriculture, Faculty of Engineering, Department of Mechanics, Liela street 2, LV 3001, Jelgava, Latvia
[*]Correspondence: maris.gailis@rtu.lv

Abstract. Performance parameters of different commercial diesel fuels is a subject of interest for fuel consumers. Fuel retailer Neste recently introduced a new brand of WWFC 5th grade diesel fuel in Baltic market, consisting of diesel fuel and hydrotreated vegetable oil (HVO) blend. Fuel samples have been recently tested on chassis dynamometer, measuring wheel power and torque and in road conditions, measuring fuel consumption. Evaluation of fuel consumption and performance parameters in road or laboratory conditions may yield uncertain results due to complexity of modern automobile engine management and emission reduction systems. To better evaluate the combustion, fuel samples have been tested in modified CFR engine at various intake air pressure, temperature and compression ratio settings. Engine indicated performance parameters and combustion phasing of regular diesel fuel and diesel fuel-HVO blend are presented. Comparing to regular diesel fuel, fuel blend with HVO showed reduced apparent heat release rate (AHRR) during premixed combustion phase at low inlet air temperature and low compression ratio conditions, comparing to regular diesel fuel. Premixed combustion phase AHRR of diesel-HVO blend increased above AHRR of regular diesel fuel at higher inlet air temperature and higher compression ratio conditions. Diffusion controlled combustion phase AHRR of diesel-HVO blend increased above AHRR of regular diesel fuel at higher inlet air temperature, higher compression ratio conditions and supercharged air supply.

Key words: Compression ignition, internal combustion, autoignition, heat release, ignition delay, IMEP, paraffinic fuel, NextBTL, biofuel, renewable fuel.

INTRODUCTION

Diesel fuels from renewable resources have been available in retail for some time. Traditionally those fuels are produced by esterification of vegetable oil and are not considered as premium fuel due to relative batch to batch variation of properties, low heating value, high cold filter plugging point, aging, water attraction, risk of biological contamination and high viscosity. Use of the first-generation biofuel, designated as ‘Fatty Acid Methyl Ester’ (FAME), is currently limited up to 7% volumetric blend in

EN590 summer grade diesel fuel. Use of neat FAME fuel is usually limited to pre-common rail era diesel powered automobiles. FAME is not added to winter grade diesel fuel in Nordic and Baltic countries. Another type of renewable diesel fuel has been recently commercialized. It is produced by hydrotreating vegetable or animal oils, and known as hydrotreated vegetable oil (HVO). Another designation for this product, used by oil producer Neste Group, is NextBTL. This promising renewable product contains mainly straight and branched alkanes, also known as paraffins. Other types paraffinic diesel fuel are gas to liquid (GTL) and Fischer-Tropsch (F-T) fuels. Paraffinic fuels does not contain oxygen and aromatics (Sajjad et al. (2014); Neste Group, 2016). As explained by Neste Group (2016), adding tens of percent HVO will improve lower grade base fuel properties and bring them up to the required standard. Premium grade diesel fuel, designated as 'Pro Diesel', has been introduced in Baltic market in 2016 by Neste Oil. This fuel is a blend of fossil diesel fuel and up to 15% vol. HVO. The interest of consumers on this product is high and fact based answers could be helpful. Effects of HVO and its blends with fossil diesel fuel on engine combustion, performance and emissions are investigated by many researchers, but some aspects are still unclear. Key properties of neat HVO are presented in Table 1. Neat HVO properties differ from EN590 standard diesel fuel mainly by cetane number, kinematic viscosity and density. HVO have higher heating value on mass basis, but lower density leads to lower volumetric heating value, comparing to typical EN590 fuel. Due to the differences, use of neat HVO may require recalibration of engine control system.

Aatola et al. (2008) investigated effect of injection timing on fuel consumption and regulated emissions using neat HVO and its blend with regular diesel fuel in heavy duty diesel engine with common-rail fuel injection system. Use of HVO with standard engine settings reduced nitrogen oxide (NO_x) production and gravimetric specific fuel consumption (SFC). Volumetric specific fuel consumption was increased with increase of HVO content in the blend. When injection timing was optimised for HVO, even greater emission reduction was found.

Sondors et al. (2014) used neat HVO and regular diesel fuel in the tractor Claas Ares 557ATX, equipped with engine John Deere 4045 with Stanadyne rotary distribution pump with electronic injection timing control. Engine power and torque was tested at full load conditions. Engine power and torque was decreased by approximately 5% and specific volumetric fuel consumption was increased by approximately 4% in tested engine whole speed range.

Pexa et al. (2015) compared in-line 4-cylinder Zetor 1204 engine performance characteristics using neat rapeseed methyl ester (RME) and neat HVO fuels. The engine was equipped with mechanical in-line injection pump, start of injection was 12° before top dead centre (TDC). They reported decrease of maximal engine power by 6.4%, using HVO. Difference in power and torque increased at higher engine speed. They found slight decrease of SFC, when HVO was used.

Napolitano et al. (2015) tested EN590 diesel fuel and hydrocracked diesel fuel-HVO blends in a light duty four cylinder 2 l diesel engine, equipped with closed loop combustion control, based on cylinder pressure trace analysis. Main injection timing was automatically adjusted to keep 50% mass fraction burning angle and indicated mean effective pressure (IMEP) close to target values, to cancel out differences of test fuel properties. They assessed fuel consumption and exhaust emissions at steady state conditions, using various engine load and speed points within New European Driving Cycle (NEDC) range. It was found that combustion process differences between tested fuels decreased with higher engine load. Increase of HVO in fuel blend increased combustion stability, decreased volumetric fuel consumption and brake specific fuel consumption. Pellegrini et al. (2015) tested apparently similar samples of fuel as Napolitano et al. (2015), using single cylinder engine with variable compression ratio. Injection timing was corrected to achieve the same crank angle of 50% of fuel mass burned depending on test fuel. They reported reduction of unburned hydrocarbons and CO emissions with increase of HVO part in fuel. At high exhaust gas recirculation (EGR) rate, 30%, effect of added HVO on reduction of NO_x emissions was negligible. Test fuels hade higher cetane number that was outside of the usual range of commercial diesel fuel. Pellegrini et al. (2015) and Napolitano et al. (2015) suggested that increase of cetane number by adding HVO in fuel was main contributor to combustion and emission differences between test fuels. Pellegrini et al. (2015) admitted that the methodology they used did not permitted to carry out a complete assessment of the fuels at constant engine setting parameters.

Karavalakis et al. (2016) assessed exhaust emissions and fuel economy from two heavy duty engines, Cummins ISX15 and ISB6.7. Both engines were equipped with current generation emission reduction systems. Testing was performed over the heavy-duty urban dynamometer driving schedule and heavy-duty diesel truck transient cycle, using CARB ULSD diesel fuel and diesel-HVO blends. Fuel economy, calculated using carbon balance method, was reduced in case of Cummins ISB6.7 with increase of HVO fraction in blend, but not in case of ISB6.7 engine.

Most researchers reported that use of HVO in diesel fuel blend reduced unburned hydrocarbon and CO emissions. Effect of adding HVO in diesel fuel blend on emissions of NO_x and particle matter, fuel consumption and engine torque and power is less clear and appears to be dependent on test conditions. Effect of HVO and other paraffinic fuel in diesel fuel on combustion phasing in some research reports is masked by corrected injection timing (Napolitano et al. 2015, Pellegrini et al. 2015). This approach is very useful to reveal possible benefits of paraffinic diesel fuel in future applications, where engine control system can adapt to fuels with different autoignition properties. Majority of actual practical diesel engine control systems do not have control loop with combustion process feedback. Sugiyama et al. (2011) reported that injection quantity using HVO is increased, comparing to diesel fuel. Using different injection timing and injected fuel volume for each test fuel and cetane number that is out of regular range, difference in combustion properties of diesel fuel un diesel – HVO blend is unclear.

This study differs from the work of other researchers by using standard engine type – CFR, and commercial grade diesel fuel – HVO blend with cetane number adjusted within standard range. By setting constant injection timing and injected fuel volumetric amount for standard diesel fuel and diesel fuel – HVO blend, and no pilot injection, autoignition and combustion properties of test fuels are clearly shown in various compression ratios, inlet air pressure un temperature.

MATERIALS AND METHODS

Experimental work was conducted at Riga Technical University, Engine Laboratory of Department of Automotive Engineering, January 2017.

Test Fuels

The fuels used in this study were purchased at the same time and the same Neste Latvia retail station on May 2016. Regular diesel fuel was designated as 'Artic Fuel, Class 0' and did not contain FAME. Properties of test fuels were obtained from refinery certificate of quality and are presented in Table 1. Only regular diesel fuel (D) and HVO-diesel fuel blend (DHVO) were used in testing. Properties of neat HVO are included for comparison. Fuels were stored in clean polyethylene containers.

Table 1. Properties of test fuel and neat HVO

Fuel	D	DHVO	HVO*
Density at 15 °C, kg m^{-3}	824.4	822.2	775…785
Cetane number	51.1	55.0	80…99
Cetane index	47.9	52.0	> 56.5
Viscosity at 40 °C, $mm^2\ s^{-1}$	1.937	2.537	3.500
Polyaromatics. % vol.	1.3	1.1	0.0
FAME. % vol.	0.0	0.0	0.0
HVO. % vol.	0.00	9.15	100.00

*HVO properties according to Aatola et al. (2008)

HVO consists of different alkanes (paraffins). It is known that addition of normal alkanes with long chain length to diesel fuel shortens autoignition time and increases cetane number (Glavincevski et al., 1984). Cetane index was introduced due to complexity and expenses of experimental determination of cetane number. Cetane index was not intended to use for alternative fuels, such as HVO (Murphy 1983; Bezaire et al., 2010). That explains high cetane number and approximate cetane index for neat HVO, shown in Table 1.

Engine and Instrumentation

The experimental setup consisted of single cylinder four stroke compression ignition engine, coupled with asynchronous electric motor, critical flow nozzle air flow meter, inlet air heater and in-cylinder pressure indicating system. The test engine technical characteristics are close to CFR F5 engine, which is a standard equipment for cetane number determination. The engine features 2-valve cylinder head with cylindrical variable volume pre-chamber. Engine compression ratio (CR) can be continuously changed by moving the plug in the pre-chamber. In-line high pressure fuel pump has micrometer type controls for setting fuel delivery rate and injection timing. Fuel is injected in the pre-chamber and the injector is equipped with a needle position switch.

Asynchronous electric motor maintains constant rotational frequency for motoring and firing. Critical flow nozzle is used for controlling inlet air mass flow and pressure, allowing imitation of naturally aspirated and supercharged engine operation. Engine air supply system is equipped with an inlet air heater and a surge tank. Main characteristics of the test engine are presented in Table 2.

Table 2. Characteristics of the test engine

Parameter	Value
Engine type	IDT69
Air supply	Controlled pressure and temperature
Coolant temperature, °C	100 ± 2
Bore and stroke, mm	85 × 115
Cylinder volume, cm^{-3}	652
Compression ratio	7 : 1 to 23 : 1
Fuel injector opening pressure, MPa	10.4 ± 0.4
Diameter of cylindrical pre-chamber, mm	42
Inlet valve opens/ closes, deg	10° ± 2° ATDC / 34° ± 2° ABDC
Exhaust valve opens/ closes, deg	40° ± 2° BBDC / 15° ± 2° ATDC
Valve overlap, deg	5° ± 2°
Engine speed, min^{-1}	900 ± 10
Power of absorbing electric motor, kW	5.5

In-cylinder pressure is measured in pre-chamber, using pressure transducer Kistler 6061B and charge amplifier Kistler 5018A. Inlet air pressure is measured using pressure transducer Omega MMA100. Inlet air temperature is measured with K-type thermocouples. Crankshaft angular position is detected using encoder EPC 702, with the resolution 0.1 crank angle degree (CAD). Data acquisition system is based on National Instruments chassis NI9068 and various input modules. In-house LabVIEW code was developed, allowing monitoring and data saving during the tests. More detailed description of this test engine setup can be found in Gailis et al. (2016).

Test Methodology

Test engine was started and warmed up to stabilise oil temperature around 40 °C and coolant temperature at 100 ± 2 °C. Engine speed was held constant at900 ± 10 min^{-1}. Before each test the start of injection (SOI) was set at 13° before top dead centre (BTDC) and fuel delivery rate was set at 13 ml min^{-1}. These settings were based on typical conditions for cetane number determination, using CFR engine. SOI was influenced by CR and inlet air pressure. Rising CR from 14 to 16 increased SOI advance by 1.5 CAD. Rising inlet air pressure by 0.7 bar increased SOI advance by approximately 2 CAD. SOI was adjusted before the test and monitored during the test. Design of the injector and low injection pressure were presumable reasons for this phenomenon.

Engine stabilization time between tests was 180 s in case of compression ratio or inlet air pressure change and 1,200 s in case of fuel change. Variable testing parameters are listed in Table 3. Testing was conducted in eight steady state operation points for both fuels. All combinations of parameter setup were tested. During each test data of 150 consecutive engine cycles were collected. To statistically evaluate the results, each test was non-consecutively repeated three times.

Table 3. Test conditions

Parameter	Value
Test fuel I	D
Test fuel II	DHVO
Inlet air temperature I, °C	65
Inlet air temperature II, °C	95
Compression ratio I	14 : 1
Compression ratio II	16 : 1
Inlet air pressure I, bar	1.0
Inlet air pressure II, bar	1.7

Data Processing

Data post processing and report generation is performed using in-house developed MATLAB code. Mean value of 150 consecutive engine cycles is used for cylinder pressure data analysis. Apparent heat release rate (AHRR) is calculated using Eq. (1) according to Stone (1999).

$$\frac{dQ_n}{d\varphi} = \frac{\gamma}{\gamma - 1} p \frac{dV}{d\varphi} + \frac{\gamma}{\gamma - 1} V \frac{dp}{d\varphi} \tag{1}$$

where dQ_n – apparent heat release rate, J deg^{-1}; φ – crank angle degree; γ – ratio of specific heats; V – cylinder volume, m^3; p – cylinder pressure, Pa.

Polytropic exponent is used as ratio of specific heats and calculated by finding polynomial fit coefficient for cylinder pressure and volume relation in logarithmic scale. Polytropic exponent is calculated separately for compression and expansion stroke of each engine cycle and mean value is used as ratio of specific heats for AHRR calculation. Value of polytropic exponent was different for each engine cycle. Approximate value of polytropic exponent was 1.3.

Cumulative heat release (CHR) is calculated using Eq. (2) according to Heywood (1988).

$$Q_n = \int_{\varphi start}^{\varphi_{end}} \frac{dQ_n}{d\varphi} d\varphi \tag{2}$$

where Q_n – cumulative heat release rate, J.

Relative cumulative heat release (RCHR) is calculated from CHR and stated in percent. RCHR is used for combustion phasing analysis. Duration of RCHR from start of combustion (SOC) to 30% is designated as initial combustion phase. Premixed combustion dominates in this phase. Duration of RCHR from 30% to 75% is designated as early combustion phase. Diffusion controlled combustion dominates in this phase. Duration of RCHR from 75% to 90% is designated as late combustion phase.

Indicated work is calculated using Eq. (3) according to Heywood (1988).

$$W_i = \int_{\varphi start}^{\varphi_{end}} p \, dV \tag{3}$$

where W_i – indicated work, J.

Gross indicated work is calculated only in compression and expansion strokes, so gas exchange work is excluded from the result. Indicated mean effective pressure ($IMEP$) is calculated from gross indicated work, using Eq. (4) according to Heywood (1988).

$$IMEP = \frac{W_i}{V_d} \tag{4}$$

where $IMEP$ – indicated mean effective pressure, bar; V_d – displaced cylinder volume, m^3.

To compare work efficiency of engine cycle between test conditions and fuels, IMEP is also calculated from indicated work, which is calculated in smaller intervals of 5 CAD. Difference between data points of the two tests of interest is calculated and analysed.

Temperature of charge at start of injection (SOI) is calculated using ideal gas law and Eq. (5).

$$T_{SOI} = \frac{p_{SOI} \cdot v_{SOI}}{m \cdot R_i} \tag{5}$$

where T_{SOI} – temperature at SOI, K; V_{SOI} – volume at SOI, m^3; m – mass of charge, kg; R_i – specific gas constant of air, J kg^{-1} K^{-1}.

Mass of charge is calculated using ideal gas law, taking inlet air temperature, in-cylinder pressure and volume after inlet valve closure.

RESULTS AND DISCUSSION

The results presented in this sub-chapter are arranged by compression ratio and inlet charge pressure.

Heat Release Rate Analysis

Cylinder pressure trace, averaged from 150 consecutive engine cycles is shown in Fig. 1, a & 1, b. Injector needle position switch signal indicated that injection time was constant for both fuels at all tested conditions. Duration of injection was 17 CAD and end of injection was 4° after top dead centre (ATDC).

AHRR trace is basically output of a simple thermodynamic model, which describes how much heat would have to be added, to produce observed pressure variations, assuming adiabatic compression and expansion process due to cylinder volume change (Stone 1999). The results of AHRR and RCHR calculation in conditions CR14/P1.0/T65 are shown in Fig. 1, c.

The ignition delay is followed by premixed combustion period. In this period, rapid combustion of evaporated fuel, which is mixed with the air within flammability limits occurs. In case, shown in Fig. 1, c, calculated bulk charge temperature at SOI is 627 K and measured cylinder pressure is 25.4 bar. Premixed combustion phase lasts from approximately 7° BTDC till 8° ATDC for both fuels. Heat release during premixed combustion phase rate is significantly higher for fuel D. Ignition delay difference for both test fuels is very small. Comparingly smaller amount of evaporated, mixed and burned fuel can be assumed in case of fuel DHVO. This can be attributed to different evaporation properties of HVO, comparing to diesel fuel. Distillation curves are presented in works of Aatola et al. (2011) and Napolitano et al. (2015). Approximately 50% of energy is released during premixed stage of combustion, using regular diesel fuel, comparing to 42% for DHVO fuel. Diffusion controlled combustion phase and late combustion phase appears to be extended for fuel DHVO, comparing to fuel D.

The results of AHRR and RCHR in conditions CR14/P1.0/T95 are shown in Fig. 1, d. Calculated charge temperature at SOI is 659 K and measured cylinder pressure is 24.7 bar. Due to relatively large ignition difference delay between fuels, premixed combustion of fuel DHVO starts at lower temperature and pressure, comparing to fuel D. Diffusion controlled combustion phase and late combustion phase appears to be extended for fuel DHVO, comparing to fuel D.

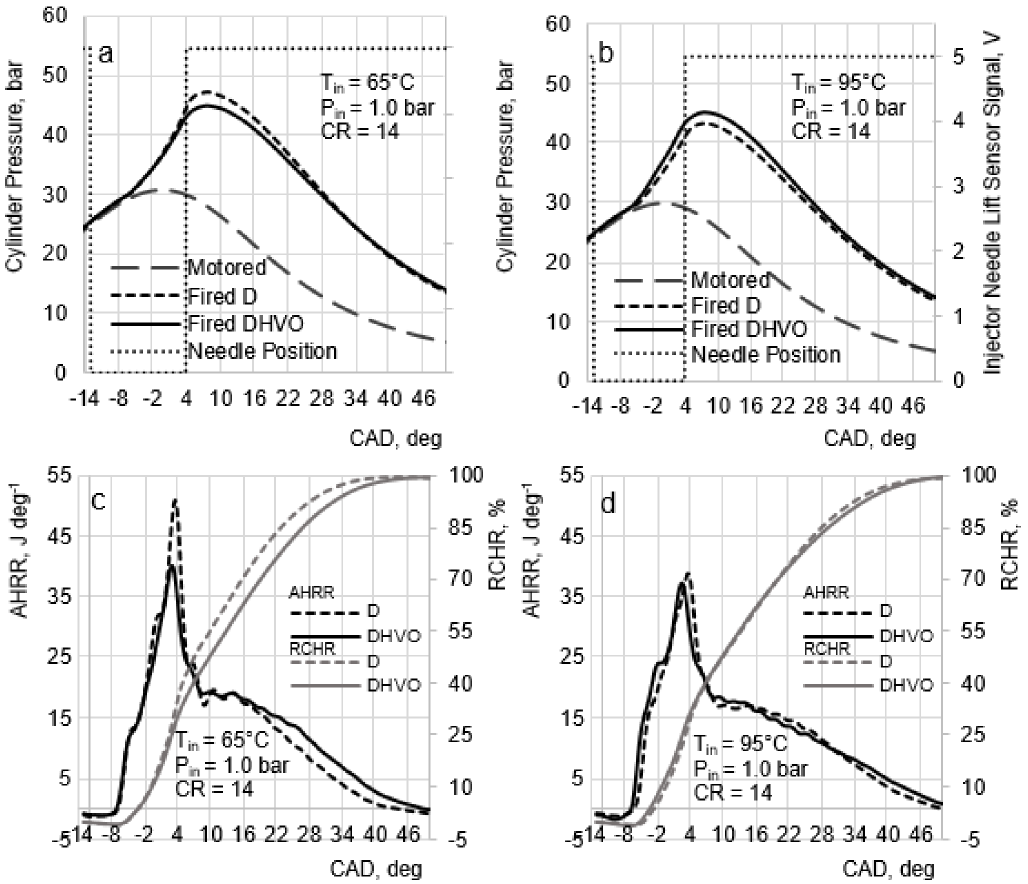

Figure 1. Cylinder pressure trace and injector needle position switch signal trace, apparent heat release rate and relative cumulative heat release, naturally aspirated mode, compression ratio 14 : 1.

The results of AHRR and RCHR in conditions CR14/P1.7/T65 are shown in Fig. 2, c. Supercharged operating mode is imitated in this case. Calculated charge temperature at SOI is 603 K and measured cylinder pressure is 43.3 bar. Premixed combustion phase is extended for fuel DHVO, comparing to fuel D. During diffusion controlled combustion phase, which lasts approximately from 7° to 24° ATDC, fuel D have higher AHRR and this phase is shorter for fuel D. The difference in diffusion phase duration is also shown in Fig. 8, a. During late combustion stage, fuel DHVO shows apparently higher AHRR.

The results of AHRR and RCHR in conditions CR14/P1.7/T95 are shown in Fig. 2, d. Calculated charge temperature at SOI is 649 K and measured cylinder pressure is 42.3 bar. Increase of initial charge temperature shortens premixed combustion phase for fuel DHVO, while having little effect on fuel D. AHRR during early diffusion controlled combustion phase is higher for fuel DHVO.

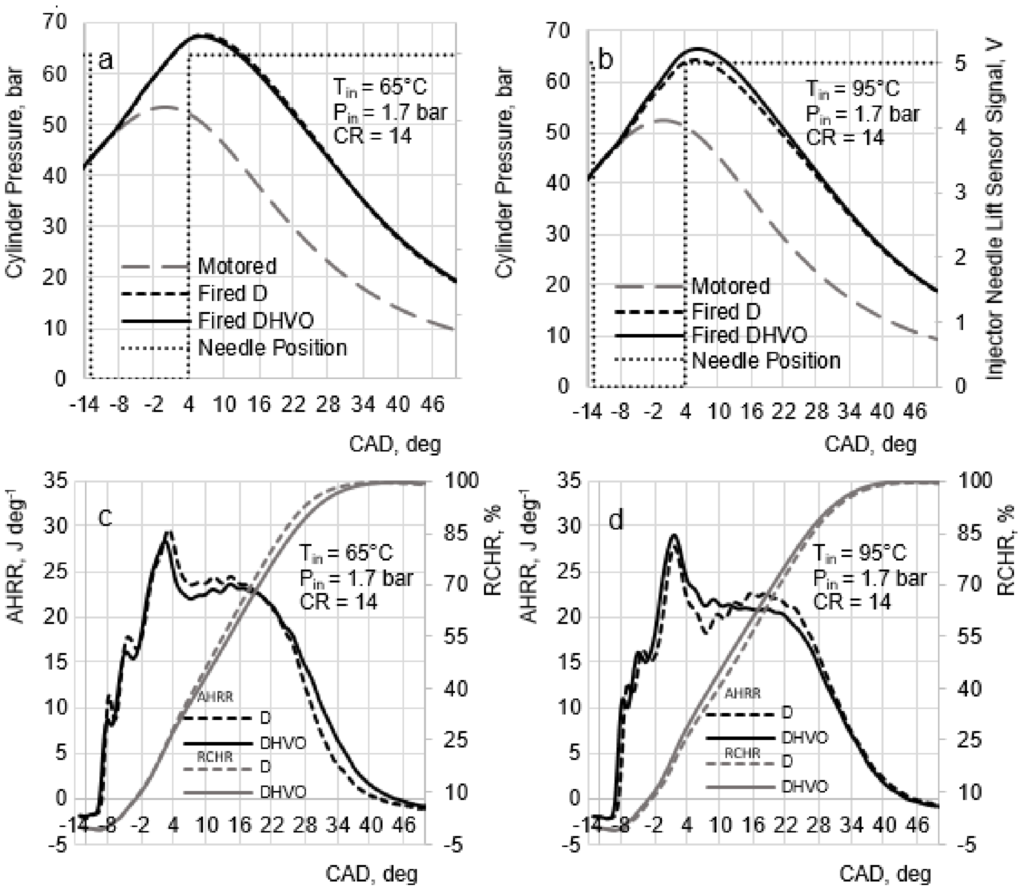

Figure 2. Cylinder pressure trace and injector needle position switch signal trace, apparent heat release rate and relative cumulative heat release, supercharged mode, compression ratio 14 : 1.

The results of AHRR and RCHR in conditions CR16/P1.0/T65 are shown in Fig. 3, c. Calculated charge temperature at SOI is 634 K and measured cylinder pressure is 29.1 bar. Difference in ignition delay between the both fuels is quite large. Despite of shorter ignition delay, premixed combustion of fuel DHVO starts and continues with higher AHRR, comparing to fuel D. During diffusion controlled combustion phase AHRR for fuel DHVO is significantly lower. Apparently, in this case, conditions for diffusion are more beneficial for fuel D.

The results of AHRR and RCHR in conditions CR16/P1.0/T95 are shown in Fig. 3, d. Ignition delay difference between test fuels is smaller, but combustion phasing is like in previous case.

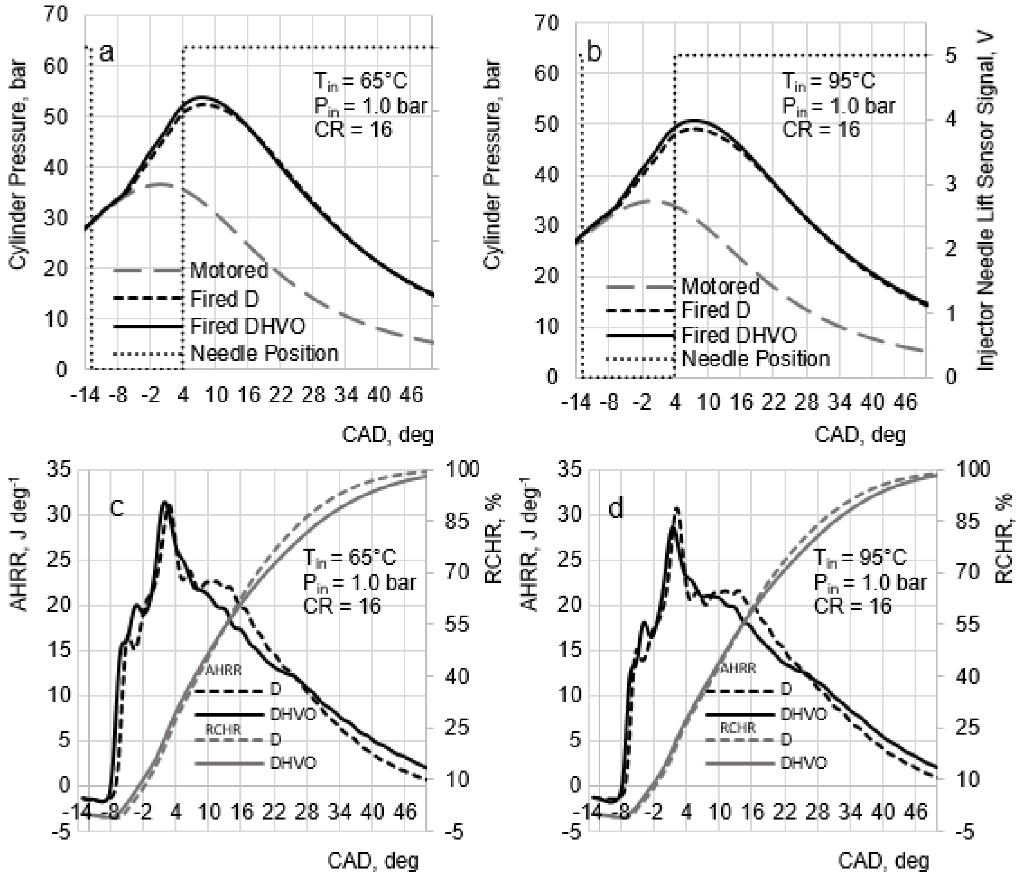

Figure 3. Cylinder pressure trace and injector needle position switch signal trace, apparent heat release rate and relative cumulative heat release, naturally aspirated mode, compression ratio 16 : 1.

The results of AHRR and RCHR in conditions CR16/P1.7/T65 are shown in Fig. 4, c. Calculated charge temperature at SOI is 614 K and measured cylinder pressure is 49.2 bar. Ignition delay is very close to the values of the case of CR14/P1.7/T65. By comparing those cases, it can be noticed that behaviour of the test fuels during premixed combustion phase is different. In this case, where initial charge temperature is higher, AHRR during early premixed combustion stage is higher for fuel DHVO, comparing to fuel D. The trend is opposite in lower charge temperature. During diffusion controlled combustion phase AHRR is lower for fuel DHVO and this phase is insignificantly extended, comparing to fuel D.

The results of AHRR and RCHR in conditions CR16/P1.7/T95 are shown in Fig. 4, d. Calculated charge temperature at SOI is 671 K and measured cylinder pressure is 48.3 bar. Absolute value of the ignition delay is very small and such is the absolute difference in ignition delay between test fuels. AHRR trace is similar for both fuels during premixed combustion stage. Low value of AHRR during this stage can be explained by raised temperature and pressure, comparing to another test modes.

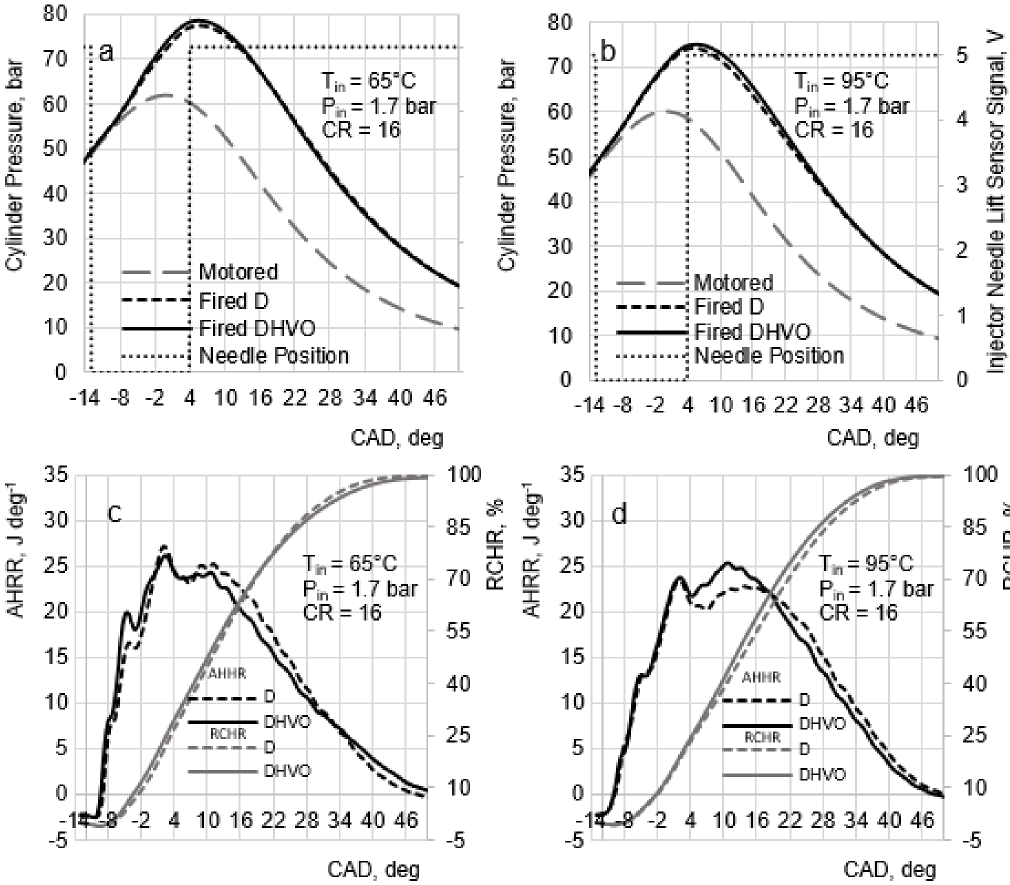

Figure 4. Cylinder pressure trace and injector needle position switch signal trace, apparent heat release rate and relative cumulative heat release, supercharged mode, compression ratio 16 : 1.

During diffusion controlled combustion AHRR is higher for fuel DHVO. At very late combustion stage AHRR is lower for fuel DHVO. This trend is opposite in another tested conditions.

Ignition Delay

Evaporation of the injected fuel decreases charge temperature and AHRR becomes negative following injection. Ignition delay is assumed as duration in engine cycle between SOI and the moment when AHRR becomes positive due to chemical energy release. During the ignition delay fuel droplets are evaporated and mixed with the air. The ignition delay is affected by physical factors such as pressure, temperature and charge motion and properties of the fuel. In this experiment, physical factors at the SOI point were kept similar for both test fuels. According to Heywood (1988), physical characteristics of the regular diesel fuel, such as vaporization rate and viscosity, does not significantly affect ignition delay in partially or fully warmed engines. Chemical properties of the fuel are another major contributor to ignition delay. A widely-used measure ability of the fuel to autoignite is cetane number. Cetane number was higher for test fuel DHVO, so shorter ignition delay for this fuel was expected.

Shorter ignition delay results in lesser amount of injected fuel mass before the combustion begins. Conditions, such as pressure and temperature, are constantly changing in the combustion chamber of the reciprocating engine during engine cycle due to movement of the piston. In this study SOI is kept constant between different tests.

If conditions for both test fuels are similar at SOI, differences in ignition delay will result in different conditions at start of combustion.

Ignition delay is shown in Fig. 5. Absolute values were mostly affected by inlet air pressure. Shortest ignition delays are found during supercharged test conditions. Error bars in all following diagrams represent confidence interval, calculated with the significance *P = 0.05*. Statistically significant result of ignition delay difference between tested fuels is obtained only in CR14/P1.7/T65 test conditions.

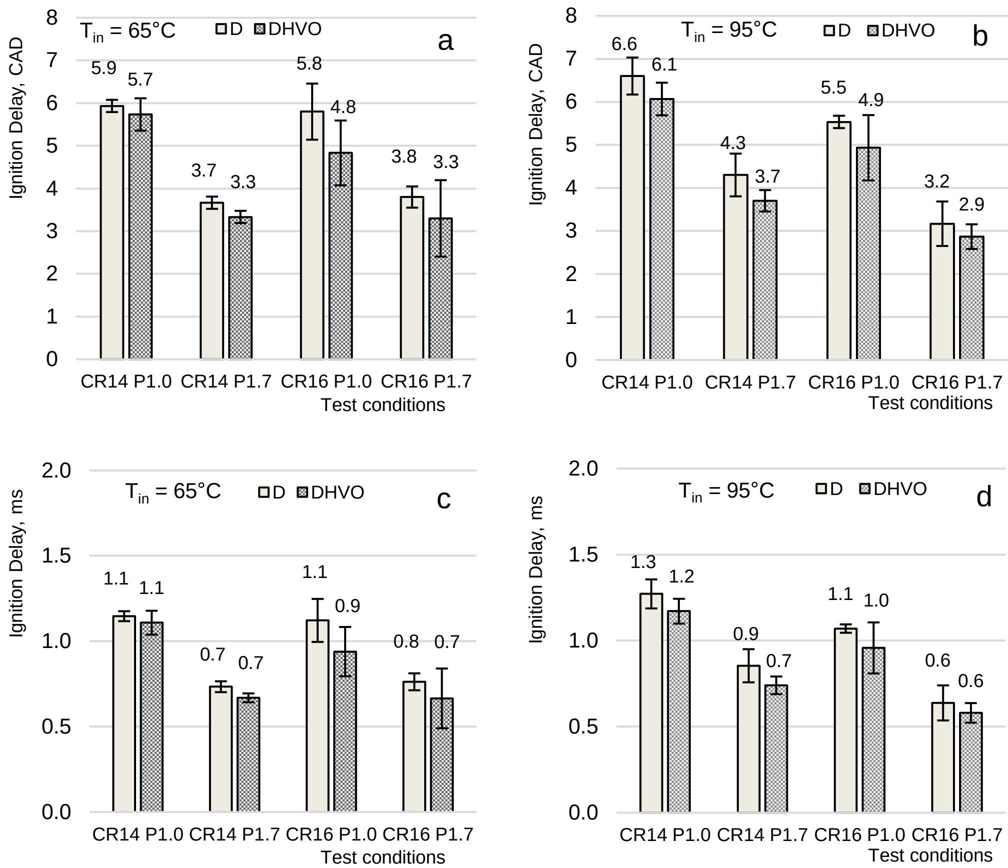

Figure 5. Ignition delay in all test modes.

Differences between ignition delay of test fuels are shown in Fig. 6. Ignition delay is shorter for fuel DHVO in all tested conditions. Difference is ignition delay between test fuels is less dependent from changes of CR and inlet charge pressure at higher initial charge temperature.

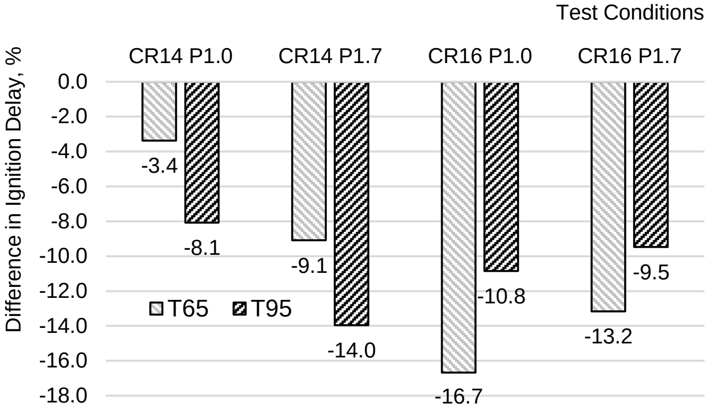

Figure 6. Difference in ignition delay in all test modes.

Shorter ignition delay for fuel DHVO leads to lower temperature and pressure at the start of combustion. It can be assumed, that in case of fuel DHVO, less fuel is evaporated and mixed with air during ignition delay.

Combustion Phasing

Duration of initial combustion phase is shown in Fig. 7. Mainly premixed combustion is dominating in this phase. Results are statistically insignificant, but fuel DHVO shows a trend of longer initial combustion phase in test conditions of low charge temperature and low charge pressure. In this analysis, lower AHRR can be assumed, if analysed phase is extended.

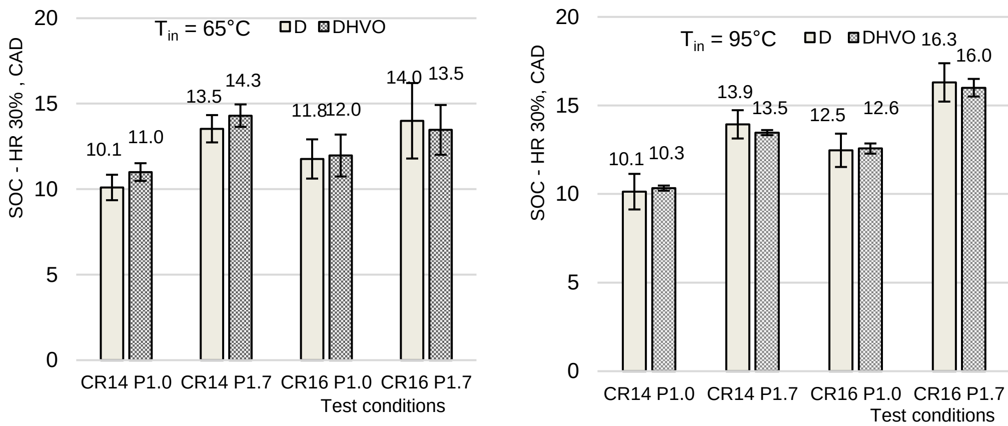

Figure 7. Duration of initial combustion phase, from start of combustion to 30% of relative cumulative heat release.

Duration of early combustion phase is shown in Fig. 8. Mainly diffusion controlled combustion is present in this phase. Results are mostly statistically insignificant, but fuel DHVO shows a trend of longer diffusion controlled combustion phase in tested conditions, where charge temperature and pressure are lower. At test conditions, where charge temperature was high and pressure highest, early combustion phase for fuel DHVO was shorter than for fuel D.

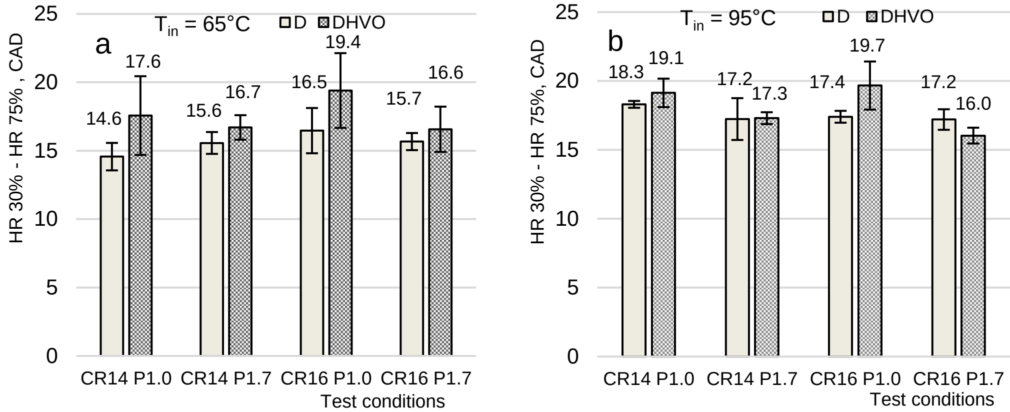

Figure 8. Duration of early combustion phase, from 30% to 75% of relative cumulative heat release.

Duration of late combustion phase is shown in Fig. 9. Fuel DHVO shows a trend of longer late combustion phase in all tested conditions. Difference between length of late phase of combustion for compared fuels is statistically insignificant but appears to diminish with higher charge temperature and pressure.

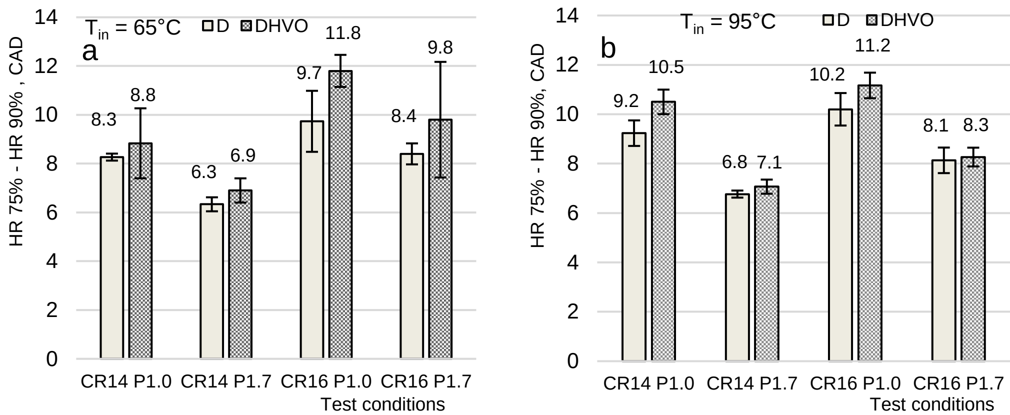

Figure 9. Duration of late combustion phase, from 75% to 90% of relative cumulative heat release.

Duration of combustion is shown in Fig. 10. Fuel DHVO shows trend of longer duration of combustion in conditions when inlet air temperature is 65 °C, comparing to fuel D. Raised inlet air temperature at 95 °C appears to have larger effect on combustion duration of fuel D.

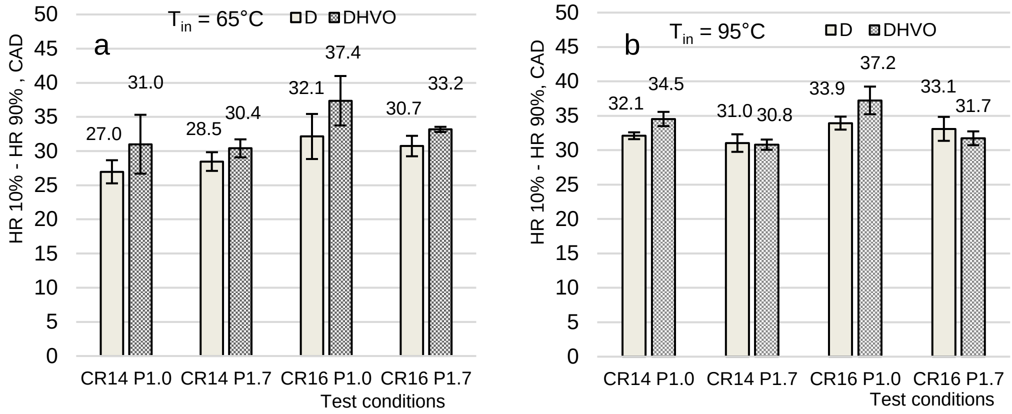

Figure 10. Duration of combustion, from 10% to 90% of relative cumulative heat release.

Phasing of combustion at 50% of released heat is shown in Fig. 11. Phasing is shown in crank angle degrees after TDC. Phasing is later in engine cycle at low compression ratio (CR14) and low inlet charge temperature for fuel DHVO, comparing to fuel D. This can be attributed to extended premixed and diffusion controlled combustion phases for fuel DHVO at low temperature and pressure conditions.

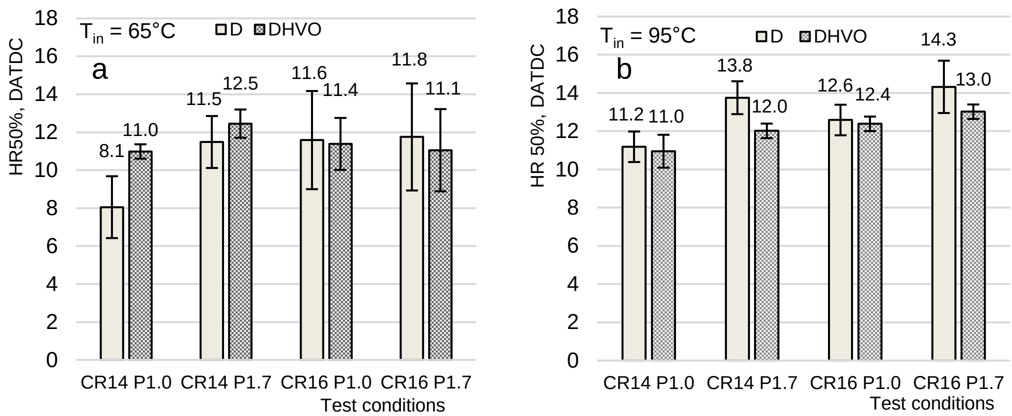

Figure 11. Phasing of combustion, CAD after TDC for 50% of relative cumulative heat release.

Assumed phasing of the end of combustion at 90% of released heat is shown in Fig. 12. End of combustion appears to be phased later in engine cycle for fuel DHVO at low temperature and low pressure conditions. At test conditions, where charge temperature and pressure is relatively high, end of combustion for fuel DHVO is earlier in engine cycle than for fuel D. Difference between ends of combustion for compared fuels is statistically insignificant at tested conditions.

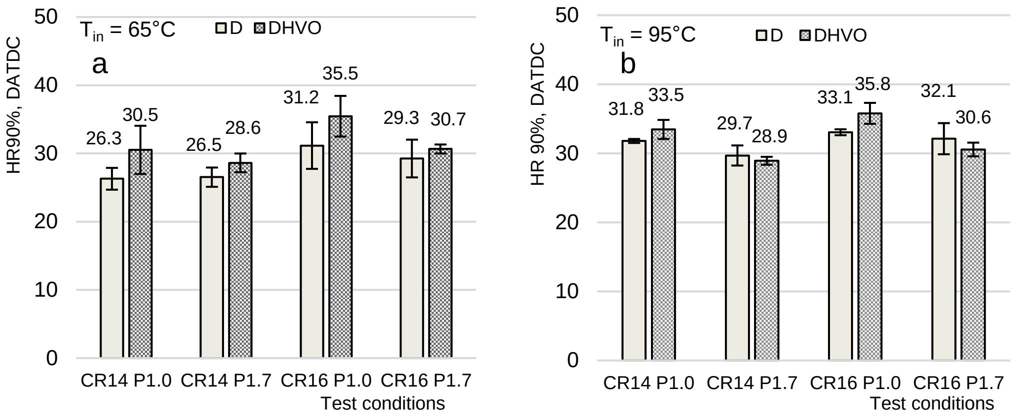

Figure 12. The end of combustion, CAD after TDC for 90% of relative cumulative heat release.

Comparison of gross IMEP between tested fuels is shown in Fig. 13. The volume of injected fuel and injection timing is held constant at all test modes. Heating values of neat HVO and EN590 grade diesel fuel were reported by Aatola et al. (2008). Volumetric heating value of fuel, containing HVO, is expected to be slightly lower, comparing to regular diesel fuel. Higher values of gross IMEP, when DHVO fuel is used, are found at all tested conditions, except CR16/P1.7/T95. Differences between fuels are larger when initial charge temperature is 95 °C. As pressure changes in the main combustion chamber is not included in calculation of IMEP, these results are not entirely reliable.

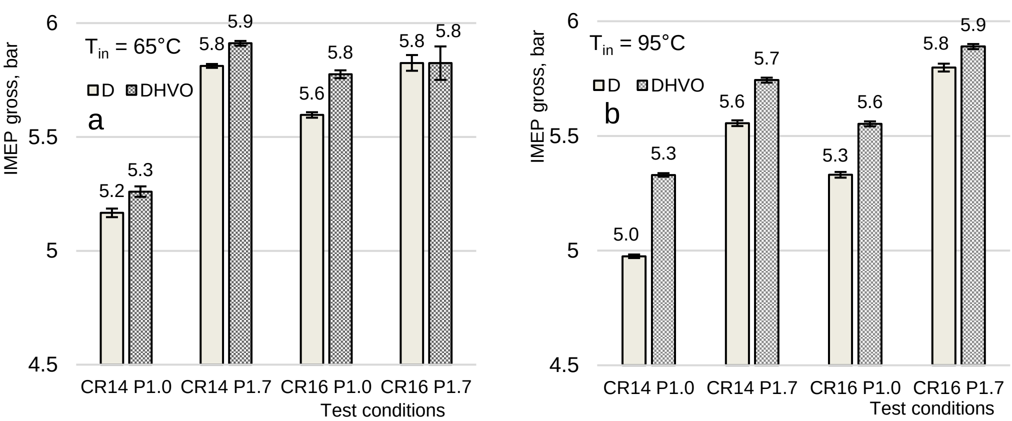

Figure 13. Gross indicated mean effective pressure (IMEP) at all test conditions.

Indicated Work Output

To analyse causes of IMEP variation between tests and tested fuels, IMEP is calculated in limited steps with length of 5 CAD for each averaged engine cycle. Difference between data points of both test fuels is calculated by subtraction the result for fuel D from the result for fuel DHVO. CAD based difference of IMEP between tested fuels is shown in Fig. 14. Positive value means that work output of fuel DHVO is higher at given point. Results reveal difference of work output during engine cycle between tested fuels.

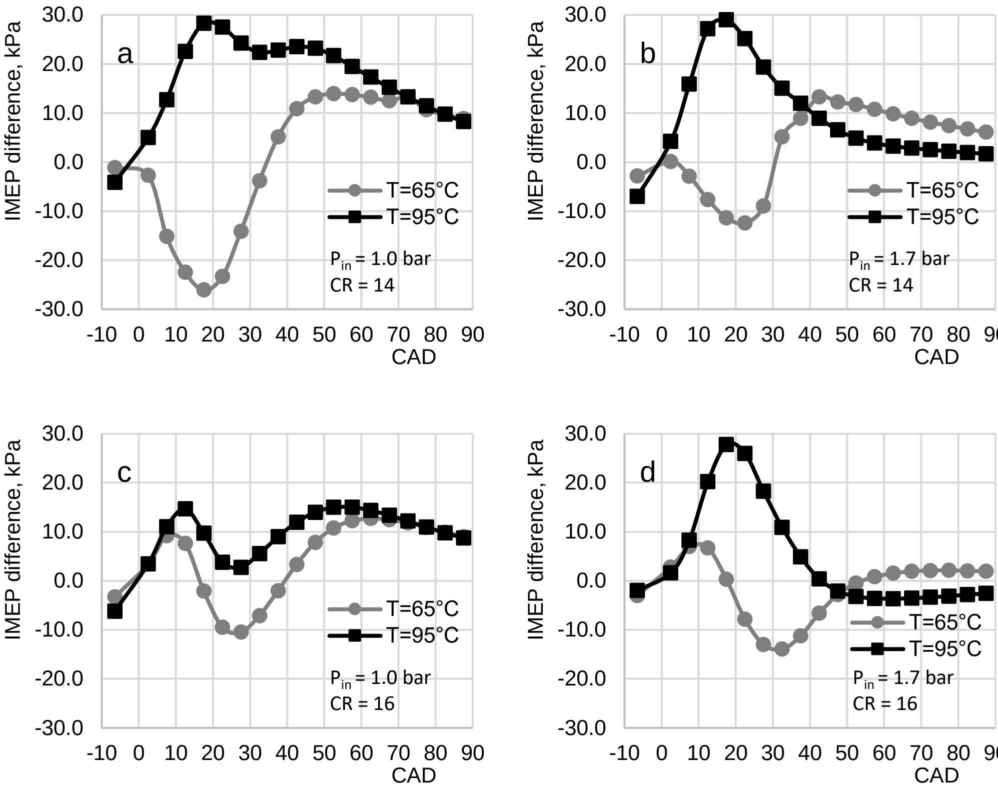

Figure 14. Difference between indicated work output during expansion stroke using fuels DHVO and D at all test conditions.

At low inlet air temperature (65 °C) and low compression ratio (CR14), premixed combustion phase (Fig. 7, a) and diffusion controlled combustion phase (Fig. 8, a) is extended using DHVO fuel. Energy release is retarded in engine cycle in case of DHVO fuel. In first part of expansion stroke work output is higher for fuel D, which is shown in Figs 14, a &14, b, lines T65 °C.

At the same inlet air temperature (65 °C) but with increased compression ratio (CR16), premixed combustion phase (Fig. 7, a) is shorter for fuel DHVO and it reflects on work output difference between test fuels. Higher work output for fuel DHVO in the very beginning of expansion stroke is show in Figs 14, c & 14, d, lines T65 °C.

At higher inlet air temperature (95 °C) premixed combustion phase (Fig. 7, b) is shorter using DHVO fuel than using fuel D. In conditions of naturally aspirated air supply (P1.0), diffusion controlled combustion phase (Fig. 8, b) for fuel DHVO is longer than for fuel D. Energy release is retarded in engine cycle in case of DHVO fuel. Work output is higher for fuel DHVO at the beginning of expansion stroke, following by lower values during diffusion controlled combustion and increased again from 50 CAD which is shown in Figs 14, a & 14, c, lines T95 °C.

In conditions of supercharged air supply (P1.7), premixed combustion phase (Fig. 7, b) and diffusion controlled combustion phase (Fig. 8, b) is shorter for fuel DHVO comparing to fuel D. Work output is higher for fuel DHVO in the first part of expansion stroke, which is shown in Figs 14, c and 14, d, lines T95 °C.

Cyclic Variation

Stability of engine operation can be characterized by variation of IMEP between engine cycles. According to Heywood (1988), vehicle driveability is affected, when coefficient of variation of IMEP (COV IMEP) exceeds 10%. Calculated results of COV IMEP gross are shown in Fig. 15. Overall values of COV IMEP are sufficiently low. No trend for COV IMEP dependency on tested fuels is found at tested conditions.

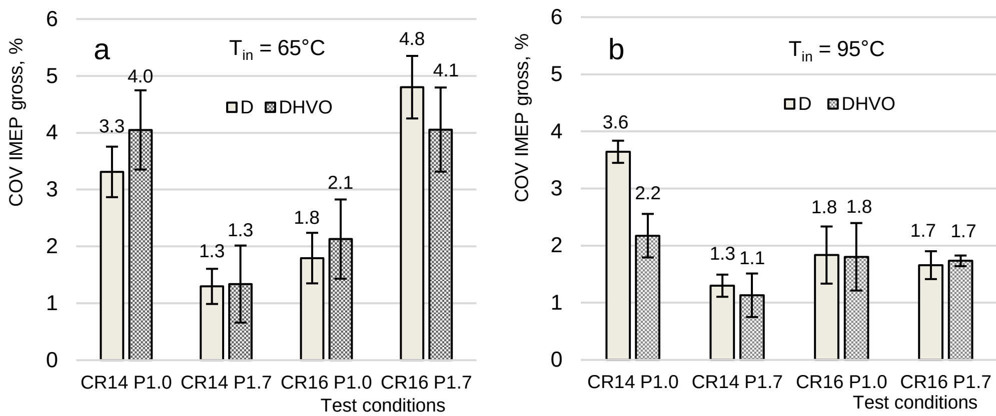

Figure 15. Covariation of gross IMEP at all test conditions.

CONCLUSION

The following conclusions from the results obtained in this study can be made:

- Ignition delay using DHVO fuel at inlet air temperature 95 °C is approximately 8…11% shorter than using fuel D.
- Absolute difference in ignition delay between test fuels diminishes with increase of inlet air temperature, pressure and compression ratio.
- Tested commercial fuels appear to have different combustion phasing, depending on test conditions.
- At inlet air temperature 65 °C, naturally aspirated air supply and compression ratio 14 : 1 AHRR of premixed combustion phase is reduced and duration extended for fuel DHVO, comparing to fuel D. The results are statistically insignificant.
- Increase of inlet air temperature at compression ratio 14 : 1 appears to increase AHRR and shorten duration of premixed combustion phase for fuel DHVO, while having little effect on fuel D.

- Increase of compression ratio at inlet air temperature 65 °C appears to increase AHRR and shorten duration of premixed combustion phase for fuel DHVO, comparing to fuel D. The results are statistically insignificant.
- At inlet air temperature 65 °C, compression ratio 14 : 1 and naturally aspirated air supply AHRR of diffusion controlled combustion phase is reduced and duration extended for fuel DHVO, comparing to fuel D. The results mostly are statistically insignificant.
- Late combustion phase appears to be extended for fuel DHVO in tested conditions, comparing to fuel D. The results are not statistically significant.
- 50% on released energy is achieved later in engine cycle at inlet air temperature 65 °C and compression ratio 14 : 1 for fuel DHVO, comparing to fuel D. The results are statistically insignificant.

This study reveals differences between tested commercial fuels in sensitivity and response of heat release rate during premixed and diffusion controlled combustion to variations in basic conditions, such as inlet air temperature, compression ratio and inlet air pressure. Impact of combustion differences on work output in engine cycle is shown. Depending on practical engine design and working conditions, those differences may influence performance parameters and exhaust gas composition.

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Improving job satisfaction with different intervention methods among the school personnel in Estonia and Latvia

G. Hrenov[1], I. Vilcane[2], V. Urbane[2] and P. Tint[1,*]

[1]Tallinn University of Technology, Faculty of Economics, Institute of Business Administration, Ehitajate 5, EE19086, Tallinn, Estonia
[2]Riga Technical University, Faculty of Engineering Economics and Management, Institute of Labour Safety and Civil Defence, Kalku street 1, LV-1658, Riga, Latvia
[*]Correspondence: piia.tint@ttu.ee

Abstract. This investigation was carried out in two high schools: one in Estonia (EST1) and one in Latvia (LAT1). The offices EST2 and LAT2 were chosen from the countryside of the both countries. Office EST1 is situated in an atrium-type building for educational and research needs. The second building is mainly for education (auditoriums) and the offices LAT1 are situated on the ground floor. The third and the fourth offices were taken for comparison. Office EST2 is situated in a countryside in an old wooden building; the fourth office LAT2 is located in a new building in Latvian countryside. All together 181 office-workers were involved. At first, the work environment conditions were measured. The ergonomics of workplaces was assessed with ART-tool and Kiva-questionnaire was used to study psychosocial conditions and job satisfaction at computer-equipped workplaces. Occupational hazards were measured to clarify, do the work environment influence on the behaviour and the job motivation and satisfaction of the worker at workplace? After the first questioning of workers using Kiva-questionnaire, the Metal Age programme was implemented and after the intervention, the Kiva-questionnaire was carried out again. The results showed that if the preventive measures for solving the problems at workplace are implemented, and the employers and the employees are trained and consulted using the appropriate programmes, the stress situations could be avoided. The workers in all offices were confident that the discussion about the problems is very important as the work with computers is intensive and there is a very short time to communicate with each other. The educational work is also stressful.

Key words: work conditions, ergonomics, computer-use, psychosocial climate, high-schools.

INTRODUCTION

In theory, there are many definitions and explanations for job satisfaction. Locke (1976) defines job satisfaction as a pleasurable or positive emotional state that is related to the work that the individual performs. The satisfaction with working conditions produces a positive influence on teachers' retention (Kearney, 2008). Some of the authors indicate that the salary mainly influences on teachers' satisfaction (Hughes, 2012), but the other studies show only a slight effect (Ondrich et al., 2008). Many researchers have concluded that the main source of job satisfaction for teachers does not originate from the salary, but from the interpersonal relationships that teachers experience with administrators, other teachers, and students (Butt et al., 2005; Maele & Houtte, 2012; Bozeman, 2013). Additionally, teachers' satisfaction with school working conditions has shown influence both, on job satisfaction and retention (Mont & Rees, 1996; Weiss, 2002; Borman & Dowling, 2008).

One of the challenges for the business is to satisfy its employees in order to cope up with increasingly changing and evolving environment and to achieve the success and remain in competition (Raziq & Maulabakhsh, 2015). In order to increase efficiency, effectiveness, productivity and job commitment of employees, the business must satisfy the needs of its employees by providing good working conditions. The results of this study indicate a positive relationship between the working environment and the employees' job satisfaction. Job satisfaction is an orientation of emotions that employees possess towards role they are performing at the work-place (Vroom, 1964). Clark (1997) argues that if employees are not satisfied with the task assigned to them, they are not certain about factors such as their rights; working conditions are unsafe, co-workers are not cooperative, supervisor is not giving them respect and they are not considered in the decision making process. Resulting of that they feel themselves separated from the organization. The employees' morale should be high as it will be reflected in their performance. With low morale they will make lesser efforts to improve (Clark, 1997).

The working environment consists of two broader dimensions such as work and context. Work include all the different characteristics like the way how the job is carried out and completed, involving the tasks like task activity training, control on one's own job related activities. Spector (1997) observed that most business ignore the working environment within their organization resulting in an adverse effect on the performance of their employees. The second dimension of job satisfaction are physical working conditions and the social working conditions (Sousa-Poza & Sousa-Poza, 2000; Gazioglu & Tanselb, 2006; Skalli et al., 2008).

Babin & Boles (1996) argued that the supervisory support and the worker's involvement decreases the work stress; it is helpful in increasing job satisfaction and job performance.

Studies that consider the working conditions, physical overload and psychosocial risk factors are complex and have not been conducted in Estonia until now. The results of the investigation of the work environment in Latvia are presented in the scientific papers of Gravele et al. (2013), Lakisa et al. (2013), Martinsone et al. (2013) and Sprudza et al. (2014).

The results of the current paper are very important, offering ideas for the further research to improve of the psychosocial work environment. The results could also be implemented in other post-socialist countries as the early stage in the work environment was almost the same for all of these states.

The research question: is it possible to reduce the physical and psychosocial risk at workplaces by speaking with people, training them and solving the problems regarding the issues of their complaints? Different hazardous factors (indoor climate, psychosocial factors, static posture etc.) are influencing the computer-workers (Weiss, 2002; Tint et al., 2012). If the improvement methods in the working environment are implemented, the level of stress of workers has to be decreased.

The aim of the study is to compare the disturbing factors and find the solutions for improving the job satisfaction in different countries high schools workers' (Estonia, Latvia).

MATERIAL AND METHODS

The office-rooms of the high school workers and accordingly the working conditions in these rooms in Estonia and Latvia were chosen as the buildings are very different: the work-premises in Estonia are located in the atrium-type building and in Latvia in the ordinary multi-storey building. The atrium-type house is energy-efficient, but the working conditions might be complicated (the problems caused by the shortage of the natural lighting and/or ventilation). Therefore, the complaints with working conditions are different in these two types of buildings.

The psychosocial character of computer workers' health risks in modern- and general-type buildings is investigated. Nowadays, different type of modern glazed buildings are used for office work. These buildings create good lighting conditions as people feel themselves connected with the nature, but there sometimes also arise some disturbing problems, like high temperature in summer, high concentration of carbon dioxide etc. The influence of indoor climate conditions on development of health damages at workplace are also taken into consideration. The computer workers (accountants, secretaries, etc.) often work in a static posture. The most injured regions of the body were the right wrist and the neck. The work conditions (indoor climate, lighting) are closely connected with the development of the musculoskeletal disorders (MSDs). Low temperature (< 20 °C in office) in winter and high temperatures and draught in summer; deficiency of day-lighting etc. are supplementary factors for developing the MSDs. MSDs of the computer professionals are associated in addition to the individual factors also with the organizational factors like the length of the rest breaks, rotation, printing and sitting duration of the worker and with the factors related to the workplace (the possibility to regulate the work chair and work table; the placement of the screen, keyboard and mouse) (Surakka, 2014). The Metal Age programme (Näsman, 2011) is energy-effective, but the working conditions are complicated as used. A Kiva-questionnaire was forwarded to the workers by the Internet or as a copy before the intervention of the Metal Age programme. 181 office-workers (including high school workers) from Estonia and Latvia were interviewed about the health risks and health disturbances connected with their work. The health disturbances were specified. The development of MSDs connected with office work are dependent on the ergonomics of the workplaces. The programme was carried out during winter and spring season.

The assessment of the ergonomics of the workplaces (ART-tool)

In the current study, the risk level of office-workers was assessed using the ART tool (HSE, 2007). In 2007, the Health and Safety Executive (HSE) presented the prototype of a tool for risk assessment of repetitive tasks of the upper limbs. The technical content of the ART tool draws upon earlier work to develop the occupational repetitive actions methods (Colombini et al., 2002) and Quick Exposure Check (David et al., 2008). As a result, the ART tool (Pille et al., 2016) examines twelve risk factors that have been grouped into four stages: (1) frequency and repetition of movements; (2) force; (3) awkward postures (of the neck, back, shoulder/arm, wrist and hand); (4) additional factors (which include the aspect of task duration, recovery, perceived work pace and other object and work environment factors).

The result is the sum of the four stages: A, B, C and D. These stages are divided into sub-stages A1 – arm movements (infrequent: score 0; frequent: 3; very frequent: 6); A2 – repetition (10 times per minute or less: score 0, 11–20 times per minute: 3, more than 20 times per minute: 6); B – force (light force: score 4, moderate force: 6, strong force: 8, very strong force: 12); C1 – head/neck posture (in an almost neutral posture: 0, bent or twisted part of the time (e.g. 15–60): 1; bent or twisted more than half of the time (more than 50%): 2); C2 – back posture (in almost neutral position: 0, bent forward, sideways or twisted part of the time: 1, bent forward, sideways or twisted for more than half of the time: 2); C3 – arm posture (kept close to the body or supported: 0, raised away from the body part of the time: 2, raised away from the body more than half of the time: 4), C4 – wrist posture (almost straight/in a neutral position: 0, bent or deviated part of the time: 1, bent or deviated more than half of the time: 2); C5 – hand/finger grip power grip or do not grip awkwardly: 0, pinch or wide finger grip for part of the time: 1, pinch or wide finger grip for more than half of the time: 2); D1 – breaks less than one hour: 0, 1–2 hours: 2, 2–3 hours: 4, 3–4 hours: 6, 4 hours or more: 8); D2 – work pace (not difficult to keep up with the work: 0, sometimes difficult to keep up with the work: 1, often difficult to keep up with the work: 2); D3 – other factors (less than 2 hours: x 0.5, 2–4 hours: x 0.75, 4–8 hours: x1, more than 8 hours: x 1.5; Eq. 1). The body postures (in graphical mode) and conditions (by time) are given (Colombini et al., 2002). The total score is calculated by the equation 1 (Pille et al., 2016):

$$\text{Task score} = A1+A2+B+C1+C2+C3+C4+C5+D1+D2+D3 \tag{1}$$

If you assess both arms, the scores for the left arm and right arm should be kept separate and not combined.

The calculation of the exposure score (risk level) is achieved when the task score is multiplied by the duration multiplier (Eq. 2).

$$\text{Task score x Duration multiplier} = \text{Exposure score} \tag{2}$$

Task scores and exposure help prioritise tasks that need most urgent attention and help check the effectiveness of any improvements.

The system for interpreting the exposure score is proposed in Table 1.

Table 1. Risk levels depending from the scores

Exposure score	Proposed risk level	Action needed
0–11	low	Consider individual circumstances
12–21	medium	Further investigation required
22 or more	high	Further investigation required urgently

Metal Age programme

The Metal Age method aims to create concrete, practical and tailored solutions to improve the relations in the workplace. The approach consists of four phases:

1) Orientation phase – the matrix shows the situation at the work unit from three different point of view; the individuals', the work units and organizations;

2) Intervention planning phase aims to find the development areas for improving the well-being at work for the Metal Age planning group. At this stage the participants should evaluate the development areas freely and list the development areas before grouping them together;

3) Prioritization phase – which challenges are the most important and urgent. A crucial part of the planning process of the Metal Age method is prioritization. Without emphasizing, there is risk that the working place only lists a number of development areas. Further, the list may became so extensive that there are not enough resources and nothing will be done;

4) Suggestion phase – suggestions for concrete actions. The phase for establishing concrete actions begins after finalization of the score setting in the prioritization phase. Concrete actions are agreed on for the development area that had the highest score during prioritization;

5) Follow-up phase (Kiva-questionnaire). The Metal Age planning session is concluded by the group agreeing on follow-up meeting held after some months.

The Kiva-questionnaires

Kiva-questionnaire characterizes the wellbeing and job satisfaction of workers at work. The ratings were given in a 10-point scale (1- not at all, 10- very much so, certain or well). The Kiva-questionnaire was composed of seven questions:

1. Have you enjoyed coming to work in the last weeks?
2. I regard my job meaningful.
3. I feel in control of my work.
4. I get on with my fellow-workers.
5. My immediate superior performs as superior.
6. How certain are you that you will keep the job with this employer?
7. How much can you influence factors concerning your job?

The Kiva-questionnaire after the Metal Age programme implementation was conducted with the same 181 persons selected from four institutions (from those most interested in co-operation and improvements in the working environment).

Measurements of working conditions

The indoor air conditions were measured using the following standards and measuring equipment: EVS-EN-ISO 7726:2003 'Thermal environments- Instruments and methods for measuring physical quantities'; EVS-EN 15251:2007 'Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics', EVS-EN 12464-1:2011 'Light and lighting- Lighting of workplaces- part 1: Indoor work places', EVS 891:2008 'Measurement and evaluation of electrical lighting in working places', ISO 16000-26:2012 'Indoor air- Part 26 Sampling strategy for carbon dioxide (CO_2)', LVS EN 12464-1:2011 'Light and lighting- Lighting of work places- Part 1: Indoor work places', LVS EN ISO 7726:2004 L 'Ergonomics of the thermal environment- Instruments for measuring physical quantities', Labour Protection Requirements in Workplaces (Latvia, 2010).

The measurement equipment used for microclimate: TESTO 435. TESTO 435 enables also the measurements of CO_2. Workplaces lighting and and screens were measured using the light-metre TES 1332 (ranges from 1-1500 lx). The lighting was measured on the worktable, on the screen and on the keyboard. Dust was measured with HazDust EPAM-5000. EPAM-5000 is a portable air monitor designed for measuring trace level for ambient air pollution. The unique sampling design allows for real-time data and filter gravimetric analysis directly behind the optical sensor. EPAM-5000 offers a weather tight carrying case, temperature compensated electronics, easy to clean optical sensor and a standard 24 hour battery or continuous sampling with solar power panel accessory.

Statistical analysis

The arithmetic mean and standard deviation (SD) were calculated (Kiva-questionnaire). In ART-tool the statistics is taken into consideration in the method (Colombini et al., 2002).

RESULTS

Measurements in the work environment

Table 2 shows the results of measurements in the work environment. In winter the humidity of the air is too low. By the norms (EVS-EN 15251:2007), the relative humidity of 40–60% is required for the worker to feel comfort. The level of carbon dioxide ~1,000 ppm is felt by the workers as poor work environment air. The lighting of workplaces equipped with computers is usually good, in the frames of norms (300–500 lx), but sometimes info technologists prefer working in dark (without electrical lighting). However, this situation has to be avoided.

Table 2. Results of measurements indoors in offices (during 2016)*

Room type	T, °C Cold/ warm season U = 0.6°C	R, % Cold/ warm season U = 2.05	L, lx U = 10.4%	CO_2, ppm U = 10%	Dust, mg m^{-3} U = 10%
Office EST1	20–23 / 25–28	25–27 / 40–70	595–790	537–988	0.020
Office LAT1	20–22 / 24–28	15–25 / 35–75	500–550	503–740	0.025
Office EST2	18–22 / 20–24	20–30 / 40–74	450–550	450–1,210	0.015
Office LAT2	17–20 / 22–28	15–30 / 40–70	500–610	470–1,102	0.012

* Outdoor temperature during the measurements in cold season was – 5 to 1 degrees; in warm season it was 18–22 degrees; the humidity of the air during cold season was 40–80%; during the warm season 60–90%. U – the uncertainty of measurements; T – temperature of the air; R – relative humidity; L – lighting; CO_2 – concentration of carbon dioxide in the air; Dust – dust concentration in the air.

The assessment of the ergonomics of the workplaces

The results of the assessment (Table 3) show that office workers' risk level is medium (14–19.2). Office EST2 located in a country-side had high risk level on the right hand (too much working with computer, not following the rules about breaks, bad ergonomics of the workplace).There is a difference in the risk level of the left and right hand for the office-workers.

The risk scores by the ART-tool (Colombini et al., 2002) are determined separately for the right and left hand. The difference is assigned during the each individual case according to the standardized methodology described previously and presented under the Table 3.

Table 3. Assessment of monotonous work and/or in static posture by means of the ART tool (presented in Table 1) in offices

Work-place	Left/right (L/R) part of the body	A1/A2 0…6**	B, 0…12	C1/C2 0…2	C3/C4 0…4 / 0…2	C5/D1 0…2 / 0…8	D2/D3 0…2	D4 0.5…1.5	Risk* level
Off.	L	1/2	4	1/1	0/1	0/1	1/2	1	14
EST1	R	3/3	4	1/1	0/1	0/1	1/2	1	18
Off.	L	1/2	4	1/1	0/1	0/0	1/2	1.2	15.6
LAT1	R	3/3	4	1/1	0/1	0/0	1/2	1.2	19.2
Off.	L	2/3	4	1/2	1/1	1/1	0/1	1	17
EST2	R	2/3	4	1/2	2/2	1/2	1/2	1	22
Off	L	1/2	4	1/1	0/1	0/1	1/1	1	14
LAT2	R	2/2	4	1/1	1/2	1/2	1/2	1	19

**Risk level: 0–11 = low risk; 12–21: medium risk; 22 or more: high risk level; ** 0…6 – the numbers indicate the min and max of the assessment scale.*

Responses to the Kiva questionnaire

The Kiva questionnaire was conducted twice: before the intervention of the Metal Age programme and after it (Table 4). The number of used questionnaires was 62 in office EST1, 67 in office LAT1, 35 in office EST2 and 17 in office LAT2. According to the Kiva questionnaire, the investigated workers had high satisfaction coefficients with work. In addition, the stress indicators did not evaluate the stress-levels high. Kiva methodology for deploying a team is intended to find solutions to the specific results of the work of the team. It is connected with the character of work to find suitable working arrangements to be developed and therefore it is suitable for work-related psychosocial and MSDs prevention.

Table 4. Responses to the Kiva questionnaire

The question	Office 1, EST1 B(SD)/A*(SD)	Office 2, LAT1 B(SD)/A(SD)	Office 3, EST2 B(SD)/A(SD)	Office 4, LAT2 B(SD)/A(SD)
1	6.5(2)/7.6(3)	7,85(2)/7.9(1)	7.5(3)/7.4(2)	6.125(3)/7.85(2)
2	7.7(1)/7.95(2)	8.27(3)/8.1(1)	7.0(1)/7.2(2)	8.37(3)/7.8(2)
3	8.1(1)/7.9(3)	6,56(3)/7.5(2)	6.5(3)/6.8(2)	8,1(3)/7.6(2)
4	8.95(1)/8.7(2)	7,3(2)/8.5(1)	7.5(2)/7.4(2)	7,9(2)/8.65(3)
5	6.8(2)/8.1(3)	5,68(2)/7.8(1)	6.5(2)/6.7(2)	6,46(3)/6.5(2)
6	7.4(1)/7.5(2)	7,83(3)/7.6(2)	6.5(1)/7.2(2)	7.82(3)/7.9(2)
7	6.8(2)/7.3(1)	7,2(1)/6.4(1)	6.5(1)/6.5(2)	6,8(2)/7.6(1)

B/A– the mean values before the Metal Age intervention/ after the Metal Age intervention.*

The changes in the Kiva questionnaire in offices are shown in Table 4. The relations between the employer and the employees were usually improved (questions 1–2, 5–7). A slight decrease appeared in questions 3: Does your immediate superior help you develop your skills? To the fifth question: 'My immediate superior performs as superior?' the answers showed the lowest score at the beginning of the investigation. After the Metal Age programme implementation, the scores were arisen considerably. It means that the management behaviour has to be improved. The managers have to undergo advanced training in management ingredients.

Prevention and rehabilitation

The proposals were given for ergonomic improvements at workplaces (new ergonomic chairs, the possibility to change the height of the worktable; the change of the situation of a monitor etc.) during the Metal Age intervention. The complaints in the air of the work environment and lighting deficiency complaints were reported to the employer. The rehabilitation of MSDs are possible using balneological methods of treatment and methods of physiotherapy (Tuulik et al., 2013).

DISCUSSION

The work environment can be described as the whole surrounding where the person is working. Working environment has a positive impact on the job satisfaction of employees. Bad working conditions restrict employees to portray their capabilities and attain full potential, so it is imperative that the business realize the importance of good working environment.

Kinzl et al. (2005) concluded that job satisfaction has positive relationship with opportunities provided to employees by the organization. These results were also proven by the authors of the current paper. The previous studies of the authors of the current paper (Pille et al., 2015) showed, that if the workers are divided into two groups (< 40 and 40 and over years), the health status is not straight dependent on the age, particularly for computer-workers. The main reason of deteriorating health of younger people is the sedentary work position and the start of with work with computers in younger and younger age. In the research of Bojadijev et al. (2015), the results indicate that the age of employees is the most powerful predictor of job satisfaction. This conclusion has to be connected to the health status of the worker. A satisfied and healthy employee is the biggest asset of any organization. Effective results and productivity for any organization is dependent on the level of the satisfaction of the employees.

The organization has to motivate their employees to work hard for achieving the organizational goals and objectives. The paper of Raziq & Maulabakhsh (2015) also encourages people to contribute more to their jobs and the management has to help the workers in their personal growth and development. They have conducted correlation analysis to determine the relationship of working environment components (i.e. top management, esteem needs and work hours, and job security, safety and workplace relationships) and job satisfaction. Eleven work environment factors controlling personal and job characteristics are involved into the model. The regression result reveals that work environment has a statistically significant impact on job satisfaction. The work environment is one of the most important factors, which influence on the satisfaction and motivation level of the employees (Jain & Kaur, 2014). Effective work environment encourage the happier employee with their job that ultimately influence the growth of an organization as well as growth of an economic: 71% of the employees said that they get proper health and safety facility whereas, 29% employees feel they do not get proper facilities in the working place (Jain & Kaur, 2014).

The findings of Tella et al. (2007) study reveal that the correlation between perceived motivation and job satisfaction is positive. Job satisfaction is a result of employee's perception of how well their job provides those things that are viewed as important. Bakotic & Babic (2013) found that for the workers who work under difficult working conditions, consider the working conditions as important factor for job satisfaction. So the workers under difficult working conditions are satisfied through the improvement of this factor. This will make them equally happy. Work environment performs to have both positive and negative effects on the psychological state and welfare of employees. The office workers in Estonia and Latvia (mainly teaching staff) are satisfied with the working conditions, but in the country-side the conditions in offices (not educational) have to be improved.

CONCLUSIONS

Good working environment has an enormous impact on the job satisfaction of employees. Bad working conditions restrict employees to show their capabilities, so it is important that the business realize the importance of good working environment. Kiva-questionnaire, Metal Age intervention, objective methods for improvement of ergonomic situation at workplaces and environmental measurements are useful to plan prevention and early rehabilitation before the disability appears.

The indoor air and other problems in the same workroom could be defined individually in quite different ways. Therefore, an individual approach for every workplace has to be implemented considering the anthropological and other features of the worker who will work in the certain workplace. The info-technology workers often work in under-lighted working conditions although there is a possibility to raise the (artificial) lighting to the normal limits (400–500 lx).

The main conclusion from the investigation is that stress situations at workplace could be prevented by use of proper intervention programmes (Metal Age).

In the modern era, the management of workforce has become more difficult because employees are highly qualified and aware of their rights while working in an organization. Good working environment increases employee loyalty, level of commitment, efficiency and effectiveness, productivity and reduces prohibit cost emerging as a result of dissatisfied employees. Such as, it is very wide category that incorporates the physical scenery (e.g. noise, equipment, heat), fundamentals of the job itself (e.g. workload, task, complexity), extensive business features (e.g. culture, history) and even extra business (e.g. industry setting, workers relation). However all the aspects of work environment are correspondingly significant or indeed appropriate when considered job satisfaction and also affects the welfare of employees satisfied with those who work under normal working condition and in return overall performance will increase.

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Critical velocity of solid mineral fertilizers in a vertical upward airstream and repose angle

J. Hůla*, M. Kroulík and I. Honzík

Czech University of Life Sciences Prague, Faculty of Engineering, Kamýcká 129, CZ165 21 Prague 6 – Suchdol, Czech Republic
*Correspondence: hula@tf.czu.cz

Abstract. Critical velocity of mineral fertilizers in airstream is important not only at the application of fertilizers by spreaders but also at combine of fertilizing and sowing. The knowledge of angles of repose is important to design hoppers on spreaders for solid mineral fertilizers. Critical velocities for six solid mineral fertilizers were measured in the vertical aspiration duct of a laboratory sorting machine. Variation curves were constructed for particular fertilizers and the mean critical velocity of fertilizers (velocity of uplift) was computed. The mean critical velocity of fertilizers was between 8.53 and 12.43 m s^{-1}. The lowest critical velocity was found out in the fertilizer UREA 46%, the highest in the fertilizer LAV. Statistical significance of differences in the critical velocity of fertilizers was assessed. Angles of repose of eight solid mineral fertilizers were also measured and statistical significance of differences was evaluated. The highest values of repose angle were determined for potassium salt and ammonium sulfate (35.9° respectively 34.9°), the lowest values for UREA and LAV (28.7° respectively 29.6°). The obtained results extend information applicable to an assessment of parameters of the operation quality of spreaders during mineral fertilizer application.

Key words: mineral fertilizers, variation curves, repose angle.

INTRODUCTION

Aerodynamic properties of mineral fertilizers are important not only at the application of these fertilizers by pneumatic spreaders but also at simultaneous fertilizing and sowing. Unevenness of the aerodynamic properties is one of the causes of undesirable fluctuations in the quality of mineral fertilizer application by spreaders, especially at a large operating width of these machines. Aerodynamic properties are mainly related with the properties of fertilizers (bulk density, granulometric composition, shape), and also with the parameters of flowing air while the airstream evenness is important.

The evaluation of aerodynamic properties of solid mineral fertilizers is based on the studies of physical and aerodynamic properties of agricultural material and products (Stroshine, 2000; Csizmazia & Polyak, 2001). Methodically, the measurement of aerodynamic properties of solid mineral fertilizers employs the findings of Stroshine (2000), Güner (2007), Russo (2011). Many literature sources dealt with aerodynamic properties of seeds (Srivastava et al., 2006).

The objective of experiments was to determine critical velocities of some solid mineral fertilizers and to assess statistical significance of differences. Angles of repose of solid mineral fertilizers were measured and statistical significance of differences in the angles of repose was assessed. The knowledge of angles of repose is important for designing hoppers for solid mineral fertilizers. The bottom of the hoppers of solid mineral fertilizer spreaders should be designed so that fertilizers would move fluently to a metering port.

MATERIALS AND METHODS

To measure critical velocities of solid mineral fertilizers a K-293 laboratory air sorting machine was used with the adjustable through-flow volume of air flowing in the vertical aspiration duct. Samples of 800 g in weight were weighed for each mineral fertilizer. At the gradually increasing velocity of the upward airstream in the vertical aspiration duct of the sorting machine fertilizer particles with different aerodynamic properties were separated from each other. Four repeated measurements were done in all samples of mineral fertilizers.

For the chosen groups of solid mineral fertilizers the measured values were used for plotting variation curves. The values of the mean critical velocity (mean velocity of uplift) of mineral fertilizers were computed:

$$v_{krit} = \frac{\sum (m_i \cdot v_i)}{m} \text{ (m s}^{-1}\text{)} \tag{1}$$

where v_{krit} – mean critical velocity (mean velocity of uplift) of fertilizers (m s^{-1}); m_i – weight of the respective class (g); v_i – velocity of the class centre (m s^{-1}); m – weight of mineral fertilizer sample (g).

Assuming the normal distribution of frequencies, the mean critical velocity is approximately identical with the most numerous class of variation curve.

The Statistica 10 programme was used for processing measured data. Variation curves of critical air velocities for particular fertilizers were constructed and mean values and error bars are shown. Descriptive statistics of critical vertical air velocities are also presented. The analysis of variance was used to assess the statistical significance of differences in the mean values of critical velocities. A graph of critical velocities was constructed where significant differences are designated by different letters.

The angles of repose of solid mineral fertilizers were measured in a special measuring trough when fertilizers were poured into a metal trough which had the shape of the bottom of a hopper in a mineral fertilizer spreader. Using a hydraulic cylinder the metal trough was gradually tilted until the fertilizer started sliding and the trough was emptied due to gravity. Five repeated measurements of repose angles were done in samples of mineral fertilizers. Descriptive statistics were determined also for the angles of repose of solid mineral fertilizers and statistical significance of differences in the angles of repose was represented in a graph.

The six most used fertilizers in farms in the Czech Republic were chosen for the measurement of critical velocities in a vertical upward airstream. Also repose angles were measured for these fertilizers. As well the repose angles were measured for two other fertilizers, where difficulties in continuous movement in the hoppers of spreaders sometimes occur. Size fraction of fertilizers after sieving on sieves are in the Table 1.

The shape of six tested fertilizers is shown in the photographs in Fig. 1. The other two fertilizers had a crystalline structure (magnesium sulfate and ammonium sulfate.

Table 1. Representation (distribution) of fertilizers size fractions (%)

Apertures of the sieves	UREA 46%	LAV[x]	Magnesium sulfate 32–16	AMOFOS	NPK 15-15-15	Superphosphate	Ammonium sulfate 20%	Potassium salt 60%
1 mm	3.8	0.0	0.3	0.0	0.0	0.0	37.1	69.1
1–2 mm	63.6	0.0	2.1	0.2	2.3	0.2	43.6	25.7
2–3 mm	32.5	2.3	26.7	16.1	32.3	10.7	17.4	5.0
3–4 mm	0.1	48.3	45.2	70.3	40.2	46.1	1.8	0.2
4–5 mm	0.0	47.1	25.7	13.4	22.9	42.3	0.1	0.0
> 5 mm	0.0	2.3	0.0	0.0	2.3	0.7	0.0	0.0

[x] *LAV – Ammonium nitrate with calcite.*

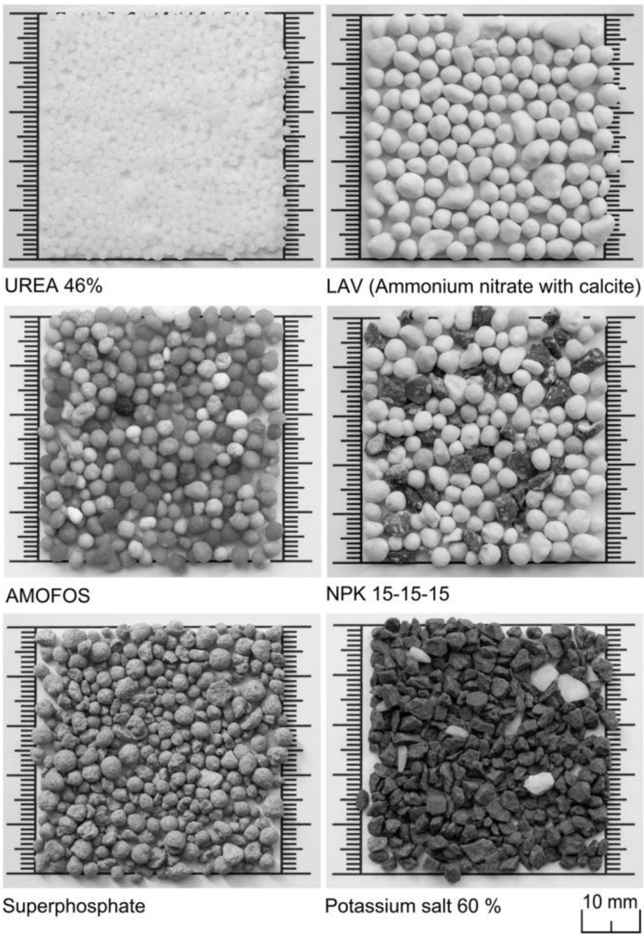

Figure 1. Shape of six tested fertilizers – shape of granules, crushed mineral (potassium salt 60%).

Properties of mineral fertilizers were measured in laboratory conditions in accordance with recommendation (Decree No. 273/1998). The air temperature was 18° C, relative air moisture was 38%. Moisture content and bulk density of tested mineral fertilizers at the time of laboratory measurements are given in the Table 2.

Table 2. Moisture content and bulk density of mineral fertilizers

Fertilizer	Moisture (% weight)	Bulk density (g cm^{-3})
UREA 46%	0.29	0.72
LAV (Ammonium nitrate with calcite)	0.18	0.97
Magnesium sulfate 32–16	3.19	0.98
AMOFOS	0.32	0.97
NPK 15-15-15	2.96	1.07
Superphosphate	0.76	1.22
Ammonium sulfate 20%	0.20	0.86
Potassium salt 60%	0.17	1.05

Conditions in real work situation during spreading of mineral fertilizers can be within a wide range (e.g., from mild frost in early spring to the high temperature at the end of spring).

RESULTS AND DISCUSSION

Table 3 shows descriptive statistics of critical vertical velocities for the tested mineral fertilizers. Coefficient of variation (CV) as the relative value of the measure of dispersion of values around the mean value makes it possible to compare various sets of measured data. Coefficients of variation are from 0.32 to 1.42%. The values of the minimum and the maximum define the categories statistical data sets belong to. Asymmetry from the Gaussian normal distribution is expressed by the coefficient of skewness. The condition of data normality is satisfied if the interval of skewness lies between the values -2 and 2. Normality of distribution was fulfilled, so one of the basic assumptions for the use of most statistical analyses was satisfied.

Table 3. Descriptive statistics of critical vertical velocities (m s^{-1})

Indicator	UREA 46%	LAV	AMOFOS	NPK 15-15-15	Super-phosphate	Potassium-salt 60%
Mean (m s^{-1})	8.53	12.43	11.94	12.42	12.24	10.22
Median (m s^{-1})	8.51	12.44	11.94	12.42	12.21	10.26
Standard deviation (m s^{-1})	0.12	0.04	0.12	0.06	0.10	0.11
Coefficient of variation (%)	1.42	0.32	0.99	0.48	0.79	1.06
Skewness	0.89	-0.93	0.10	0.05	1.08	-1.54
Difference max-min (m s^{-1})	0.29	0.09	0.26	0.14	0.22	0.24
Minimum (m s^{-1})	8.40	12.38	11.82	12.35	12.15	10.06
Maximum (m s^{-1})	8.69	12.47	12.08	12.49	12.37	10.30

Figs 2–4 illustrate variation curves of the tested fertilizers with the percentages of particular fractions at an increasing velocity of the vertical airstream. The scales of axes are identical in all figures. In graphs mean values and error bars for standard error are indicated. These graphs clearly indicate differences between fertilizers with respect to their aerodynamic properties.

When determining the properties of mineral fertilizers in an upward airstream, statistical significance of differences in the mean values of critical velocities was assessed by the analysis of variance. An *F-test* was performed which indicated statistically significant differences in the values of critical air velocities for the particular solid mineral fertilizers.

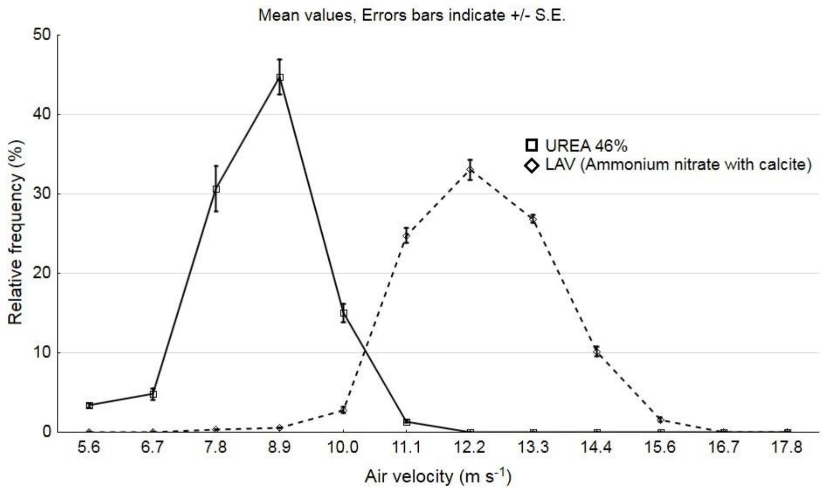

Figure 2. Variation curves for fertilizers UREA and LAV.

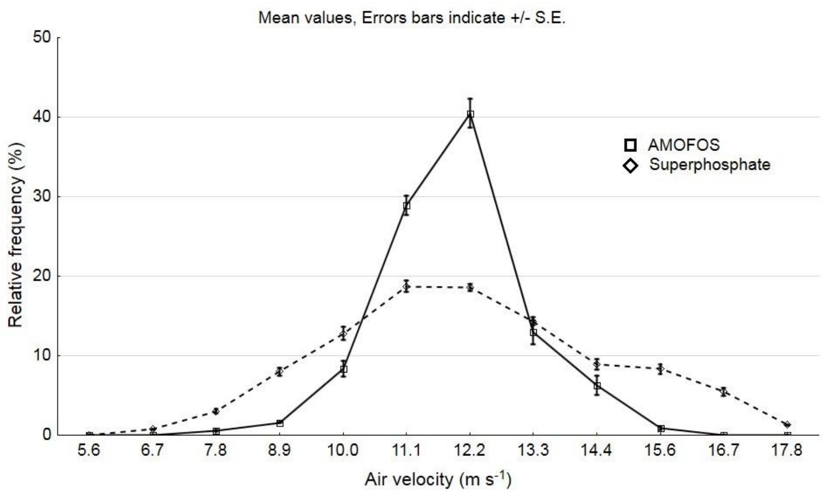

Figure 3. Variation curves for fertilizers AMOFOS and Superphosphate.

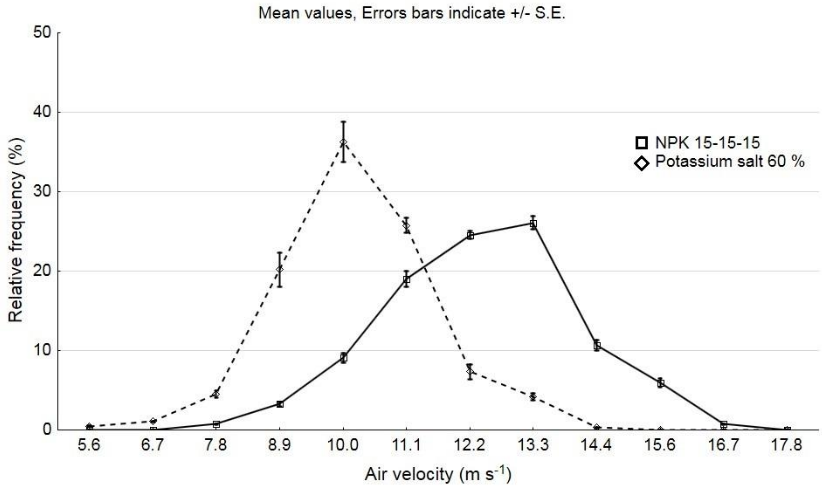

Figure 4. Variation curves for fertilizers NPK and Potasium salt.

A crucial assumption of the analysis of variance is the homogeneity of variances for all variants. The performed test revealed that the result of the analysis of variance is not burdened with an error that would be caused by the non-homogeneity of variances.

The graph in Fig. 5 transparently shows critical velocities for the particular fertilizers. Statistically significant differences are designated by different letters. There are no statistically significant differences between fertilizers with the same letter. As for critical velocities, statistically in significant differences are between the fertilizers LAV, NPK and Superphosphate (the values from 12.24 to 12.43 m s^{-1}). The lowest mean critical velocity was found out in the fertilizer UREA 46% (8.53 m s^{-1}), the second lowest critical velocity was observed in potassium salt 60% (10.22 m s^{-1}).

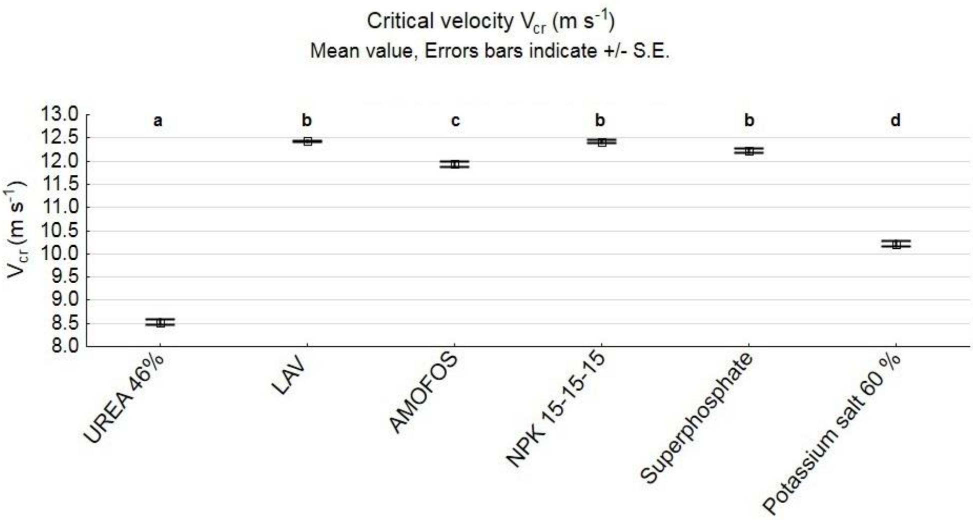

Figure 5. Graph of critical velocity – significant differences are indicated by different letters (a, b, c, d).

It was measured altogether 8 fertilizers for a comparison of the angles of repose. Table 4 shows average values of the angles of repose, Fig. 6 documents the statistical significance of differences in the angles of repose. Fertilizers are arranged in the graph according to increasing values of the angles of repose. This property of mineral fertilizers was also found to show statistically significant differences between some fertilizers. The highest values of repose angle were determined for potassium salt and ammonium sulfate (35.9° respectively 34.9°), the lowest values for UREA and LAV (28.7° respectively 29.6°).

Table 4. Repose angle of solid mineral fertilizers

Fertilizer	Repose angle (°)
UREA 46%	28.7
LAV	29.6
Magnesium sulfate 32–16	32.2
AMOFOS	32.6
NPK 15-15-15	32.9
Superphosphate	33.5
Ammonium sulfate 20%	34.9
Potassium salt 60%	35.9

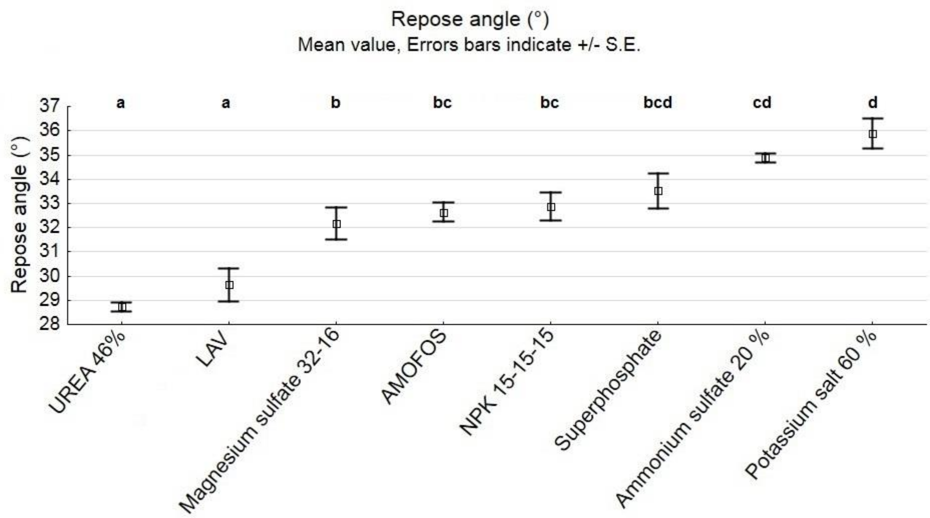

Figure 6. Repose angle of mineral fertilizers – significant differences are indicated by different letters (a, b, c, d).

The results confirm the information in literature about the properties diversity of mineral fertilizers and relating these properties with quality fertilizers application (Csizmazia, 2000; Hrůza et al., 2007; Krupička et al., 2015). Aerodynamic properties of solid mineral fertilizers can be assessed as well considering the aerodynamic properties of seeds and other agricultural material and products (Stroshine, 2000; Csizmazia & Polyak, 2001).

Measurement of critical velocity and repose angle allowed to compare the properties of selected solid mineral fertilizers, which are supplied to the farms in the Czech Republic. It is assumed that similar values of fertilizer critical velocity will have similar quality indicators of spreading when using the centrifugal and pneumatic mineral fertilizer spreaders (LAV, NPK 15-15-15, superphosphate).

Spreading in smaller working width of the centrifugal fertilizers spreaders can be assumed for fertilizers with a substantially lower of critical velocity (UREA 46%, potassium salt 60%) than for other tested fertilizers. The measurement results of critical velocity are an argument for preferential use of pneumatic spreaders instead the centrifugal spreaders.

CONCLUSIONS

Statistical evaluation of critical velocities of some solid mineral fertilizers revealed the degree of unevenness of aerodynamic properties of these fertilizers. Detailed knowledge of aerodynamic properties of materials that are applied through an airstream (solid mineral fertilizers, seeds) can be a contribution to an increase in the application precision, which is in line with objectives of precision agriculture.

Different aerodynamic properties of mineral fertilizers are one of the reasons of unevenness during application of mineral fertilizers mainly by centrifugal spreaders. When working width of the centrifugal spreaders is become larger then more problems with unevenness of spreading occur. Spreaders with jibs and the air-operated of fertilizers to the spreading tail pipes are preferred for a large working width (e.g. 36 m).

The bottom of the hoppers for tested solid mineral fertilizer spreaders should be designed with a greater inclination angle than 36°.

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Contribution of pumped hydro energy storage for more RES utilization on autonomous power systems

Y. Katsiagiannis[1], A. Annuk[2] and E.S. Karapidakis[1,*]

[1]Technological Educational Institute of Crete, Faculty of Applied Science, Department of Electrical Engineering, Estavromenos Campus, GR71004 Heraklio, Greece
[2]Estonian University of Life Sciences, Institute of Technology, Department of Energy Engineering, 56 Kreutzwaldi Str., EE51014 Tartu, Estonia
[*]Correspondence: karapidakis@staff.teicrete.gr

Abstract. This paper addresses the performance issues of autonomous power systems under high renewable energy sources (RES) penetration. Renewable energy sources could be the main option for isolated power generation at remote locations in case that energy storage introduced. At the moment, pumped hydro storage (PHS) units and batteries storage systems (BSS) represent the most mature technologies for large scale energy storage. The basic criteria for this kind of energy storage unit installations include, (a) the existence of an autonomous power system with local power stations, (b) the high electricity production cost, (c) the potential of renewable energy sources (mainly wind and solar), and (d) the non-flat terrain morphology (for PHS). Greek islands represent ideal cases for large scale energy storage installations, as they fulfil all the above criteria. This paper shows the effect of the installation of a planned PHS unit in Crete island. The calculations are based on real data provided by the Cretan power system operator, whereas the results show the effect of energy storage units operation on the energy mix, as well as the economic viability of the project, which is combined with significant environmental benefits.

Key words: Isolated power systems, energy storage, pump hydro systems, renewable energy sources.

INTRODUCTION

Currently diverse challenges have emerged, such as climate change, economic recession, and security of energy supply. Furthermore, the rapid depletion of fossil fuels and their high and volatile prices have necessitated an urgent need for alternative energy sources to meet the corresponding energy demands (Ilić et al., 2011). Renewable energy sources (RES), such as wind and solar, are clean, inexhaustible and environmental-friendly alternative energy sources with negligible fuel cost (Kymakis et al., 2009). However, RES technologies, such as wind turbines (WTs) and solar photovoltaics (PVs), are dependent on a resource that is unpredictable and depends on weather and climatic changes, and the production of WTs and PVs may not match with the load demand (Annuk et al., 2011a; Annuk et al., 2011b), so there is an impact on the reliability of the electric energy system. This reliability problem can be solved by a proper combination of the two resources (WTs and PVs) together with the use of an energy storage system, such as batteries, as a type of energy-balancing medium (Brekken et al., 2011).

The Greek power system consists of the mainland interconnected system, which consumes the largest portion of total electricity demand (≈ 90%), and a large number of isolated autonomous power systems, with the vast majority of them located in the Aegean Archipelago islands (Hatziargyriou et al., 2006). In most of these systems, the cost of electricity production is much higher than in interconnected systems due to the high operating costs of their thermal generating units, mainly diesel and gas turbines, and the import and transportation costs of the fuel used.

More of these islands present significant wind and solar potential, which make ideal the exploitation of these renewable energy sources by using technologies such as wind turbines (WTs) and photovoltaics (PVs), and significant progress has been made till now. These technologies, when installed properly, may provide significant benefits to the system (Papadogiannis et al., 2009). Unfortunately, production fluctuation from RES may not match the demand. Usually, the demand is higher in early night hours, with simultaneous decrease in case of solar power production.

In such systems, contrary to interconnected ones, mismatches in generation and load and/or unstable system frequency control might lead to system failures much easier. Increased share of intermittent RES, may be economically attractive (Tsikalakis et al., 2003) but unless special precautions are made, dynamic security of the whole system may deteriorate (Karapidakis & Hatziargyriou, 2002).

Energy storage may be an interesting solution to alleviate technical barriers for increasing intermittent RES penetration. One of the main disadvantages of energy storage is its high initial cost. However, when sized properly, energy storage can provide an economically viable solution, especially in the cases of autonomous power systems that present high operating costs.

Although many technologies are available for energy storage, pumped hydro storage (PHS) represent the most mature technology for large scale energy storage. This paper includes a brief presentation of PHS technology, analyses the effect of the installation of the examined PHS unit in Crete island and concludes with the main considerations and results of the analysis.

MATERIALS AND METHODS

A wide variety of energy storage technologies are commercially available and include PHS systems, rechargeable batteries, flow batteries, and compressed air. Potential benefits include capacity reduction, frequency support, standing reserve provision and black start capability. Depending on technical requirements and geographical settings, a particular utility may avail of one or more of these technologies. Research effort has also focussed on ultra-capacitors, high-speed flywheels and superconducting magnetic energy storage. While these are highly responsive, their energy storage capabilities are limited, making such approaches more suitable for power quality applications and for improving system reliability.

The most widely established large-scale form of energy storage is PHS. Typically, such plant operates on a diurnal basis – charging at night during periods of low demand (and low-priced energy) and discharging during times of high or peak demand. A PHS plant may have the capacity for 4–8 hours of peak generation with 1–2 hours of reserve, although in some cases the discharge time can extend to a few days. Worldwide capacity is almost 100 GW, with facilities ranging up to 2,000 MW. The high construction costs, long development times and environmental considerations (most feasible locations are already being exploited) suggest that future growth in this area will be limited. Traditionally, PHS is utilised for energy management and the provision of standing reserve, but more recent installations possess the ability to provide frequency support and operate at partial capacity (Fox et al., 2007).

Hydroelectric plants typically have fast ramp-up and ramp-down rates, providing strong regulating capabilities, and their marginal generation cost is close to zero. In many countries, a natural synergy exists between hydroelectric generation/pumped storage and wind power. Clearly, if hydro generation is being replaced by wind energy then emission levels will not be directly affected, but the hydro energy can be transformed into potential energy stored for later use. The existing hydroelectric plant can reduce their output, using the reservoirs as storage, to avoid wind energy curtailment.

PHS systems usually consist of the following parts: an upper reservoir, waterways, reversible (pump/generator) turbines or separated units of peltons and pumps as in this examined case**,** and a lower reservoir, shown schematically in Fig. 1.

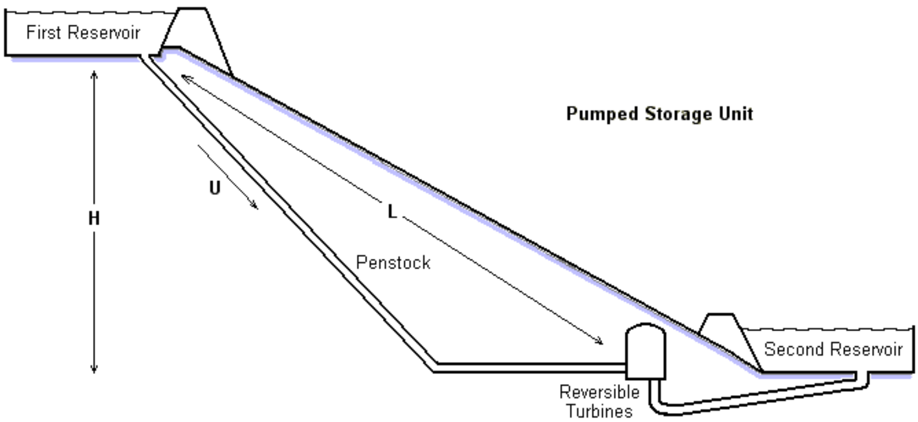

Figure 1. Components and structure of pump hydro storage system.

As in any hydraulic system, in PHS there are losses during operation, such as frictional losses, turbulence and viscous drag, and the turbine itself is not 100% efficient. The water retains some kinetic energy even when it enters the tailrace. For the final conversion of hydro power to electricity, generator losses have to be also accounted. The overall efficiency of a PHS system is defined as the ratio of the energy supplied to the consumer while generating, and the energy consumed while pumping, and it usually lies in the range of 65–75%.

Unit commitment is a very significant optimization task, which plays a major role in the daily operation planning of power systems, especially in the framework of the deregulated power markets. The objective of unit commitment is to minimize the total operating cost of the generating units during the scheduling horizon, subject to a number of system and unit constraints. The overall problem can be divided into two sub-problems: the mixed-integer nonlinear programming problem of determining the on/off state of the generating units for every hour of the dispatch period (usually 24 hours) and the quadratic/cubic programming problem of dispatching the load among them. The simultaneous solution of both problems is a very complicated procedure, the difficulty of which grows proportionally to the number of units and constraints taken into consideration (Simopoulos et al., 2006; Katsigiannis & Karapidakis, 2007).

The total operating cost of the generating units consists of Fuel costs, Start-up costs and Shut-down costs. Fuel costs are calculated using unit heat rate and fuel price information. The use of dual fuels for flame stabilization when the unit operates at low output levels, for example during start up ramps, further complicates the fuel cost computation. Start-up costs are expressed as a function of the number of hours the unit has been down (exponential when cooling and linear when banking). Shut-down costs are defined as a fixed amount for each unit per shut-down. The constraints which must be satisfied during the optimization process are (Kazarlis, 1996):

- *System constraints*: They include system power balance (demand + losses + exports), and system reserve requirements.
- *Local constraints*: They include unit initial conditions, unit high and low power limits (economic, operating), unit minimum-up time, unit minimum-down time, unit status restrictions (must-run, fixed-MW, unavailable, available), unit rate limits, unit start-up ramps, unit shut-down ramps, unit flame stabilization fuel mix, unit dual or alternate fuel usage, unit or plant fuel availability, and plant crew constraints.

On the island, in many locations average wind speed is higher than 8.5 m sec^{-1}. Moreover, Crete presents one of the highest solar potentials in whole Europe reaching up to 2,100 kWh m^2 per yr. These characteristics make Crete ideal for the installation of wind and solar technologies. As a result, already 33 wind farms have been installed with rated power of 187.1 MW. Moreover, Cretan topology is quite suitable for PHS installation. The terrain is very mountainous with altitudes more than 2 km. Additionally, more than 1,000 small PV parks (mainly of 80 kW each) and 1,800 roof PVs have been installed, reaching a total of 95.5 MW. Table 1 presents the percentage of annual energy production in 2015 for all installed units of the island (conventional and RES), in which RES penetration exceeds 20%. The annual load demand is almost stable within the last seven year and approximately 3T Wh.

Table 1. Characteristics of Crete Island's electricity units (year 2015)

Technology	Fuel	Annual share
Steam turbines	Mazut	36.70%
Diesel generators	Mazut	24.85%
Gas turbines	Diesel	3.85%
Combined cycle (CC)	Diesel	14.47%
WTs	-	16.03%
PVs	-	5.11%

The basic solution methods of unit commitment problem include the priority list method, dynamic programming, branch-and-bound, Lagrangian relaxation, and numerous artificial intelligence methods. In Cretan power system, the priority list method is used, which mimics the scheduling practices followed by system operators. The units are committed in ascending order of the unit average full load cost so that the most economic base load units are committed first and the peaking units last in order to meet the load demand. Priority list methods are very fast but they are highly heuristic and give schedules with relatively high production costs. Table 3 presents the main technical characteristics and priority list for Cretan power system's thermal (conventional) units.

The examined PHS system will have the ability to provide guaranteed power through three (3) hydro turbines with an installed capacity of 25 MW each (as a corresponding hydro power station with nominal output of 75 MW) for 8 hours per day, producing at least 600 MWh daily. In parallel, the system includes four (4) wind farms, with total capacity of 166 MW that aren't in the same place. This capacity will be limited to 120 MW during wind farm production, following the Greek legislative framework. The main technical characteristics of the examined project are presented in Table 2 and the basic single line diagram is depicted in Fig. 2.

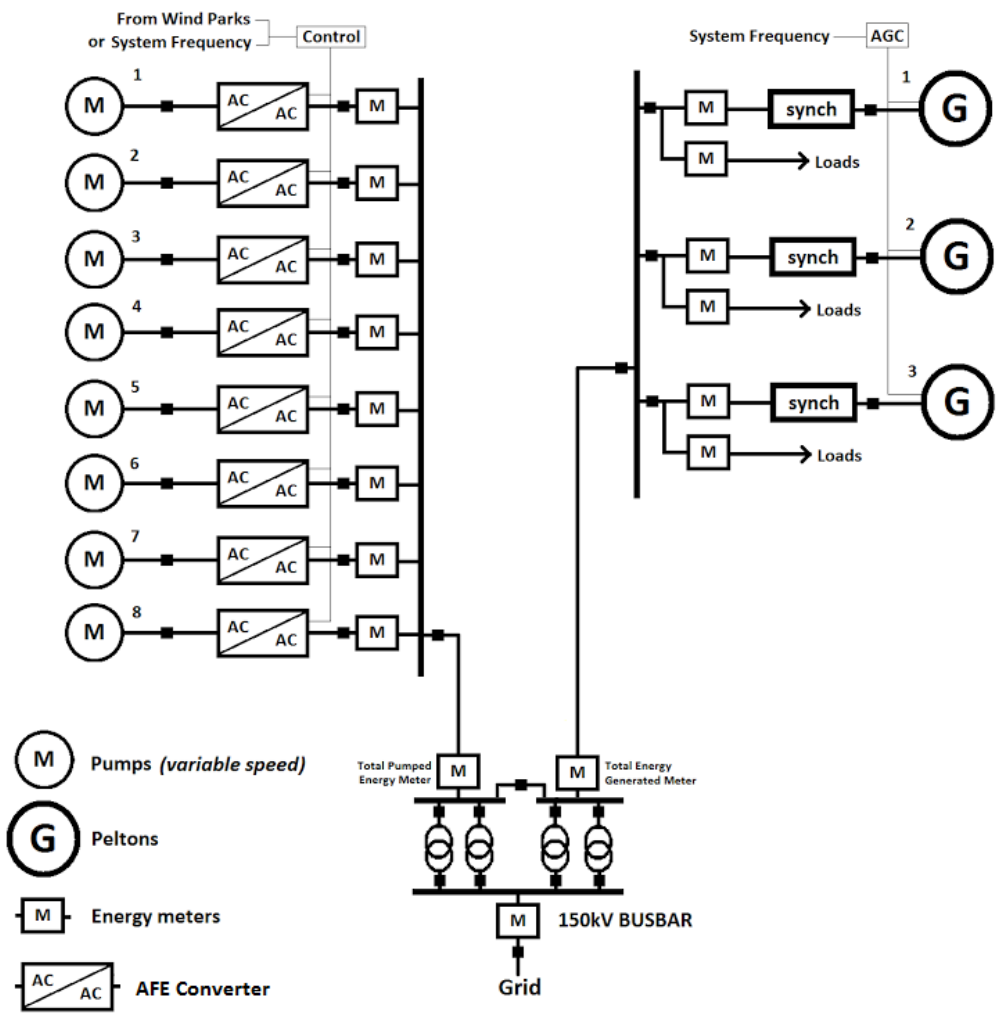

Figure 2. Single line diagram of the examined project.

Table 2. Main technical characteristics of the project

Wind Farms	
Total Installed Capacity	166 MW
Maximum Permitted Capacity (Injected)	120 MW
Pumping & Hydroelectric Station	
Pumps (8 pumps x 12.5MW)	100 MW
Hydroelectric station (installed capacity)	100 MW
Hydroelectric station (guaranteed capacity)	75 MW
Upper & Lower reservoir tank (total storage)	1,250 MWh
Upper & Lower reservoir tank (actual storage)	1,100 MWh

According to the national operational code for the non-interconnected islands (RAE, 2014), all the PHS should submit an overall daily bid of energy supply, which is available to offer in the network for the next day (24 hours time interval). By this action, the network administrator is required to absorb this energy supply prior to the energy produced by conventional units, as energy produced by RES technologies.

Furthermore, in cases that the network administrator considers that more power is needed to meet the power demand that cannot be satisfied by other production units, only then can he require from the PHS to provide the next day into the grid part or the whole of its capacity in 'guaranteed energy'. More specifically, in this case if the PHS is not able to provide the required stored energy in order to adequately meet the given requirement and cannot cover it directly from its own RES units, it has the ability to consume energy (by pumping) directly from the network during the night. This energy is considered as energy that absorbed from the network, and is billed in a different way. Table 3 shows the different billing options that exist in PHS operation, according the Greek legislative framework.

Table 3. Billing options for PHS system

Energy & Power Compensation	Revenues
Energy delivered by the hydro turbines	236 € MWh^{-1}
Energy delivered by the WFs directly to the network	100 € MWh^{-1}
Energy absorbed from the network	186 € MWh^{-1}
Power compensation availability	127,000 € MW^{-1}

RESULTS AND DISCUSSION

The results show that on annual basis the hydro turbine produces at least 220 GWh of electricity (75 MW guaranteed power for 8 hour per day for all year around). By considering a total PHS system efficiency of 72%, the electricity needed for pump operation is 304 GWh. The simulation results show that 88% of this electricity is covered from the WFs of PHS system. From the remaining produced WFs electricity, 5.5% is delivered directly to the network, whereas 6.5% cannot be absorbed.

This study used the well-known and reliable economical indices that include net present value (NPV), after tax internal rate of return (IRR with 29% tax rate), benefit to cost (B/C) ratio, simple payback and equity payback for discount rate i = 6%. The considered costs are 3,000,000 € MW for PHS system construction (without the WFs) and 1,200,000 € MW for WTs. The 75% of these initial costs are covered from a bank loan of 7% interest rate. Total annual operational and maintenance (O&M) costs are assumed to be 2% of the initial cost (these costs do not include the cost of absorbed electricity from the network). The total lifetime of the project is considered to be 40 years (Kousksou et al., 2014). Due to the fact that WFs lifetime is approximately 20 years, reinstallation of equal capacity WTs is considered during halftime of the project life.

Concluding, the conducted capital budgeting study concludes that the examined PHS project is economically viable as it is shown in Table 4. It has to be taken into account that the considerations for hydro turbine electricity production are pessimistic, so during real operation the results could be significantly improved. The environmental results show the amount of annual greenhouse gases (GHGs) emission reduction for the specific fuel mix of Cretan power system.

Table 4. Economical and environmental evaluation of the examined project

NPV	60,710,000 €
IRR (after tax)	8.8%
B/C ratio	1.49
Simple payback	10.3 years
Equity payback	11.2 years

CONCLUSIONS

In this paper, the effect of PHS units installation on the (largest in Greece) autonomous power system of Crete Island is examined. The analysis showed the significant effect of PHS units operation on the energy mix, as it produces 7.5% of total energy production in Crete (considering a modest scenario). Moreover, the analysis proved that the project is economically attractive, while it provides significant environmental benefits. The viability of this project also shows that additional PHS stations can be installed in the Cretan power system, increasing the wind power penetration and decreasing the dependence on expensive fossil fuels (diesel and crude oil). This study proves that in the majority of small autonomous power system, the target of reliable operation with high penetration of renewable technologies and low initial cost is feasible. The analysis of results showed the significant contribution of further wind turbines installations combined with energy storage, projects which will be widely applied in the near future.

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Comparison of tillage systems in terms of water infiltration into the soil during the autumn season

S. Kovář*, J. Mašek and P. Novák

Czech University of Life Sciences Prague, Faculty of Engineering, Kamycka 129, CZ165 21 Prague 6 – Suchdol, Czech Republic
*Correspondence: kovars@tf.czu.cz

Abstract. The soil belongs to the most valuable parts of the planet Earth. It is, endangered by water erosion, which causes huge destruction every year, or damage to farmland. More than half of the agricultural land in the Czech Republic is threatened by water erosion. The measurement was performed in the location Nesperská Lhota. The trial has been established on loamy sand Cambisol. In the field experiment, there were created 6 different variants which wad differed by soil tillage and crop. In the individual variants maize and oats were located. The field trial has been existing for a long time, as it was founded in 2009. Two measuring methods of water infiltration were used for the measurements: a mini disk infiltrometer and a single ring. The measurement was performed in the period of September 2016 before the harvest of maize. The soil aggregates were already stabilized at that time after all tillage operations. The measurement result showed the difference between the methods of soil tillage. The greatest ability of infiltration had a variant of maize with inter-row oats. Surprisingly, it was followed by maize, which was processed by ploughing technology. The lowest infiltration capacity was showed by oats reduced by soil tillage. A variant without vegetation had the second lowest infiltration. Our results obtained at rate of water infiltration into the soil affirm the need to control measures in the late vegetative stages. It is important for most of the rainfall to be quickly infiltrated so that it prevents the formation of massive surface runoff.

Key words: mini disk infiltrometer; soil tillage; single Ring infiltrometer; water erosion.

INTRODUCTION

Soil tillage constitutes the mechanical interference into the soil, in which there is a difference in the intensity of processing of soil aggregates and a difference in the change of the soil structure and the distribution of organic material (Hanna et al., 1994; Titi, 2002). The given characteristics are reflected subsequently in water permeability. The type of tillage influences extend of water erosion, which is one of the global problems (Kovář et al., 2016). Water erosion causes each year the destroying or damaging of large areas of agricultural land. Apart from the kinds of sown crops, the type of tillage influence water erosion, too. Novák et al. 2012 reported that the loss of soil is significantly higher by water erosion in conventional tillage (during sowing of maize) than in conservation tillage.

The focus on cost reduction is the main feature of current trends in agriculture and the application of technologies that eliminate environmental risks in comparison with conventional technologies (Bocchi et al., 2000; Zhang et al., 2014). The technologies of differentiated tillage are introduced newly. It is possible to use a large number of methods to detect susceptibility to water erosion (Mloza-Banda et al., 2016). These methods include e.g. measurements by Mini Disk infiltrometer or using Single Ring infiltrometer. Both methods save both the time and as well as the complexity of the measurement. These characteristics cause that the two methods start being used as gradually spread measurement method. A single ring infiltrometer (SR) is widely used for field measurements of infiltration (Jačka et al., 2014).

The aim of the measurements was to compare differences in the rate of water infiltration into the soil and water conductivity according to the type of soil treatment and species sown crops.

MATERIALS AND METHODS

First the value of soil moisture through the moisture meter Theta probe (Delta devices) was determined before the measurement. Two methods were used for measurement of the rate of water infiltration into the soil. The measurement of both methods can be seen in Fig. 1.

The first method was the measurement through the Single Ring infiltrometer test. The method used was simplified falling-head (Bagarello et al., 2004). This device consists of a plate with a diameter of 15 cm and a wall thickness – 2 mm. Its height is 20 cm. This single ring was thoroughly embedded in the soil, taking care to minimize the changes in the measured pore system. The ring was inserted into a depth of 10 cm. Water volume of 0.5 dm^3 was then poured into a single ring and the time was set off. When the water was soaked into the soil, the time was stopped and the value was subtracted. Consequently soil moisture was measured again using the moisture meter Theta probe and it was entered into the table. It was performed in 10 repetitions.

Figure 1. Measurements by Mini Disk infiltrometer and by Single Ring.

The second method was the measurement through Mini Disk infiltrometer. The Mini Disk infiltrometer is very easy to be used, small, with low demands on the operator. Infiltrometer consists of polycarbonate tubes. The tube has a diameter of 31 mm, a height of 327 mm and it is divided into two parts. Both parts are filled with water. The upper part, which is called the bubble chamber, is used to set the air intake. The lower part of the tube has a stainless semipermeable membrane at the bottom, about the size 15.20 cm^2. through which the water is infiltrated into the soil. The scale is also marked in the lower part of the tube, from which the value of the water volume in milliliters is subtracted. It was performed in 10 repetitions. Each Mini Disc infiltrometer was filled with water and subsequently placed by percolation area in a given variation of the experiment. The readings from the scale of the circular infiltrometer were written into pretreated tables at 0 hours. Timer was set off on the prepared stopwatch and the values of the scale were subtracted and recorded every 2 minutes into the table. The measurements lasted for 30 minutes in each experimental area. Both methods of measurements were performed in parallel to the machinery passes and infiltration was measured in noncompacted area. The rate of water infiltration into the soil and complementary characteristics were measured in the experimental field experiment versions at locality Nesperská Lhota in Central Bohemia Region.

Measurements are carried out in the sandy loam Cambisol 30 September 2016. The experimental plot is on a slope with a uniform slope, average slope is 4.9°. The measurement was made in seven variants of the field trial, which had already been established in 2009. The options vary in different tillage and different crops. Plot of land for each variant was 6 m x 50 m in length side is facing the fall line.

Variants of trial:

Variation 1 – oat with conventional tillage. Land was ploughed into the middle depth (0.2 m). It was used mouldboard plough The soil was left in rough furrow through the winter. Seedbed preparation was performed using harrows and levelling bars. Last operation was sowing of oats.

Variation 2 – oat with reduced tillage. After the harvest the straw was crushed and left in the field. This was followed by reduced tillage with disc cultivator (into depth 0.08 m). The oats were sowed in spring the following year.

Variation 3 – maize with conventional tillage and inter-row crop. Land was ploughed into the middle depth (0.2 m). It was used mouldboard plough The soil was left in rough furrow through the winter. Seedbed preparation was performed using harrows and levelling bars. Oats were seeded into inter-row space (2 rows- 0.125 m). After the germination of oats was sown maize.

Variation 4 – land was ploughed into the middle depth (0.2 m). It was used mouldboard plough The soil was left in rough furrow through the winter. Seedbed preparation was performed using harrows and levelling bars. Last operation was sowing of maize. The soil surface was covered at the time of sowing almost by zero organic matter.

Variation 5 – maize with direct sowing. The straw was crushed and left on the land in the autumn of 2015. The soil remained without tillage over the winter. In spring maize was sown directly without any tillage.

Variation 6 – maize with freezable intercrop. After previously harvest tines cultivator was done into a depth of 0.18 meters followed by sowing intercrops (mustard). There was a freezing of intercrops during the winter. Maize was sown without tillage in the spring.

Variation 7 – without vegetation (black fallow). Land was maintained over time without vegetation through total herbicide Roundup (conventional tillage technology).

RESULTS AND DISCUSSION

Table 1 lists the physical properties of soil. The table shows the average values of five samples. From the values it is evident that the variants with reduced technology have higher porosity and conversely lower bulk density. Data are affected by long-term nature of the experiment. Tillage is done the same way since 2009. The increase in porosity and bulk density decline has been gradual. Noticeable positive effect of reduced technology is evident in the physical properties of soil data.

Table 1. Physical properties of soil

Variation	Depth [m]	Porosity [%]	Bulk density [g cm^{-3}]
1	0.05–0.1	36.31	1.63
	0.1–0.15	38.76	1.57
	0.15–0.2	38.51	1.61
2	0.05–0.1	41.81	1.49
	0.1–0.15	41.2	1.48
	0.15–0.2	41.67	1.54
3	0.05–0.1	40.21	1.49
	0.1–0.15	40.62	1.53
	0.15–0.2	39.78	1.56
4	0.05–0.1	37.5	1.62
	0.1–0.15	39.48	1.57
	0.15–0.2	40.84	1.53
5	0.05–0.1	40.37	1.48
	0.1–0.15	44.32	1.47
	0.15–0.2	42.9	1.51
6	0.05–0.1	40.01	1.52
	0.1–0.15	41.59	1.5
	0.15–0.2	45.8	1.54
7	0.05–0.1	39.71	1.56
	0.1–0.15	34.92	1.7
	0.15–0.2	36.7	1.65

Water infiltration into the soil and other parameters are shown in the graphs in Figs 2 to 4. In Fig. 2 the results can be seen of measurements of hydraulic conductivity measured using a single ring. The maize with freezable catch crop had the largest hydraulic conductivity and it was 706 mm h^{-1} in this measurement method. The second highest hydraulic conductivity was oat, which was prepared by conventional tillage. Its value is almost one-third compared to maize with freezable catch crop. The soil without vegetation had the smallest hydraulic conductivity. Closely followed by oats processed by reduced tillage. Measured values are relatively high for all variants. This is probably due to broken soil crusts using this method. Water infiltration is greatly accelerated by this. Water is accepted by macropores below the soil surface. Infiltration is not slowed formed soil crust, which was surely created this term.

Fig. 3 is a graph of hydraulic conductivity measured using mini discs. The maize with interrow oats had the highest value during measuring of soil of hydraulic conductivity, during a mini disk infiltrometer and it was 17 mm h^{-1}. The smallest infiltration had variant oats with conventional tillage. Values differ substantially from the previous measurement. This is probably caused by the emergence soil crust on the soil surface. Crust caused slowdown water infiltration into the soil. Surface layer crust contains fine soil particles without the macropores. The highest value of the variant 3 is probably due to a partial disruption of surface residues mustard root system. Overall, the result obtained by this method differs from the previous ones and it is not possible unambiguous interpretation by the effects of soil crusting. The difference may be caused by application of mini discs on the treated soil surface using fine particles. Another option is a set of conditions of infiltration when using mini disks.

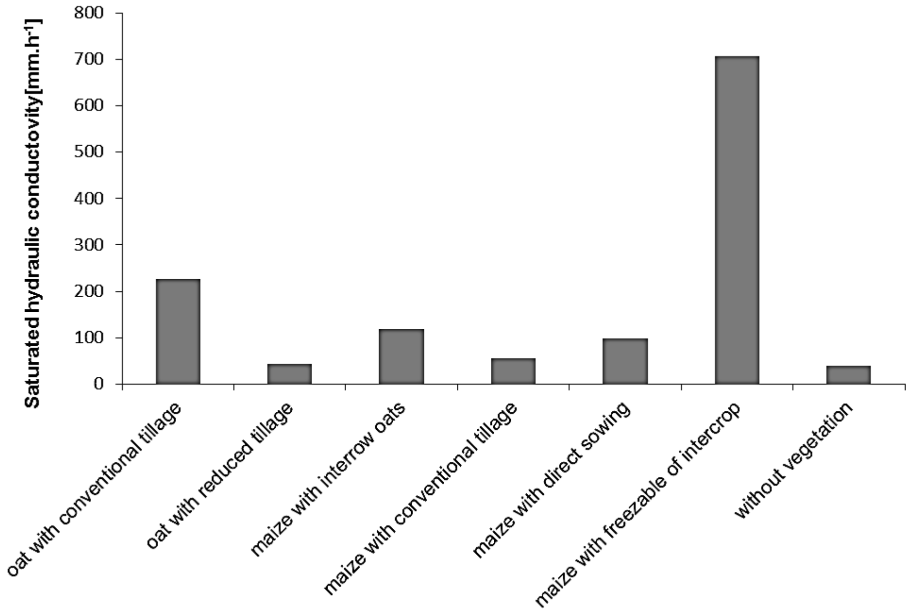

Figure 2. Hydraulic conductivity – measure with Single Ring infiltrometer.

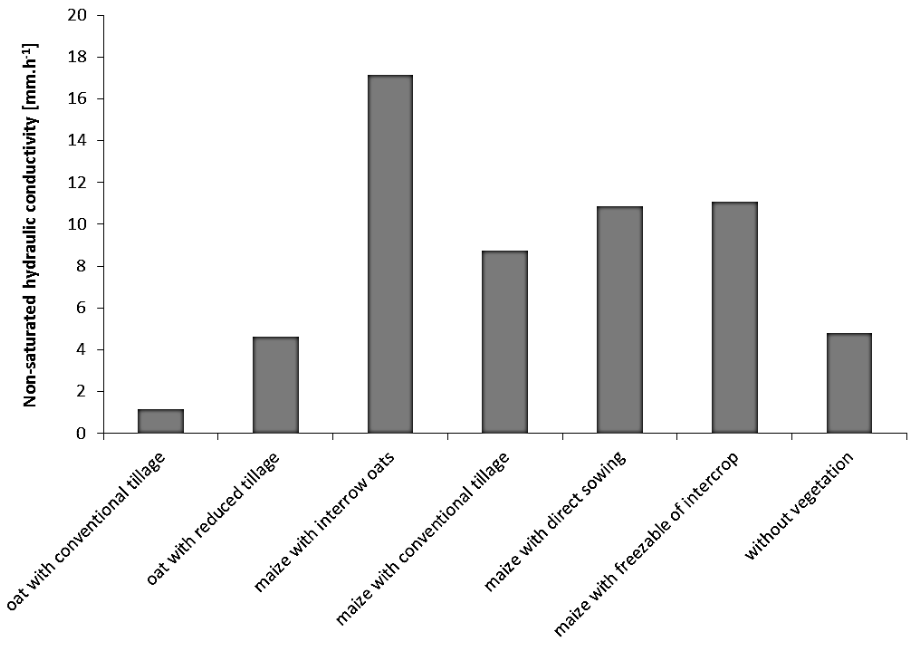

Figure 3. Hydraulic conductivity – measure with mini disk infiltrometer.

Fig. 4 shows the course of cumulative infiltration using mini discs. The measurement process can be successfully describing by quadratic interpolation. Very strong dependence was observed in all variants. From the values is evident gradual start of water infiltration into the soil. This is caused by the soil crust, as already indicated in the previous graph. Infiltration of water is very slow. The acceleration occurs after the saturation of topsoil.

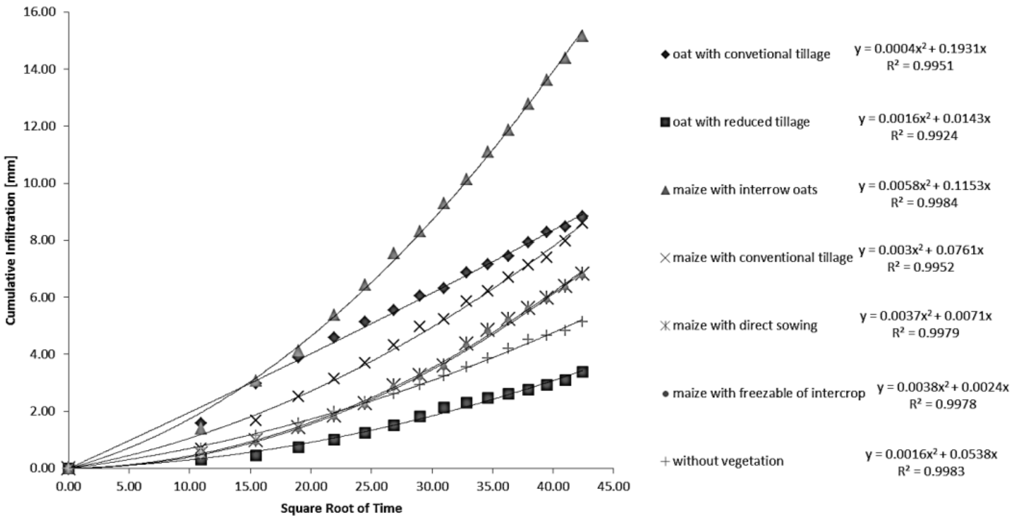

Figure 4. Cumulative infiltration of all variant.

Results of the evaluation of infiltration (hydraulic conductivity) are consistent with the results of other authors. Rasmussen (1999) and Truman et al. (2005) confirmed the benefits of technology without tillage in terms of a significant increase water infiltration into the soil. In terms of the field trial we confirmed a increase of hydraulic conductivity (especially non saturated) by use of technologies without ploughing only partially in comparison with alternatives, where ploughing was applied. During the growing season, maize and spring cereals, however, the discrepancies between variants decreased, indicating a higher adsorption capacity fading effect of soil water, which can be recorded after ploughing. For this issue, however, different behaviour of different soil types can´t be excluded.

On the other hand, Obi & Nnabude (1981) and also Heard (1988) didn´t find any differences on sandy soils with surface runoff and soil washes away with ploughing and conventionally processed soils or even the opposite effect better results with conventional surfaces.

CONCLUSIONS

Measurements show different values of surface runoff and water infiltration into the soil during the period of increased risk of torrential rainfall and possible subsequent erosion events. Variant 4 was most threatened by excessive run-off (conventional tillage with ploughing), which confirmed the risk of erosion on slope and light soil without the use of proper soil conservation technologies. Measurements show positive effect of soil cover with organic matter. The speed of water infiltration into soil also affects the water supply of plants. Soils with higher infiltration are able to maintain higher humidity during drought. Rapid infiltration also helps to retain water in landscape which is important during the risk of local flooding. It was also found different behavior of individual variants during measurement different methods. This behavior is likely to be affected by the formation of soil crusts.

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Comparison of selected remote sensing sensors for crop yield variability estimation

K. Křížová[1,*] and J. Kumhálová[2]

[1]Czech University of Life Sciences in Prague, Faculty of Engineering, Department of Agricultural Machines, Kamýcká 129, CZ165 21 Prague, Czech Republic
[2]Czech University of Life Sciences in Prague, Faculty of Engineering, Department of Machinery Utilization, Kamýcká 129, CZ165 21 Prague, Czech Republic
[*]Correspondence: krizovak@tf.czu.cz

Abstract. Currently, spectral indices are very common tool how to describe various characteristics of vegetation. In fact, these are mathematical operations which are calculated using specific bands of electromagnetic spectrum. Nevertheless, remote sensing sensors can differ due to the variations in bandwidth of the particular spectral channels. Therefore, the main aim of this study is to compare selected sensors in terms of their capability to predict crop yield by NDVI utilization. The experiment was performed at two locations (Prague-Ruzyně and Vendolí) in the year 2015 for both locations and in 2007 for Prague-Ruzyně only, when winter barley or spring barley grew on the plots. The cloud-free satellite images were chosen and normalised difference vegetation indices (NDVI) were calculated for each image. Landsat satellite images with moderate spatial resolution (30 m per pixel) were chosen during the crop growth for selected years. The other data sources were commercial satellite images with very high spatial resolution – QuickBird (QB) (0.6 m per pixel) in 2007 and WorldView-2 (WV-2) (2 m per pixel) in 2015 for Prague-Ruzyně location; and SPOT-7 (6 m per pixel) satellite image in 2015 for Vendolí location. GreenSeeker handheld crop sensor (GS) was used for collecting NDVI data for both locations in 2015 only. NDVI calculated at each of images was compared with the yield data. The data sources were compared with each other at the same term of crop growth stage. The results showed that correlation between GS and yield was relatively weak at Ruzyně. Conversely, significant relation was found at Vendolí location. The satellite images showed stronger relation with yield than GS. Landsat satellite images had higher values of correlation coefficient (in 30 m spatial resolution) at Ruzyně in both selected years. However, at Vendolí location, SPOT-7 satellite image has significantly better results compared to Landsat image. It is necessary to do more research to define which sensor measurements are most useful for selected applications in agriculture management.

Key words: Remote sensing, crop yield, satellite images, Greenseeker, NDVI.

INTRODUCTION

The concept of Precision Agriculture (PA) has developed as an indispensable reaction to higher population growth over recent decades (Zhang, 2015; United Nations, 2015). Up to 1960s, increasing crop production was enabled by expansion of agricultural areas, however, this trend slowed down when the percentage of arable land reached 9%

of total area worldwide (Moldan, 2015). Vegetation Indices (VI) are one of the tools by which it the concept of PA is currently fulfilled. These mathematical formulas are based on various combinations of reflectance values in specific bands of electromagnetic spectrum. Knowledge of spectral behaviour of vegetation is therefore essential for results interpretation. The method of evaluation canopy characteristics using VI has been gaining importance recently because the whole process operates in a non-destructive mode (Richards, 1993). It is therefore possible to carry out particular analysis repeatedly, for instance in different growth stages (Jones & Vaughan, 2010). A number of studies have been performed to prove the relation between VI and investigated vegetation characteristics, e.g. the study of Hunt Jr. et al. (2013), where triangular greenness index (TGI) was developed and successfully used to indicate leaf chlorophyll content. Prediction models for barley, canola and spring wheat yield were created by Johnson et al. (2016) using Normalized Difference Vegetation Index (NDVI) and Enhanced Vegetation Index (EVI) data. VI may be also utilized for comparison of different hybrids yield, as Marino et al. (2013) did when studying two hybrids of onion productivity.

NDVI is the basic representative of VI's. The algorithm for NDVI calculation was stated by Rouse et al. (1973) as the ratio of reflectance in near infrared (NIR) and red visible region. NDVI is considered as main indicator of greenness, e.g. of dense and healthy vegetation. Its values range from -1.0 to +1.0, where higher values (0.6–0.9) indicate denser vegetation cover (USGS, 2015). Nevertheless, Huete et al. (2002) stated, that NDVI tend to lose sensitivity as the vegetation cover becomes denser.

To acquire desired information about specific vegetation characteristic in form of VI, remotely sensed data are utilized. At present, there are a number of sources that provide such kind of imagery. The data may beacquired by spacecraft or aircraft. These carry devices onboard, that capture Earth's surface either actively or passively (Khorram et al., 2016), therefore remote sensing sensors are divided into active and passive as well. Passive sensors exploit the electromagnetic radiation emitted or reflected from Earth's surface, thus the signal detected comes from outside a sensor. Conversely, active sensors collect information per an artificial signal. Energy is emitted from within the sensor and detected after it is reflected from the surface (Wang & Weng, 2013). In literature, differences between active and passive sensors have been intensively studied. Erdle et al. (2011) tested one passive and three active reflectance sensors to examine how they provide the information about nitrogen content and crop biomass. Another study (Elsayed et al., 2015) dealt with the capability of both types of sensor to estimate Normalized Relative Canopy Temperature (NRCT). GS is a representative of the active sensors. Its signal is emitted towards the target and the amount of reflected radiation is detected. GS convert such data into NDVI directly (Trimble, 2017). On the other hand, satellite data in this study were all acquired by passive sensors. There are differences in desired wavelengths between particular sensors.

It is clear from the above literature review that different methods and sensors can be used for crop yield prediction. Therefore, this study aims to compare selected sensors in terms of their capability to predict crop yield by NDVI utilization.

MATERIALS AND METHODS

Study area

The data for this study were obtained from two experimental fields. The first one (Ruzyně) was situated in Prague-Ruzyně (50°05'N, 14°17'30"E), Czech Republic. A larger part of the field has a southern aspect and the elevation ranges from 338.5 to 357.5 m above average sea level (a.s.l). The size of area is 11.5 ha. The average slope of the field is approximately 6%. The soil of this experimental plot can be classified as Haplic Luvisols partially covering fine calcareous sandstones with higher content of coarse silt and lower content of clay particles and clay. The value of cation exchange capacity in the top layer containing clay is 20–35%. The soil profile is neutral and the sorption capacity is from saturated to fully saturated. Content of available minerals is from good to very good. In the slope positions and in loess loam profiles of Luvisols with remnants of alluvial horizon can be found. Some parts where the topsoil directly overlays the parent material of loess loam are strongly eroded. The average precipitation is 526 mm per year and the average temperature is 7.9 °C.

The second field (Vendolí) was located near to Vendolí in Eastern Bohemia (49°43' 47.94"N, 16°24' 14.21"E), Czech Republic, and it has 26.4 ha. The plot is undulated with the average slope approximately 6%. The elevation ranges from 543 to 571 m a.s.l. The soil of this experimental plot can be classified as modal cambisols lying on calcareous sandstone. Some parts, on sloppy terrain especially, are strongly eroded, while big amount of stones is lying on the top parts of the field. The average precipitation is 700 mm per year and the average temperature is between 6–7 °C.

Conventional arable soil tillage technology based on ploughing was used on these fields. Crop rotation system, based on wheat, barley and oilseed rape crops alternation, is common practice in the Czech Republic. Our experiment included the data from the year 2007 and 2015 for Ruzyně with winter barley and 2015 only for Vendolí with spring barley.

Field data

A combine harvester Sampo 2070 equipped with an LH 500 yield monitor (LH Agro, Denmark) with a DGPS receiver with EGNOS correction measured yield in Ruzyně location. The horizontal and vertical accuracy of this system was ± 0.1 to 0.3 m and ± 0.2 to 0.6 m, respectively. Measured yield data were processed by an on-board computer on the combine harvester and saved together with the location data every 3 s. An axial combine harvester New Holland CR9080 equipped with New Holland factory yield monitor and DGPS receiver with correction measured yield in Vendolí location. The precision of this system horizontally was ± 0.1 to 0.3 m and vertically it was ± 0.2 to 0.6 m. The data were saved with the coordinates every 1 s. The grain moisture content was measured continuously in the case of both fields and the yield was recalculated to 14% moisture content. The yield values were corrected using a common statistical procedure; all values that exceeded the range defined as mean ± 3 standard deviations were removed. Because of the large amount of data for both location studied (more than 8,000), the Method of Moments (MoM) was used to compute the experimental variograms. Experimental variograms of yield were computed and modelled by weighted least-squares approximation in GS+ software (Gamma Design Software, St. Painwell, MI, USA). A detailed description of this method can be found in

Kumhálová et al. (2011). Ordinary punctual kriging was done using the relevant data and exponential variogram model parameters for yield data visualisation.

NDVI values from GS handheld crop sensor were collected during the winter barley growth in April 23rd, and May 19th 2015 at Ruzyně location, and May 8th, May 30th and June 30th at Vendolí location. Experimental variograms of NDVI values were computed by common procedures using an exponential and spherical model (see Table 1). The data were processed in ArcGIS 10.3.1 software (Esri, Inc., Redlands, CA, USA).

Table 1. Summary statistics, variogram model parameters and the methods of interpolation used for yield and GS in the experimental field

	Yield			GS – NDVI				
Crop	Winter barley		Spring barley	Winter barley		Spring barley		
Location	Ruzyně		Vendolí	Ruzyně		Vendolí		
				2015		2015		
				23-april	19-may	8-may	30-may	20-june
Count	8,808.0	10,974.0	18,537.0	103.0	103.0	110.0	110.0	110.0
Mean	5.618	5.322	4.049	0.779	0.802	0.321	0.697	0.672
Median	5.481	5.385	4.111	0.790	0.810	0.310	0.715	0.680
Standard deviation	1.373	0.836	1.377	0.062	0.030	0.076	0.083	0.068
Minimum	1.109	1.391	0.204	0.390	0.670	0.190	0.440	0.510
Maximum	10.149	9.254	8.733	0.890	0.850	0.580	0.850	0.830
Skewness	0.015	-0.666	-0.025	-2.946	-2.206	0.458	-0.693	-0.567
Methodofinterpolation	Kriging							
Methodofestimation	Method of Moments (MoM)							
Variogram model	Exponential				Spherical			
Distance parameter (r)	22.9	11.0	72.30	205.7	610.9	210.9	297.0	215.9
Approximaterange = 3 x r	68.7	33.0	216.9	617.1	-	-		-
Nugget variance	0.3170	0.4200	0.5390	0.0025	0.0005	0.0044	0.0038	0.0047
Sill variance	1.0100	0.5900	1.9140	0.0051	0.0012	0.0063	0.0077	0.0026

Total monthly precipitation and temperature data were provided by the agro-meteorological station at the Crop Research Institute in Prague-Ruzyně and from weather station Davis in Vendolí. Precipitation and temperatures for the observed year are also provided in Table 2.

Table 2. Precipitation and temperatures in different growth stages by BBCH scale recorded on the experimental fields in the year 2015 for winter and spring barley

	Precipitation (mm)			Temperature (°C)		
	2007	2015	2015	2007	2015	2015
	Ruzyně		Vendolí	Ruzyně		Vendolí
Plant	Winter barley		Spring barley	Winter barley		Spring barley
BBCH 0-19	32.0	48.7	30.4	10.9	11.0	5.5
BBCH 20-29	90.4	100.4	7.6	5.7	3.8	9.7
BBCH 30-59	2.4	43.7	35.8	12.8	12.3	13.0
After BBCH 60	146.6	64.6	132.6	18.1	17.1	18.6
Sum	271.4	189.5	206.4	-	-	-
Mean	90.5	63.2	51.6	12.6	10.9	11.7

Remote sensing data

Landsat satellite images were downloaded directly from the USGS Global Visualization Viewer (http://earthexplorer.usgs.gov/), as free remotely sensed data.Images from Landsat 5 (L-5), Landsat 7 (L-7) and Landsat 8 (L-8) were used for this study. WV-2, QB and SPOT-7satellite images were purchased from the ArcDATA Company. Table 3 provides the bandwidths of red visible (RED) and near infrared (NIR) range of sensors used in this study. For atmospheric correction, the Fast Line-of-sight Atmospheric Analysis of Hypercubes was used (Li et al., 2014; Dominguez et al., 2015). All image pre-processing was implemented with ENVI SW (ENVI; version 5.3, Excelis, Inc., McLean, VA, USA).

NDVI were computed for every image with ENVI SW. All images were then exported into ArcGIS SW for further processing. Very high resolution (VHR) images (WV-2, QB and SPOT-7) were resampled according to Landsat satellite image outputs to 30 m. Yield data were resampled according to satellite images to spatial resolution of 0.6 m, 2 m, 6 m and 30 m. Data from GS were resampled according to Landsat images to 30 m spatial resolution for further processing.

Pearson's correlations between the yield maps and NDVI derived from satellite images and GS sensor were calculated using Statistica 13 (StatSoft Inc., Tulsa, USA) procedure.

Table 3. Bandwidths of red visible (RED) and near infrared (NIR) range of selected satellites and sensors

Satellite	Sensor	RED range (nm)	NIR range (nm)
L-5	TM	630–690	760–900
L-7	ETM+	630–690	750–900
L-8	OLI	640–670	850–880
QB		590–710	715–918
SPOT-7		625–695	760–890
WV-2		630–690	705–895
	GS	660, ~25 nm FWHM	780, ~25 nm FWHM

RESULTS AND DISCUSSION

Correlation coefficients (R) between NDVI (from original and resampled data sets of Landsat, QB, WV-2 and SPOT-7 satellite images) and yield were calculated for individual image data and plant species in selected locations (see Table 4). Correlation matrices between NDVI from GS crop sensor, Landsat satellite images and yield were then calculated for individual data sets (see Table 5). Summary statistics for NDVI calculated from original and resampled satellite images for selected crops are in Table 6. Summary statistics of crop yield and GS for selected dates only for 2015 provides Table 1.

Winter barley was grown in 2007 and 2015 in Ruzyně location. The year 2007 was drier up to BBCH 60 phenological stage in comparison with the year 2015 in Ruzyně location (see Table 2). Low precipitation in the growth stage BBCH 30-59 (2.4 mm) can cause a significant displacement of relatively higher yield to water-accumulating depressions. This fact is confirmed also by correlations presented in Table 4, where R between NDVI a yield had average value 0.856. The movement of higher yield to terrain concave areas in 2007 was also validated by summary statistics presented in Table 1, whereby both standard deviation and min-max range were higher than in 2015. In our previous articles (Kumhálová et al., 2011; Kumhálová et al., 2014), the influence of topography to yield in drier years was also found.

Table 4. Correlation coefficients between normalised difference vegetation index (NDVI) (from original and resampled L, QB and WV-2 satellite images with different spatial resolution (SR)) and yield of selected crops and years (levels of statistical significance: * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$)

Year	Yield		Growth stage	NDVI	
2007	Ruzyně		BBCH 59	Winter barley	
Satellite	L-5 TM	QB	L-5	QB	QB
SR	30 m	0.6 m	30 m	0.6 m	30 m
Date	May 24	May 22	May 24	May 22	May 22
Yield	1	1	0.861***	0.861***	0.835***
2015			BBCH 21-22		
Satellite	L-8 OLI	WV-2	L-8	WV-2	WV-2
SR	30 m	2 m	30 m	2 m	30 m
Date	March 18	March 23	March 18	March 23	March 23
Yield	1	1	0.264**	0.133***	-0.018
2015	Vendolí		BBCH 75	Spring barley	
Satellite	L-8 OLI	SPOT	L-8	SPOT-7	SPOT-7
SR	30 m	6 m	30 m	6 m	30 m
Date	July 1	July 4	July 1	July 4	July 4
Yield	1	1	0.341**	0.565***	0.501***

The year 2015 was drier year in sum of precipitation than the year 2007, but the precipitation distribution was more balanced during the growth stages (see Table 2). On the contrary, the precipitation distribution in BBCH 30–59 (43.7 mm) could probably cause the later crop beaten. In this year, harvesting losses caused by crop beating decreased the yield (see Table 1). This fact was confirmed by low *R* values between yield and NDVI (see Table 5); although the NDVI values were relatively high during BBCH 21–22 and crops were in a good condition (see Table 6). GS measurements on April 23rd (BBCH 31) and May 19th (BBCH 55) and comparisons between NDVI from GS and Landsat images and yield in Table 5 are in good accordance with previous statements. Nevertheless, *R* between NDVI from GS and Landsat images were weak (see Table 5).

Spring barley was grown in 2015 in Vendolí location. The precipitation distribution during the growth stages were balanced except the BBCH 20–29. The precipitation distribution was lower during these growth stages (7.6 mm) – see Table 2. Nevertheless, this weather running could lead to higher *R* (0.613) between yield and NDVI calculated from Landsat image in 30th May (see Table 5). It is validated by summary statistics presented in Table 1 as well, whereby standard deviation reached higher value. The precipitation distribution over the all growth stages could cause displacement of higher yield to places with better growth conditions. GS measurements were carried out on May8th (BBCH 35), May 30th (BBCH 55) and June 20th (BBCH 65). *R* between NDVI from GS and Landsat images was weak in early growth stage (8th May). On the contrary, the *R* value reached 0.679 between these two (GS and Landsat satellite) measurement methods in 30th May. The last measurements NDVI on 20th June with GS and on 20th

with Landsat were similar in comparison with yield, but the *R* between the measurement methods reached the value 0.453 only. These differences can be caused by other measurement method used and other spatial distribution of values measured. SPOT-7 image, acquired on 1st July, was chosen for crop evaluation. Very high resolution image in late date was available only, because of very cloudy scene during the crop growth. The *R* between yield and Landsat and SPOT-7 images was different. The Landsat image was cloudy in northern part of the experimental field. That is why 38 pixels from this part of field had to be removed (see Table 6).

Table 5. Correlation coefficients between normalised difference vegetation index (NDVI) from GS sensor, Landsat images and crop yield (levels of statistical significance: * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$)

		Winter barley – Ruzyně					
2015	Date/SR	GS NDVI	GS NDVI	L-8 NDVI	L-8 NDVI		
Date		April 23	May 19	April 19	May 14		
Yield	30m	0.011	0.022	0.260**	0.145		
L-8 NDVI	April 19	0.310*	-	-	-		
L-8 NDVI	May 14	-	0.359***	-	-		
		Spring barley – Vendolí					
2015	Date/SR	GS NDVI	GS NDVI	GS NDVI	L-7 NDVI	L-8 NDVI	L-8 NDVI
Date		May 8	May 30	June 20	April 29	May 30	June 24
Yield	30m	0.323***	0.458***	0.387***	0.001	0.613***	0.415**
L-7 NDVI	April 29	0.035	-	-	-	-	-
L-8 NDVI	May 30	-	0.679***	-	-	-	-
L-8 NDVI	June 24	-	-	0.453***	-	-	-

L-8 – Landsat 8 OLI image; L-7 – Landsat 7 ETM+; SR – spatial resolution.

Table 6. Summary statistics for NDVI calculated from original and resampled satellite images for selected years and crops

Year	2007 – winter barley			2015 – winter barley			2015 – spring barley		
	Ruzyně						Vendolí		
Satellite	L-5	QB	QB	L-8	WV-2	WV-2	L-8	SPOT-7	SPOT-7
SR	30 m	0.6 m	30 m	30 m	2 m	30 m	30 m	6 m	30 m
Count	115	306704	115	102	26684	102	231	6311	269
Mean	0.756	0.635	0.635	0.528	0.414	0.418	0.888	0.802	0.797
Median	0.759	0.638	0.635	0.532	0.416	0.418	0.901	0.809	0.809
Standard deviation	0.077	0.041	0.039	0.046	0.057	0.056	0.095	0.044	0.055
Minimum	0.556	0.477	0.544	0.315	0.185	0.269	0.519	0.623	0.531
Maximum	0.876	0.799	0.721	0.626	0.619	0.559	1.087	0.886	0.876
Skewness	-0.664	-0.401	-0.138	-1.047	-0.153	-0.353	-0.413	-0.732	-0.763

Summary statistics in Table 6 show that NDVI derived from Landsat images had higher mean and maximum values than NDVI derived from other satellites used in this study. This fact may support the conclusion, that Landsat images are more sensitive to crop biomass content. It can be explained by the differences in RED and NIR bandwidth among the sensors (see Table 3). QB, WV-2 and SPOT-7 have wider band range, than any of Landsat sensors. When comparing available Landsat sensors, L-5 and L-7 have similar calibration in contrast with L-8 (see Table 3). Studies dealing with this different

L-8 setting were also performed (Holden et al., 2016; Roy et al., 2016).GS handheld sensor and L-7 provide data in approximately same wavelengths. Nevertheless, there is a difference between GS and L-8. Despite this fact, L-8 data are very well correlated both with GS NDVI ($R = 0.679$, 30th May 2015 at Vendolí) and also with yield ($R = 0.613$, 30th May at Vendolí). However, this may be also caused by measuring date accordance. Differences in red band wavelengths are not so substantial in any case.

Another cause of differences may be input data resampling. Apart from Landsat, all satellite data were resampled to 30 m spatial resolution. Table 6 shows summary statistics for both, original and resampled data. Resampling seems to have no influence on QB data, all categories of summary statistics differ very slightly and mean values are even equal. WV-2 and SPOT-7 original and resampled data differ more in summary statistics than other sources. Each sensor was used to evaluate different dataset. Results that are more accurate may be gained when evaluating selected sensors by calculating NDVI from the same dataset. In addition, Bégué et al. (2008) stated that single date images may be unsatisfactory for yield prediction.

As mentioned above, there is the opinion that NDVI may be poor indicator of crop biomass when the canopy becomes denser (Huete et al., 2002). Gao et al. (2000) stated, that Enhanced Vegetation Index (EVI) tend not to be saturated over dense vegetation, like NDVI does, and seems to be sensitive enough to plant structural characteristics.In study by Zhu et al. (2016) similar issue was studied. L-5, L-7 and L-8 imagery were used to calculate NDVI and EVI for land cover changes evaluation in the city of Guangzhou, China. Due to the different wavelength setting, EVI was chosen as better indicator of greenness. Erdle et al. (2011) compared utilization of active and passive sensors. According to their study, made on seven wheat cultivars, active sensors disadvantage is that they are capable to measure limited number of VI. Conversely, passive sensors perform a possibility to develop different VI. Above that, GS measures only two fixed bands, while another active sensor Crop Circle is capable to capture three user configurable bands, e.g. green, red edge and NIR.As stated in Cao et al. (2015) study, indices derived from Crop Circle perform significantly better, than indices acquired by GS. Ali et al. (2014) examined the potential of yield prediction on dry direct-seeded rice using GS and then chlorophyll meter (SPAD) and simple leaf colour chart. Their result allegation was that all of these methods can be used for in-season yield prediction. Thus, according to that, GS is comparable with more simple measurement methods.

CONCLUSION

The results showed that all satellite images used in this study can sufficiently explain crop variability in given dates and can be used for yield prediction and crop growth evaluation. NDVI spectral index seemed to be good tool for simple and fast evaluation of the agriculture crop, because several data sourceswere possible to use for its calculation. Passive remote sensing sensors were compared with GS active sensor. Nevertheless, not very consistent results were acquired. VHR images were resampled to 30 m spatial resolution according to Landsat images in order to examine possible influence of spatial resolution on information evaluated. However, various bandwidths in RED and NIR region of selected images made the correlations between yield and NDVI different. The greatest difference in such evaluation was found between L-8 OLI sensor and WV-2 and SPOT-7 sensors. On the base of the results obtained in this study, it is necessary to undertake more research to define which of selected sensors is the most capable for yield prediction under conditions of the Czech Republic.

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Dry matter accumulation and nitrogen concentration in forage and grain maize in dryland areas under different soil amendments

S. Lamptey[1,2,4,*], S. Yeboah[1,3,5], L. Li[1,2] and R. Zhang[1,3]

[1]Gansu Provincial Key Lab of Arid Land Crop Science, Lanzhou CN7300 70, China
[2]College of Agronomy, Gansu Agricultural University, Lanzhou CN7300 70, China
[3]College of Resources and Environmental Sciences, Gansu Agricultural University, Lanzhou CN7300 70, China
[4]University for Development Studies, P.O Box TL 1882, Tamale–Ghana
[5]CSIR–Crops Research Institute, P.O Box 3785, Kumasi, Ghana
[*]Correspondence: naalamp2009@yahoo.com

Abstract. Soil amendment plays significant role in improving soil fertility and increasing crop productivity in rain–fed agriculture. Understanding the grain yield associated with dry matter and N concentration is essential for improving maize production. A 3– year field study was conducted to determine dry matter accumulation, nitrogen concentration and grain yield of forage and grain maize under different soil amendments in the Western Loess Plateau of China. The experiment was conducted using a randomized complete block design with four treatments and three replicates per treatment. Results showed that dry matter accumulation and nitrogen concentration in the swine manure in combination with chemical fertilized (SC) crops was significantly higher (by ≈ 60% and 39%) than no amendment (NA) which therefore translated into increased grain yield ≈ 74%. The SC treatment also improved leaf area index and chlorophyll content ($P < 0.05$) by approximately 34% to 32% compared to NA, which supported the above results. The nitrogen concentration in the leaf was higher at jointing and lower at maturity. Grain yield positively correlated with dry matter accumulation and nitrogen concentration at jointing, flowering and milk stage. Dry matter accumulation and grain yield also increased in the sole swine manure (SM) and maize stover (MS) treatments, but to lesser extent than SC. Based on the improvement of dry matter accumulation, nitrogen concentration and grain yield, swine manure in combination with chemical fertilizer appears to be a better fertilization option under dryland cropping systems.

Key words: Biomass production, Nitrogen content, Rain–fed, Yield.

INTRODUCTION

Agroecosystem productivity is often constrained by a low availability of water and nutrients (Rasouli et al., 2014), and the challenge is serious in many arid and semiarid regions of the world, such as the Western Loess Plateau of China (Hou et al., 2012). The semiarid Loess Plateau of China is a home to an estimated population upwards of 108 million, of which more than 70% are reported to be living and working in agricultural areas (Wang & Li, 2010; Xu–Zhe et al., 2012). Cropping on the Loess Plateau is dependent on natural precipitation. However, precipitation is relatively scarce in these areas, with high variation among years, and uneven spatial and temporal distributions (He et al., 2014). Soil moisture shortages commonly occur as a result of limited rainfall and strong evaporation in the semiarid region of China (Wang et al., 2015). Continuous loss of soil organic matter, associated with traditional methods of soil cultivation (Yin & Yin, 2010), often accelerates soil erosion processes and decline of soil fertility. However, many crops residues and livestock are produced in this region (Huang et al., 2008). Organic amendment has therefore gained interest amongst farmers at the Northwestern China. This is practiced widely as a measure to mitigate impacts on soil, and also for water conservation purposes (Huang et al., 2008).

Maize (*Zea mays* L.) is one of the most popular grain crops in the semiarid Loess Plateau region of northwestern China. In the last 50 years, maize yields in northern China have improved rapidly with mean growth rate of 5.3% (Zhen et al., 2006). The cropland dedicated to growing corn is bound to continue increasing due to the high demand for feed (Hu & Zimmer, 2013). This rapid increase in productivity has been mainly dependent on chemical fertilizer application, especially N (Guo et al., 2010). The higher crop yields have come under scrutiny because of the amendment levels needed to produce such yields and because of the perception and reality of the potential environmental impacts of those inputs. Optimizing soil and crop management to improve the crop productivity and yield stability of dryland agriculture is crucial to ensuring future food security (Lele, 2010). Management practices that consider the use of organic amendments are mentioned in several studies (Diacono & Montemurro, 2010; Cui et al., 2014) as an effective means to maintain soil water holding capacity, organic carbon and overall fertility levels when this technology is used in crop production. Liu et al. (2011) reported increases in dry matter accumulation and nitrogen concentration when fertilizer was applied in dry areas. The return of maize stover to soil has been long practiced in many parts in the Western Loess Plateau as a sustainable approach to improve soil water conservation and soil fertility (Huang et al., 2008). The use of maize stover as a soil amendment is currently challenged by the increased alternative demand for animal feed and fuel for heating and cooking (Lal, 2007). In the Western Loess Plateau of northwestern China, maize and swine production is the main crop–livestock integrated system practiced by small–scale farmers. The use of swine manure in crop production has declined since the 1980s due to increased use of inorganic fertilizers (Ju et al., 2005). Although great efforts have been made in the assessment of fertilization effects on crop yield in the region, few have focused on relationships between crop yields and nitrogen concentration under different soil amendment (Han et al., 2005; Liang et al., 2009).

Agronomic practices may play an important role in the concentration of secondary metabolites in plants (Selma et al., 2010). Maize grain yield increase is largely dependent on the improvement of nitrogen and dry matter accumulation. Rational application of organic manure has been shown to improve dry matter accumulation (Wang et al., 2009) and grain yield (Yang et al., 2015). However, there is speculation whether increase in dry matter accumulation is largely dependent on the improvement of dry matter accumulation at early growth season stage or at silking (Tollenaar & Lee, 2006; Ciampitti & Vyn, 2012). Identification of a specific period of crop development, regarded as critical for yield establishment, could indicate appropriate agronomic practices for maximizing crop yield. Therefore, an understanding of the relationships between grain yield and dry matter accumulation and nitrogen concentration at the early growth stage and late growth stage is essential for improving management practices to further increase forage and grain maize yield. Therefore, this 3–yr field study was conducted to determine (1) the effect of soil amendment on grain yield, dry matter accumulation and nitrogen concentration, and (2) the response of grain yield to dry matter accumulation and N concentration at different growth stages.

MATERIALS AND METHODS

Experimental site

The field experiment was conducted over a period of three years (2014–2016) at the Dingxi Experimental Station (35°28′N, 104°44′E, elevation: 1,971 m above sea level) located in the Anding County (Gansu Province) in NW China. The aeolian soil in that region is locally known as Huangmian (Chinese Soil Taxonomy Cooperative Research Group, 1995), which equates to a *Calcaric Cambisol* in the FAO soil classification (1990), and has a sandy loam texture ($\geq$ 50% sand). This soil has moderately low fertility, slightly alkaline pH ($\approx$ 8.3), soil organic carbon $\leq$ 7.65 g kg^{-1} and Olsen P $\leq$ 13.3 mg kg^{-1}, representing the major cropping soil in the district (Zhu et al., 1983). Long–term annual precipitation at the experimental site averages 391 mm, and ranges from 246 mm to 564 mm, as recorded in 1986 and 2003, respectively. Approximately, 60% of the rainfall occurs between July and September. Daily maximum air temperatures can reach up to 38 °C in July while minimum air temperatures can drop to negative 22 °C in January. The experimental site had been under long term cropping using conventional tillage practices. Fig. 1 shows in crop season rainfall recorded at the site for 2014 (280 mm), 2015 (274 mm) and 2016 (227 mm).

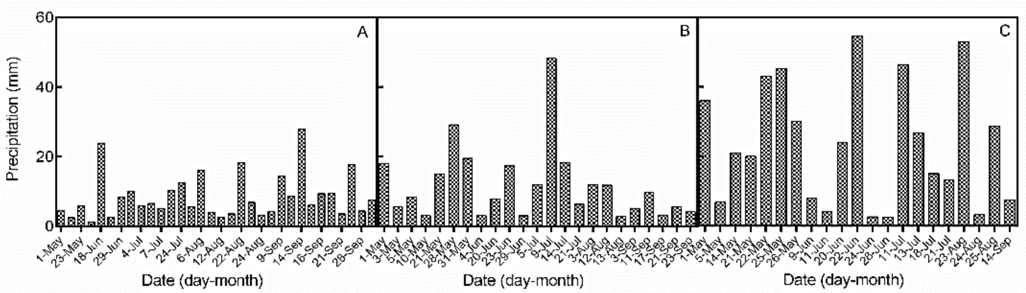

Figure 1. Daily rainfall records for the 2014 (A), 2015 (B) and 2016 (C) cropping seasons.

Experimental design

The experiment utilized a randomized complete block design with four treatments and three replications. The treatments were: No amendment (NA), which was used as control, dry swine manure (SM): 10 t ha^{-1}, maize stover (MS): 27 t ha^{-1}, swine manure + chemical fertilizer (SC): 5 t ha^{-1} of swine manure + 100 kg ha^{-1} of N as urea + 75 kg ha^{-1} of P_2O_5 respectively. Table 1 provides detailed nutrient composition of swine manure and maize stover. Treatments applied were at the same input. Maize stover from the previous crop was collected, air dried, shredded, weighed and returned to the field plots. Dry swine manure was obtained from a local swine farm, stored for 2 months, and spread on the land surface and incorporated by ploughing within 3 days of application. Representative manure was sampled at the time of application for nutrient analysis. Urea and maize stover were broadcasted and incorporated into the top 20 cm soil layer with shallow conventional tillage. The experimental design comprised 15 plots (plot dimensions: 3 m by 14.2 m), with alternate wide and narrow ridges (0.7 m and 0.4 m wide). Crops were sown with a hand held dibbler in furrows between the narrow and wide ridges. After the soil was covered with film, holes (about 20 cm apart) were made using a handheld device through the film in furrows to help collect and channel water from ridges to the rooting zone. All plots were mulched every two years with plastic film at sowing to increase soil temperature and speed up germination, and also to reduce evaporative losses. Plastic film mulching is regarded as an innovative technology for boosting maize productivity in arid environments (Gan et al., 2013). Colorless plastic film (polyethylene film 0.008–mm thick and 80 cm wide, made by Lanzhou Green Garden Corporation of China, Lanzhou), was laid by hand over the plot where the width of plastic film covering the plot surface was 60 cm wide. The crop before the experiment was established was potatoes (*Solanum tuberosum* L.). The experiment was initiated in 2012, however, this article reports the experimental data for the 2014, 2015 and 2016 cropping seasons.

Table 1. Chemical composition of maize straw and swine manure used in the study

Amendment	Organic C	N	P	K	Ca	Mg
	(%)					
Maize stover	47.5	0.74	0.38	0.45	0.55	0.74
Swine manure	39.94	2.2	1.7	1.9	2.7	0.5

Values are means (n = 3).

Sowing and field management

The experiment and the treatments were imposed on the same plots each year of the study. Maize (*Zea mays* L., cv. Funong 821) was sown in late April at a row spacing of 0.55 m with 0.35 m between plants and thus a density of 52,000 plants ha^{-1}; the crop was harvested in late September to early–October each year. Roundup® (glyphosate, 10% v/v) was used for weed control during fallow after harvesting as per product guidelines. During the growing season, weeds were removed by hand. All agronomic management except for nutrient applications, which were dependent on treatments, were equal for all plots.

Crop measurements and analyses

Leaf area index

Five maize plants were sampled from each plot using the ‘S’ type method described by Yin et al. (2016). Sampling was conducted at jointing (60 days after sowing (DAS)), flowering (90 DAS), milking (120 DAS) and maturity (153 DAS) stages, respectively, based on Ritchie et al. (1997). Leaf area index (LAI) was determined using Eq. (1) described in Yin et al. (2016):

$$\mathrm{LAI} = 0.75 \cdot P \cdot \sum_{i=1}^{n} (ai \times bi) \tag{1}$$

where LAI is leaf area index; P is planting density (plants ha^{-1}); *ai* is leaf length; *bi* is the greatest leaf width, and 0.75 is the compensation coefficient of maize.

Chlorophyll content

Chlorophyll content (Chl) of fully developed leaves was determined at jointing, flowering and milking stages using a portable chlorophyll meter (SPAD Model 502, Minolta Camera Co. Osaka, Japan). Measurements were conducted from 9:00 am to 12:00 noon on ten fully expanded leaves per plot.

Dry matter accumulation

Three plants were randomly chosen from each treatment plot, and cut to ground level for dry matter accumulation at jointing, flowering, milking and maturity stages. The plants were divided into various parts and fresh weight of these was taken using an electronic balance in the Dingxi experimental laboratory. Plant materials were then put in large brown envelopes and oven dried at 80 °C for 48 hours to a constant weight. The dried plant materials were ground for chemical analysis.

Grain yield

At physiological maturity, maize plants were manually harvested from an area of 13.2 m^2 (4 m × 3.3 m) per plot. Plants were threshed and grains weighed and converted to grain yield, and reported in kg per hectare.

Determination of nitrogen content

Leaf nitrogen content was assessed at jointing, flowering, milking and maturity stages whereas nitrogen content in the grain was assessed at maturity. The leaf and grain were ground to pass through a 1mm sieve and stored in plastic vials at room temperature until quality analyses were conducted. The C:N analyzer (elementar vario macro cube, Hanau–Germany) was used for the determination of nitrogen concentration.

Data analysis

The data were statistically analyzed with analysis of variance (ANOVA) at $P < 0.05$ using Statistical Package for the Social Sciences 22.0 (IBM Corporation, Chicago, IL, USA). The differences between the means were determined using least significant difference (LSD) at $P < 0.05$. The data analyzed were pooled for bivariate correlation analysis (two–tailed) using Pearson correlation coefficient.

RESULTS AND DISCUSSION

Leaf area index

Results of leaf area index are presented in Fig. 2. The LAI increased with crop growth and then decreased at maturity in all treatments over the study period. Significant differences ($P < 0.05$) were recorded among treatments at certain stages of measurement. The average LAI increased in the order SC > SM > MS > NA during the study period. Application of swine manure in combination with chemical fertilizer in 2014 enhanced LAI by 9%, 11% and 35% compared to SM, MS and NA respectively. In addition, SC, SM and MS treatments significantly increased LAI by 30%, 23% and 40% in 2015 and by 36%, 35% and 49% in 2016 respectively compared to NA. Differences in leaf area index can affect the spatial distribution of the crop’s canopy and the micro–environment around the plant, which in turn plays a significant role in the photosynthetic efficiency of crops (Fageria & Baligar, 2005). A suitable leaf area index is a major sign of high crop yield, as it is important in the relationship between sink and source of crops, and balance in the development of crop organs. Studies involving crop leaf area index, may provide scientific basis for achieving high yield by regulating crop physiological characters. Our results demonstrated that the use of swine manure in combination with chemical fertilizer would allow for increased photosynthesis and consequently greater yields. This study would, therefore, provide theoretical basis for higher yield in crop production.

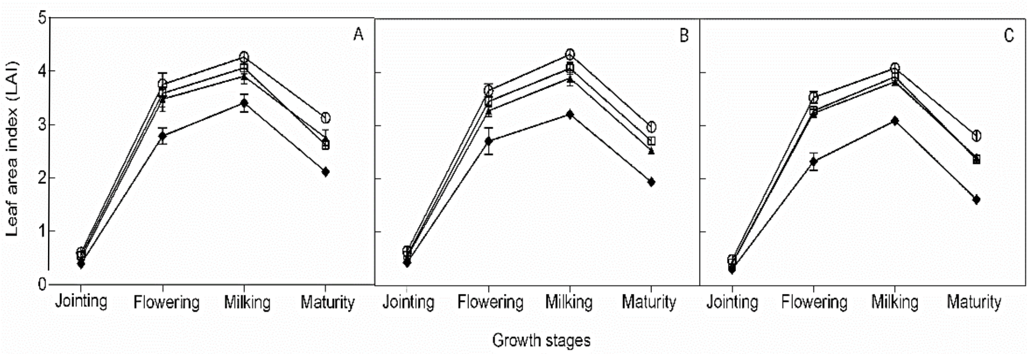

Figure 2. Leaf area index measured at jointing, flowering, milking and maturity in 2014 (A), 2015 (B) and 2016 (C) respectively. Symbols are: (■) No amendment (NA); (□) swine manure (SM); (▲) maize stover (MS) and (○) swine manure in combination with chemical fertilizer (SC).

Leaf chlorophyll content

Leaf chlorophyll content exhibited significant differences (*P* < *0.05*) in all the stages of sampling depending on treatment (Fig. 3). Application of swine manure combined with chemical fertilizer boosted chlorophyll content by 32%, 10% and 11% compared to NA, SM and MS respectively. To a lesser extent, SM and MS treatment increased chlorophyll content compared to NA. Chlorophyll is a vital pigment for absorbing, transferring and transforming in photosynthesis (Yao et al., 2007). Changes in chlorophyll content are indicative of water stress and crop phenological status. The higher chlorophyll content is in accord with the findings of Aspasia et al. (2010) who reported higher leaf chlorophyll content under combined application of organic and inorganic fertilizer. This is a significant finding since leaf greenness is an important plant biophysical parameter that determines plant physiological status (Gitelson et al., 2003) and thus relates to canopy photosynthetic capacity of plants (Suyker et al., 2005) and consequently improved yield.

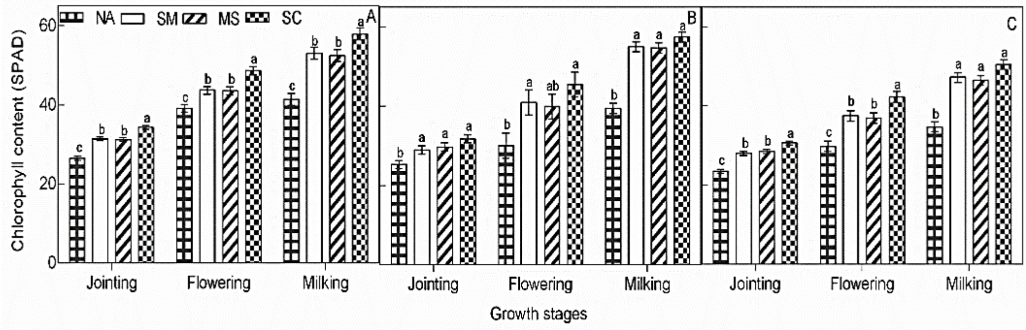

Figure 3. Chlorophyll content (SPAD) of maize measured in 2014 (A), 2015 (B) and 2016 (C) at jointing, flowering and milking. Means comparison was done using least significant difference (*P < 0.05*). Symbols are: No amendment (NA); swine manure (SM); maize stover (MS) and swine manure in combination with chemical fertilizer (SC). Bars with different letters in the same growth stage and year denote significance at *P < 0.05*. Error bars denote the standard error of means.

Dry matter accumulation

Dry matter accumulation under different soil amendment is presented in Fig. 4. Dry matter accumulation (DMA) averaged across years and treatments was 9.20 g plant^{-1} at jointing, 211.18 g plant^{-1} at flowering, 287.91 at milking and 437.71 g plant^{-1} at maturity. This resulted in 2195% increase from jointing to flowering, 36% increase from flowering to milking and 52% from milking to maturity. The three amendment treatments had higher average DMA in 2014 (283.2 g plant^{-1}), 2015 (255.3 g plant^{-1}) and 2016 (205.5 g plant^{-1}) compared to NA (213.8, 176.2 and 130.1 g plant^{-1} in 2014, 2015 and 2016 respectively). Across growth stages, SC increased dry matter accumulation by 13% and 25% in 2014, 12% and 23% in 2015, and 16% and 30% in 2016 compared to SM and MS treatments respectively. Swine manure in combination with chemical fertilizer (SC) had a positive effect on crop growth and development with an increase in dry matter accumulation. Our results agrees with the findings of Kibunja et al. (2010) who found that a combination of organic and inorganic nutrient source gave a higher total dry matter of maize. A number of mechanisms have been ascribed to the increased dry matter accumulation when organic manure is applied in combination with chemical fertilizer. In this study, increased dry matter accumulation in swine manure in combination with chemical fertilizer could be attributed to the improved leaf area growth and chlorophyll content. Fageria & Baligar (2005) reported increased dry matter production with greater leaf growth. The results reported here demonstrate that swine manure combined with chemical fertilizer could be useful in a sustainable agricultural system which has an important role in increasing the productivity and stability of yield in rain–fed agricultural areas.

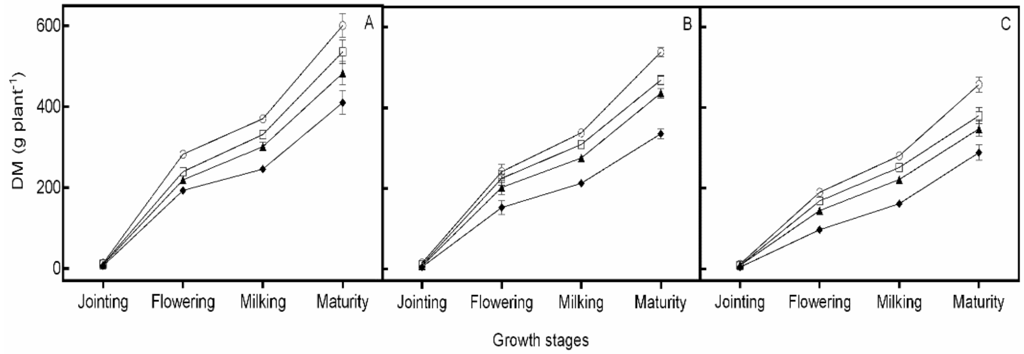

Figure 4. Dry matter accumulation curves for different soil amendment recorded at different growth stages in 2014 (A), 2015 (B) and 2016 (C). Vertical bars denote the standard error of means. Symbols are: (♦) No amendment (NA); (□)swine manure(SM); (▲) maize stover (MS), and (○) swine manure in combination with chemical fertilizer(SC).

Grain yield and yield component

Analysis of variance indicated that, the treatments had significant effect ($P < 0.05$) on grain yield and yield components, whereas year has significant effect at $P < 0.05$, for all characters except kernel weight (Table 2). There was no significant interaction between treatment and year for grain yield and yield components. Generally, higher grain yields were observed in the amended treatments relative to the control. Swine manure in combination with chemical fertilizer (SC) increased grain yield by approximately 69%, 14% and 12% on average compared to NA, SM and MS respectively. Similarly, ear number, kernel number per ear and 1,000 kernel weight increased with the application of amendments compared to non–amended soils. A similar trend was observed between the yield components and the grain yield. Results of correlation analysis showed EN, KN and KW had significant positive effect ($P < 0.05$) on grain yield of maize (Table 3). Swine manure in combination with chemical fertilizer averagely increased EN, KN and KW by 36%, 26% and 42%, respectively. Among the amendment treatment, SC increased EN, KN and KW by 17% and 13%, 6% and 7%, and 15% and 13% compared to SM and MS respectively. The significant effect of cropping year on grain yield and some yield components might due to the different intensity and timing of rainfall in different year. Variations in rainfall amount and distribution reduced soil water availability to crops which influenced photosynthesis and grain yield (Li et al., 2002).

Appropriate application of organic manure has been shown to improve grain yield (Yang et al., 2015) and dry matter accumulation (Wang et al., 2009). Comparing the soil amendment treatments, application of swine manure, especially in combination with chemical fertilizer consistently increased yield components and grain yield. The increased grain yield with SC in particular may be related to increased transport of carbohydrate. Kibunja et al. (2010) as well as Pan et al. (2009) found that a combination of organic and inorganic nutrient sources resulted in increased maize yield. Authors attributed the results to enhanced crop growth via improved leaf area index and greater transport of carbohydrate to grain from leaves, stems and sheaths. We found a positive correlation between grain yield and dry matter at all the growth stages. This finding indicate that grain yield improvement depends greatly on dry matter accumulation. Shearman et al. (2005) as well as Álvaro et al. (2008) postulated that grain yield was mainly associated with the pre–anthesis assimilate contribution to grain filling and greater dry matter translocation efficiency. The results showed that application of swine manure in combination with chemical fertilizer is especially effective to increase crop yield in Northwest agricultural regions such as the Western Loess Plateau of China, where water shortage and nutrient deficiency are the two main obstacles threatening maize production.

Table 2. Maize grain yield (GY, kg ha^{-1}), ear number per 10 m^2 (EN), kernel number per ear (KN), and 1,000 kernel weight (KW) for different soil amendment in 2014, 2015 and 2016

Treatment	Days after sowing (DAS)											
	GY			EN			KN			KW		
	2014	2015	2016	2014	2015	2016	2014	2015	2016	2014	2015	2016
NA	5,322	4,594	3,459	88	71	63	409	343	351	226	251	235
SM	7,888	6,732	5,641	104	74	81	474	440	396	299	299	280
MS	7,550	7,433	5,768	104	83	81	457	445	398	305	301	286
SC	8,900	8,209	6,156	113	91	98	488	475	431	339	332	339
LSD (0.05)	**398**	**479**	**491**	**6**	**7**	**12**	**33**	**56**	**53**	**36**	**20**	**30**
Sources												
Amendment (A)		***			**			**			***	
Year (Y)		***			***			**			ns	
A x Y		ns			ns			ns			ns	

Table 3. Correlation coefficients between Grain yield (GY), ear number per 10 m^2 (EN), kernel number per ear (KN), 1,000 kernel weight (KW), dry matter and leaf nitrogen content at Jointing (60 DAS), flowering (90 DAS) and milking (120 DAS)

				Dry matter			Leaf nitrogen content		
Variable	EN	KN	KW	60	90	120	60	90	120
GY	.960*	.996**	.982*	0.927 ns	0.941ns	0.947*	.968*	.997**	.988*

Non–significant (ns), Significant (*) at $P < 0.05$, and Significant (**) at $P < 0.01$.

Leaf and grain nitrogen concentration

Treatment had significant effect on nitrogen content in the leaf over the three study years, whereas year had effect at 90 and 120 DAS at $P < 0.05$ (Table 4). There was significant interaction between treatment and year in affecting nitrogen content in the leaf, with one exception (120 DAS). Significant ($P < 0.05$) differences in nitrogen concentration between amended crops and the control were observed at all the stages studied (Table 4). The SC treatment exhibited the highest nitrogen concentration at all the stages sampled, whereas NA had the lowest nitrogen concentration over the study period. On average, nitrogen concentration of amended treated crop was up to 33% higher than that of the control. Among the amendment treatments, SC increased nitrogen concentration by 1% and 3% on average at jointing, 8% and 9% at flowering, 6% and 8% at milking, and 18% and 25% at maturity compared to SM and MS treatments respectively.

Table 4. Nitrogen concentration (%) in leaves at 60, 90, 120 and 153 days after sowing (DAS) for different soil amendment in 2014, 2015, and 2016

Treatment	Days after sowing (DAS)											
	60			90			120			153		
	2014	2015	2016	2014	2015	2016	2014	2015	2016	2014	2015	2016
NA	2.52	2.40	2.20	1.66	1.53	1.53	1.10	1.16	1.12	0.71	0.66	0.73
SM	2.85	2.89	2.93	2.30	2.15	1.85	1.65	1.69	1.49	1.05	0.92	0.97
MS	2.85	2.88	2.79	2.24	2.14	1.87	1.66	1.71	1.34	1.10	0.94	0.72
SC	2.89	3.07	2.78	2.35	2.40	2.07	1.73	1.80	1.57	1.15	1.18	1.14
LSD (0.05)	**0.09**	**0.11**	**0.08**	**0.05**	**0.10**	**0.15**	**0.07**	**0.08**	**2.76**	**0.05**	**0.10**	**0.15**
Sources												
Amendment (A)		**			***			**			**	
Year (Y)		ns			**			*			ns	
A x Y		**			*			ns			*	

** Significant at $P < 0.01$; ***Significant at $P < 0.001$; ns, not significant.

There were significant differences between amended crops and the control in grain nitrogen concentration (Fig. 5). Application of SC increased nitrogen content in grain yield by 20% in 2014, 20% in 2015 and 26% in 2016 compared to NA. Application of SM and MS also significantly increased grain nitrogen content compared with NA, but to a lesser extent relative to SC.

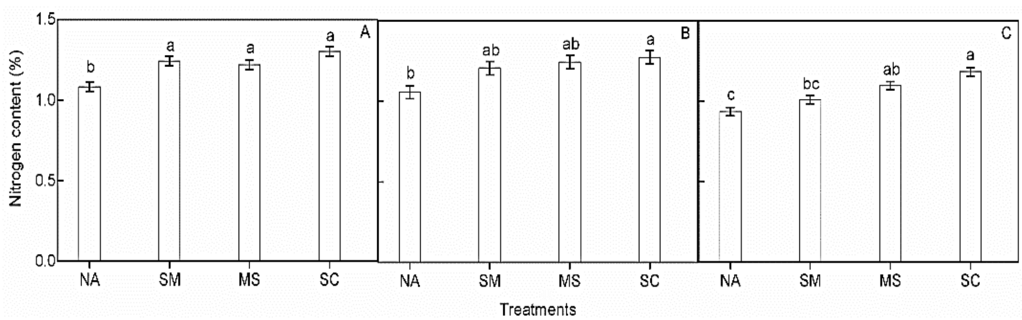

Figure 5. Grain nitrogen concentrations in 2014(A), 2015 (B) and 2016 (C). Means comparison was done using least significant difference ($P < 0.05$). Symbols are: (♦) No amendment (NA); (□)swine manure(SM); (▲) maize stover (MS), and (○) swine manure in combination with chemical fertilizer(SC). Bars with different letters in the same year denote significance at $P < 0.05$. Error bars denote the standard error of means.

The general decrease of N concentration in the leaves with maturity observed in this study is in agreement with Charles-Edwards et al. (1987) as well as Fageria & Baligar (2005) who reported that plant nitrogen concentration decreased in accordance with increasing growth stage. Higher N content in the leaf and grain achieved under swine manure, particularly swine manure in combination with chemical fertilizer (SC), suggests enhanced plant growth and quality of plant material as indicated by its leaf area and dry matter accumulation. This is a significant finding because the quality and quantity of plant materials produced impacts plant carbon pool and sequestration of carbon (West & Post, 2002) and digestibility when used as feed. Grain yield correlated positively with N concentration at all growth stages with milkng having the greatest effect (Table 3).

CONCLUSION

The main conclusions derived from this work are:

- Application of swine manure in combination with chemical fertilizer had a beneficial effect on leaf area index and leaf chlorophyll content which translated into higher dry matter accumulation and nitrogen content.
- Increased dry matter accumulation when swine manure was applied in combination with chemical fertilizer translated into higher yield components and consequently grain yield.
- The results reported in this study were consistent with positive correlations observed between grain yield, ear number, kernel number, kernel weight, dry matter accumulation and nitrogen content. This confirmed that the grain yield of the crop is sensitive to changes in dry matter accumulation, yield components and nitrogen content in the leaf, and that small stresses on these traits can result in significant impacts on grain yield.
- This set of results offer new insights into beneficial use of swine manure as a soil conditioner, particularly when applied with chemical fertilizer. The results particularly contribute to our understanding of dry matter accumulation and nitrogen concentration at different growth stages and consequently grain yield response. From this, there appears to be potential for further development of management practices involving use of swine manure in crop production under semiarid environments.

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Investigation of coaxial laser cladding process parameters influence onto single pass clad geometry of tool steel

S. Locs[1,2], I. Boiko[1,*], P. Drozdovs[2], J. Dovoreckis[2] and O. Devoyno[3]

[1]Riga Technical University, Faculty of Mechanical Engineering, Transport and Aeronautics, Institute of Mechanical Engineering, Viskalu street 36A, LV-1006 Riga, Latvia
[2]Daugavpils University, Faculty of Natural Sciences and Mathematics, Parades street 1, LV-5401 Daugavpils, Latvia
[3]Belarusian National Technical University, Faculty of Mechanical Engineering B.Khmelnitsky street 9-6, BY220013 Minsk, Belarus
[*]Correspondence: irina.boiko@rtu.lv

Abstract. This paper is devoted to the investigation of the influence of technological parameters on the single pass clad geometry and quality as well as elemental composition in the clad after coaxial laser cladding (CLC). The objects of the investigation are components of expensive machines and tools for presswork needed to be repaired, i.e. refurbished for the future application with the goal of effective using of material resources in production. Nowadays such repair of worn tools is an actual task due to tendency for thrifty management of resources at affordable cost. Experimental work was carried out using CLC system, which consists of industrial robot and a ytterbium fiber laser with a core diameter of 100 μm, integrated to the coaxial powder supplying cladding head. During research separate cladding tracks of metal powder AISI M2 (particle size 53–150 μm) were deposited on the top surface of steel plates, which were grinded before treatment. This work's highlighted parameters for variation were laser scanning speed and laser beam focus plane distance. The clad geometry was examined on cross-sections with SEM. Elemental composition was determined by the X-ray spectroscopy analysis. Gladding beads with good surface quality were achieved. Cross-sectional observation presented that clads has a good fusion with the base material without exfoliation. Keyhole shape of molten substrate area was achieved, which leads to increase of the dilution value. The future research is needed to achieve stable quality of cladding, which is extremely necessary for industry.

Key words: coaxial laser cladding, toll steel, clad geometry, keyhole in penetration.

INTRODUCTION

Manufacturing process of any products involves use of natural resources. At the end of the life cycle of any product (Jolliet et al., 2003) its disposal, recycling or recovery is required. That is why the use of advanced technologies is of a great importance not only for industrial expansion but also reduces the factors of negative impact on the environment.

Laser cladding (LC) is an effective (advanced process) method for surface engineering, which allows to improve surface properties, like hardness, wear and corrosion resistance, fatigue and strength. Due to a number of advantages, this process is successfully used for refurbishment and repair of high value parts and tools like engine components, turbines, dies, punches, press molds etc. (Toyserkani et al., 2005; Majumdar & Manna, 2013).

The major technological advantages of laser cladding are (Schneider, 1998):

- Possibility of precision energy supply;
- Low heat input, resulting in a small heat affected zone;
- Treatment is a non-contact process. There is neither tool wear nor mechanical forces impact on the workpiece;
- High accuracy and local surface treatment;
- Strong metallurgical bonding and very dense coatings;
- Slight heat deformation of the cladded component;
- Minimal dilution with the base material;
- High heating and cooling rates, resulting in a fine microstructure (metastable phases).

Another important application of LC is in additive manufacturing (AM) which appears in industry quite recently and is developing very rapidly. As it is known there are many names of this technology, for example: 'Laser Engineered Net Shaping' (LENS), 'laser powder fusion' (LPF), 'direct metal deposition' (DMD) etc. The main principle here is fabricating of single part layer by layer with a complex 3D shape by melting of injected metal powder under laser irradiation (Toyserkani et al., 2005). Combination of laser cladding technique with computer-aided design (CAD) and computer-aided manufacturing (CAM) processes creates a powerful tool for manufacturers in many engineering industries. As a result, this makes designing more flexible due to free-form modeling and quick change of design components. Manufacturing process does not require any intricate molds or dies. Advantages of this technology in comparison to traditional casting and machining allow to produce finished or semi-finished parts with complicated shape with high accuracy, economy of time and energy as well as material consumption, due to the fact that components are built by rather adding than removing material (in case of machining processes) (Xue, 2010; Majumdar & Manna, 2013). There are many parameters which have influence on this process. The main of them are laser power, laser scanning speed, powder mass feed rate and laser beam focus plane distance as well, as laser beam characteristics, continuous or pulsed wave light emission and also physical effects of the process (thermal distribution, fluid flow, phase transformation etc.). Variety of combinations of these parameters may have different effect on the clad geometry, functional properties and overall quality of the coating. By this reason experimental studies are still necessary for research of LC process (Oliveira et al., 2005).

This experiment was focused on investigation of single cladding bead formation with multiple cladding speed and laser beam focus disposition relatively the treatable surface. The purpose of the work is to determine the importance of highlighted parameters by performing statistical analysis and producing empirical models to achieve a single pass clad bead of high quality. This data is needed in order to determine appropriate regime of the process for the following experiments for surface cladding.

MATERIALS AND METHODS

The filler material used for LC was tool steel powder AISI M2 of spherical shape with particle size 53–150 μm. For substrates wear resistant high carbon steel (spring steel) DIN 66Mn4 plates were used with dimensions of 100 x 100 x 10 mm and the work surfaces mechanically grinded before treatment. Chemical compositions of the materials are listed in the next (Table 1).

Table 1. Chemical composition of powder AISI M2 (1) and substrate DIN 66Mn4 (2)

	Element content, wt%						
	C	Mn	Si	Mo	Cr	V	W
1	0.85–1.05	0.20–0.40	0.20–0.40	4.50–5.50	3.75–4.50	1.60–2.20	5.50–6.80
2	0.62–0.70	0.90–1.20	0.17–0.37	–	< 0.25	–	–

Experimental work was carried out using the precise LC equipment, which consists of industrial 6 axis robot KR30HA and 2 axis DKP-400 positioner (Kuka) and ytterbium single mode fiber laser with a core diameter of 100 μm YLR-1000 (IPG Laser) which ensures Gaussian beam intensity profile and emits on wavelength 1,070 nm. Laser with variable output power up to 1,000 W and was integrated to the coaxial powder supplying cladding head with the optical system WT03 (Permanova Lasersystem). Powder mass feeding was performed with powder feeder TWIN-10-C (Sulzer Metco), where the argon was used as a carrier gas and as a shielding gas as well in order to prevent oxidation of the powder and a molten pool. The heating temperature was measured after each deposited track using high-temperature infrared thermographic camera InfRec R300 (Nippon Avionics). Substrate temperature after single run didn't exceed 100 °C. The laser cladding equipment and experimental performance are in the next (Fig. 1).

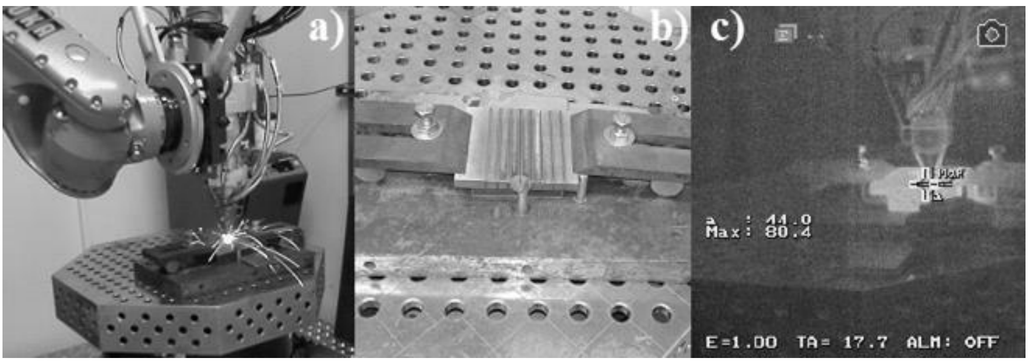


Figure 1. Laser cladding: general view of equipment (a); experimental sample with generated clad tracks (b); infrared camera shot after deposition of single track (c).

As the first step of the experiment preliminary setting-up was performed, where the numbers of single tracks was deposited at various regimes to achieve continuous and uniform clad beads in order to determine the range of process parameters for the following design of experiment (DOE). Then, with aim to investigate the process responses, single clad tacks were produced by experimental plan, which consisted of multiple combination of laser scanning speed and value of laser beam defocus. In order to examine full interaction of chosen factors experimental work was carried out against planned four level Taguchi's Orthogonal Array L_{16} for two defocusing directions i.e. (f_1: from -3 to 0) and (f_2: from +3 to 0) with step of 1 mm. Therefore 28 single tracks were produced in total. Experimental factors and levels according to defocusing directions are presented in the next (Tables 2, 3). The other parameters for every cladded track have been fixed and they were as following: laser power was set on maximum value 1,000 W; carrier gas flow (Ar) 5 l min^{-1}; shielding gas flow (Ar) 15 l min^{-1}; powder feed rate 7 g min^{-1}, laser beam focal distance 200 mm.

Table 2. Factors and levels for negative direction of defocus

Factors	Levels			
Cladding speed, m s^{-1}	0.025	0.020	0.015	0.010
Focus disposition, mm	-3	-2	-1	0

Table 3. Factors and levels for positive direction of defocus

Factors	Levels			
Cladding speed, m s^{-1}	0.025	0.020	0.015	0.010
Focus disposition, mm	+3	+2	+1	0

Plates with experimental clad beads were transversely cross-sectioned, then polished and etched with Nital (4%). Each produced clad bead was examined using scanning electron microscope TESCAN-VEGA-LMU II (SEM). Quality characteristics of LC beads were evaluated by measuring clad bead cross-section geometry, content of pores and measuring of elemental composition of alloy elements (AE). Geometry features were determined by studying of the SEM micrographs using 'Measurement' module of software 'VegaTC'. Schematic view and geometrical characteristics of the single clad bead in cross section are represented in the next (Fig. 2). Elemental composition was determined by energy dispersive X-ray spectroscopy analysis (EDS module INCAx-act Oxford Instruments, attached to SEM). The used matrix of experimental design with measures are presented in the next (Table 4).

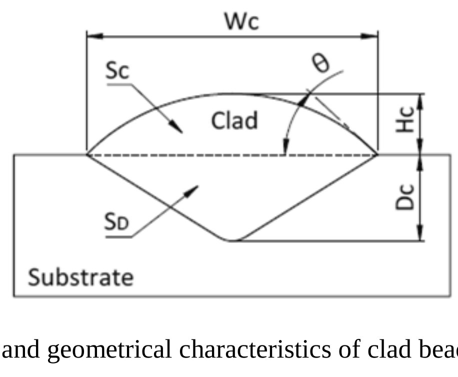


Figure 2. Schematic view and geometrical characteristics of clad bead.

Table 4. Parameters and cross-sectional measurements of clad beads

No	F mm	V m s^{-1}	H mm	W mm	D mm	Θ °	S_D mm^2	S_C mm^2	S_P mm^2	Pores %	ΣAE wt%
1	-3	0.025	0.21	1.50	1.44	39	1.12	0.23	0.00	0	2.51
2	-3	0.020	0.28	1.71	1.57	30	0.99	0.19	0.03	3	3.60
3	-3	0.015	0.37	1.90	1.67	34	1.32	0.31	0.05	3	3.39
4	-3	0.01	0.45	2.13	1.81	43	1.66	0.45	0.09	4	2.93
5	-2	0.025	0.29	1.44	1.64	45	1.32	0.48	0.08	4	2.51
6	-2	0.020	0.42	1.77	1.60	43	1.85	0.53	0.12	5	5.60
7	-2	0.015	0.44	1.95	1.96	55	2.37	1.05	0.11	3	4.01
8	-2	0.01	0.69	2.29	2.02	47	2.24	0.64	0.02	1	5.62
9	-1	0.025	0.38	1.14	2.16	64	1.23	0.33	0.00	0	3.51
10	-1	0.020	0.39	1.39	2.33	67	1.34	0.35	0.01	0	3.53
11	-1	0.015	0.49	1.75	2.23	65	1.68	0.59	0.00	0	4.85
12	-1	0.010	0.74	2.17	2.37	57	2.39	0.94	0.00	0	6.19
13	0	0.025	0.36	1.17	2.23	53	1.11	0.25	0.00	0	3.35
14	0	0.020	0.37	1.45	2.33	57	1.33	0.45	0.00	0	4.76
15	0	0.015	0.48	1.68	2.51	63	1.72	0.51	0.00	0	3.62
16	0	0.010	0.70	1.97	2.41	62	2.22	0.95	0.01	0	5.49
17	3	0.025	0.13	1.42	1.08	17	0.72	0.10	0.00	0	3.01
18	3	0.020	0.15	1.55	1.05	23	0.89	0.13	0.00	0	2.20
19	3	0.015	0.21	1.85	1.14	22	1.15	0.24	0.00	0	3.31
20	3	0.010	0.34	2.15	1.31	32	1.67	0.48	0.00	0	4.59
21	2	0.025	0.17	1.51	1.40	24	1.02	0.16	0.08	7	2.18
22	2	0.020	0.21	1.64	1.54	27	1.22	0.19	0.06	4	2.14
23	2	0.015	0.23	1.83	1.58	27	1.47	0.29	0.06	4	3.13
24	2	0.010	0.38	2.19	1.58	32	1.95	0.56	0.01	1	3.73
25	1	0.025	0.25	1.57	1.51	29	0.97	0.26	0.11	9	3.21
26	1	0.020	0.30	1.65	1.65	37	1.18	0.33	0.10	7	4.94
27	1	0.015	0.40	1.88	1.96	49	1.56	0.51	0.00	0	4.33
28	1	0.010	0.53	2.07	2.31	55	2.19	0.72	0.04	2	4.41

RESULTS AND DISCUSSION

Morphology

During laser scanning melt pool is generated by melting of base material together with injected powder particles, which forms after solidification a congeneric clad bead. By visual observation of clads surfaces it was noticed that all of them have a good fusion with the base material – no surface defects as pores, crack or exfoliation were found. Surface topology of a part of produced clad bead in dependence of parameters combination is presented in the next (Fig. 3).

Geometrical characteristics of each single track in cross-section were determined by measures of clad height (H_C), width (W_C), contact angle (θ), depth of penetration (D_C), clad area (S_C), penetration area (S_D) and total pores area (S_P). These measured characteristics are shown below (Fig. 4, a and b).

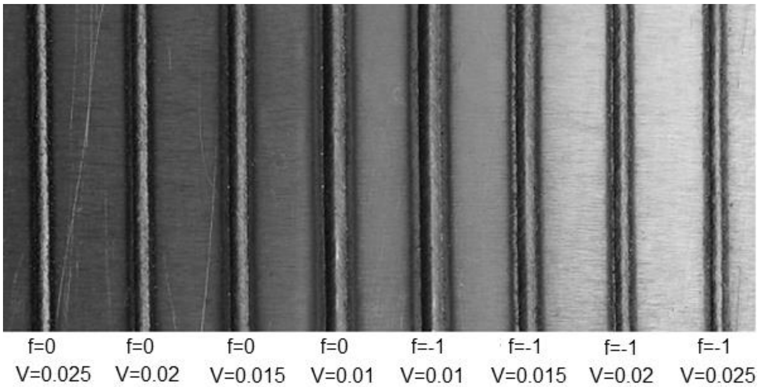


Figure 3. Surface topology of single clad beads, where f – focus deposition, mm; V – cladding speed, m s^{-1}.

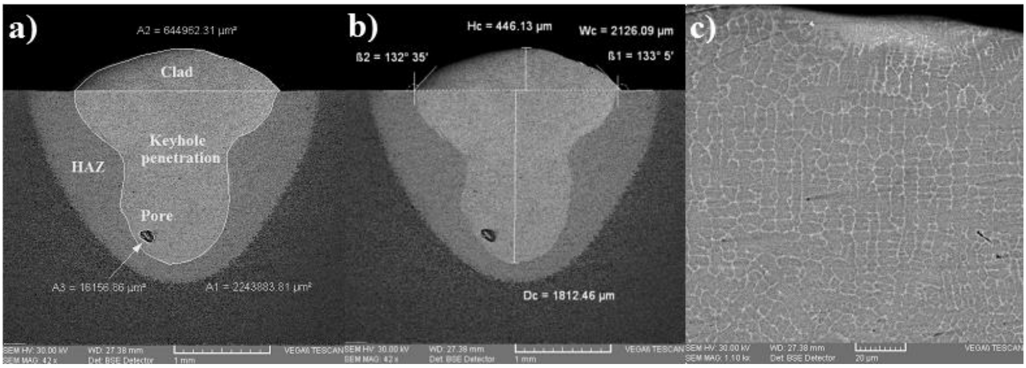


Figure 4. Clad cross sections SEM images of No.4 clad bead with geometrical measures and higher magnification micrograph of clad top region.

As it can be seen, the clearly distinguishable zones of the clad bead in comparison with the base material can be defined. The microstructure of clad beads (Fig. 4, c) had a mixture of cellular and dendritic solidification grain structures. In the upper and midle zones of clad grains were mostly cellular, however in the area bondering to the inerface with base material basicaly dendritic. Due to processing by a highly concentrated energy source clad area apparently has martensite-austenite microstructure with carbide eutectic at grain boundaries ($CrWMo_nC_m$) as it was mentioned in (Grigor'yanc et al., 2012). Typical martensitic needles inside grains weren't observed, presumably structureless martensite (hardenite) takes place, which is often a mixture of martensite and austenite without acicular structure, and usually is detected when heating by a concentrated energy flow (Kirillov et al., 1996; Isakin et al., 2015). Heat affected zone (HAZ) in the peripheral area of clad bead can also be observed. All produced clads have significant penetration inside of substrate, which have keyhole geometry as a result of high laser beam intensity. Application of such a deep penetration in the laser cladding process is assumed for creation of first layer onto tool steel substrate with aim to achieve smooth gradient of mechanical properties of the coating-substrate system to provide better resistance to external stress during tool operation in the press working process. It was also noticed, that a part of clad beads contain pores, what also might be the reason of high energy input, because the melt of irradiated materials passes to vapor state, and this leads to appearance of gas bubbles, which in their turn due to a rapid solidification of the melt pool stay entrapped in the clad bead (Majumdar & Manna, 2013; Gong et al., 2014). The generalized list of compared SEM micrographs of clad beads profiles according to varied process parameters is represented in the next (Fig. 5).

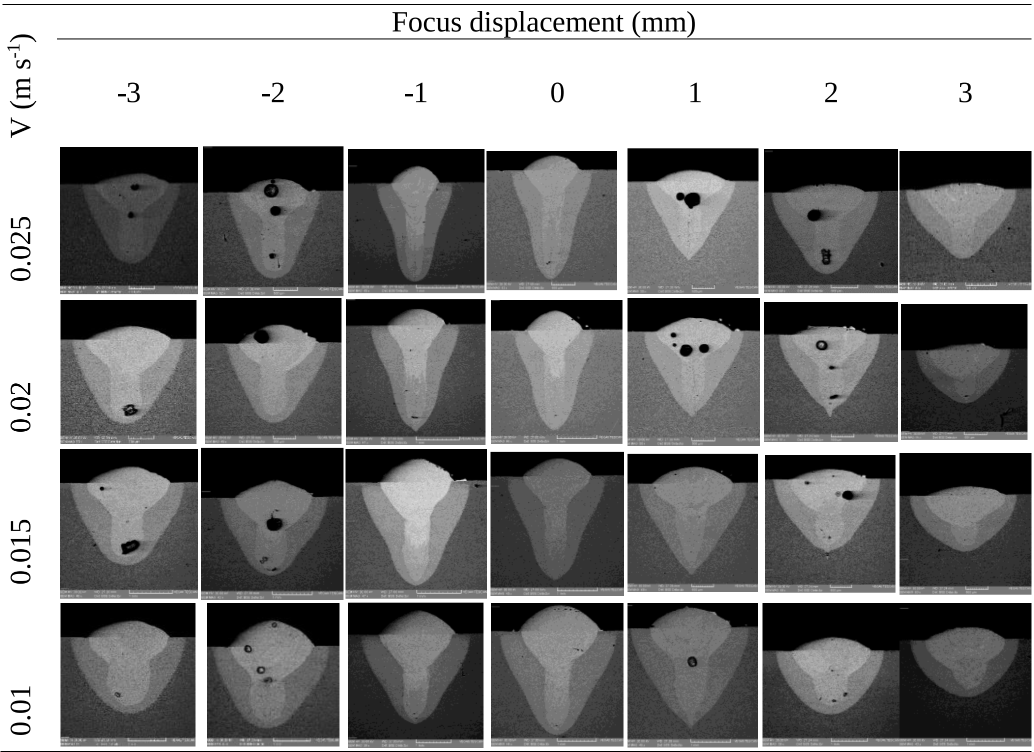


Figure 5. SEM micrographs array of clad beads under combination of parameters, where V – cladding speed.

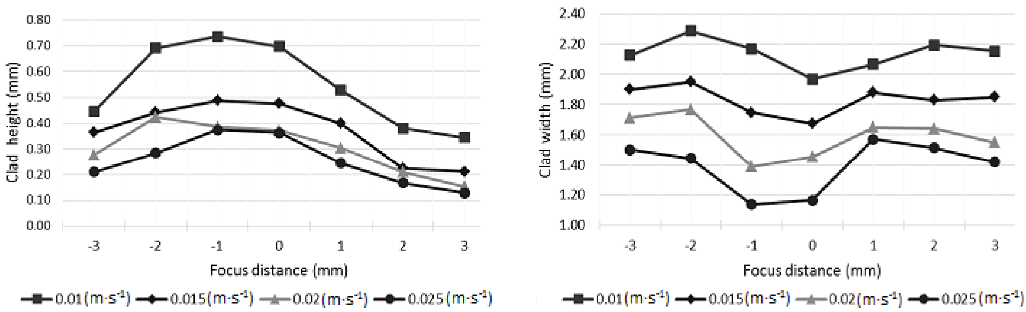
Data analysis

Clad beads quality was evaluated using the following features: geometrical characteristics (clad height, width, depth of penetration and contact angle), porosity percentage and content of alloying elements in the clad zone. In order to determine influences of the process parameters onto chosen responses predictive equations were build using regression analysis. The first order regression model was used with the following polynomial expression:

$$y = \beta_0 + \sum_{i=1}^{k} \beta_i x_i + \varepsilon. \qquad (1)$$

For evaluating of statistical significance created models were also tested by analysis of variance (ANOVA).

Clad height and width characterize productivity of LC process, by this reason it is important to achieve maximum values of these parameters. As it can be seen from the next (Fig. 6) clad height and width increase with decrease of cladding velocity. Relatively to laser beam defocus very similar nature of distributions for both of these parameters can be observed. The highest values of a clad height can be achieved by defocusing laser beam at 0 to -2 mm, where maximal values were 0.4–0.7 mm according to change of velocity regimes, e.g. smallest value for highest cladding speed. Meanwhile clad width had the worst results of focus disposition at 0 to -1 mm, but the largest values mainly correspond to defocusing at -2 mm with amount of 1.4–2.3 mm, where smallest value for highest cladding speed respectively. Optimal combination of both of these geometrical features characterizes ratio of clad height to width (wh), the highest value of this index was 1.6 mm and it corresponds to the lowest speed (0.01 m s^{-1}) and to defocus at -2 and -1 mm.



a) b)

Figure 6. The effect of focus displacement onto the clad height (a) and the clad width (b).

Clad beads depth of penetration should be as minimal as possible, because it identifies the dilution ratio, which in its turn presents rate of intermixing of clad layer and base material (Schneider, 1998). Contact angle (wetting angle) is also important parameter that indicates the quality of the clad. This angle defines statement of surface wettability and has to be smaller than 90°. In order to ensure good adhesion the optimal value of contact angle should be as $\cos(\theta) \rightarrow 1$ (Toyserkani et al., 2005). As it is seen in the Figure below (Fig. 7) both of these parameters represent very similar relationship to the velocity distributions towards to the defocus. Minimal depth of penetration corresponds to the highest velocity and the largest focusing distance (+3 mm) – that is below the treatable surface. The smallest values of clad bead depth were 1.1–1.3 mm, where the smallest one was for the highest cladding speed. Contact angle represents analogue dependency – the smallest angle corresponds to the highest velocity and the largest focusing distance. The smallest values this parameter showed by focusing laser beam at +3 mm and these values varied from 17° to 32°. The overall contact angle of produced clads was varying in range from 17° to 67°, that satisfies surface wettability conditions.

Analysis of the clad beads quality was also carried out on the basis of alloy elements content and porosity percentage in the clad. During LC process due to melting of filler and base material, oxidation and intermixing of melt and base occurs, which leads to exhaustion of the alloying components concentration in the clad layer, thereby mechanical properties become worse. The content of alloy elements was examined for each clad layer using the EDS analysis.

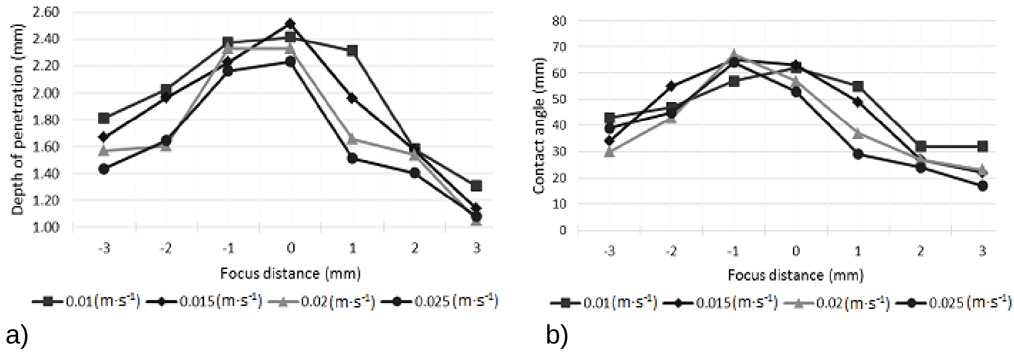


Figure 7. The effect of focus displacement onto the clad depth (a) and the clad contact angle (b).

In order to investigate interrelation, as a response parameter was determined by a total amount of mass fraction for the carbide-forming elements such as Cr, W, Mo, V. As it can be seen from the next picture (Fig. 8, a) maximal values correspond to the defocus from -2 to 0 with pick on -1 mm. It was noticed that by increasing of cladding speed exhaustion of the alloying components concentration increases. The reason most likely is the following: due to shielding effect produced by vapors generated during the melting of powder particles in the zone exposed by laser radiation (Devoyno et al., 2012).

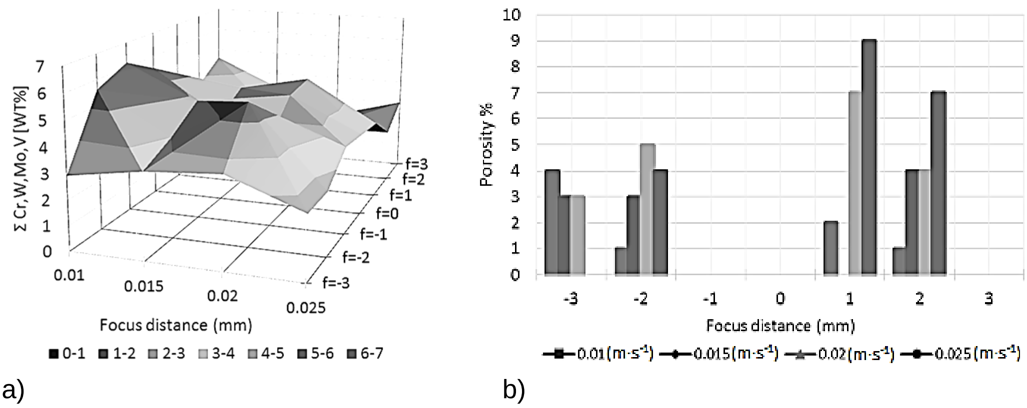


Figure 8. The effect of focus displacement onto the EA content (wt%) (a) and the porosity percentage (b).

Analysis of porosity showed irregular distribution order of values. The degree of porosity was determined by analysis of SEM micrographs and was expressed as the areas ratio of the total pores surface area towards the clad bead overall surface area. It has to be pointed that the amount of common pores increases with the increase of cladding speed. The reason is that due to material evaporation when cladding at higher speed gas bubbles don’t have time for rising to the surface. As it can be seen from the next (Fig. 8, b) the largest value reached up to 9%, but relatively to all studied clad beads average index was 2%. Meanwhile, when processing with laser beam defocus at such values as -1; 0 and 3 mm, clad beads were free of pores.

The significance of correlations between the independent variables (focus distance and cladding speed) and dependent variables (clad height, width, depth, contact angle, porosity and AE content) were evaluated by using ANOVA. Analysis carried out by separate plans according to opposite directions of laser beam defocusing i.e. negative (-f) and positive (+f) defocus directions (ND and PD) away from the focal plane. ANOVA was performed with a confidence level of 95% (*P*-value of 0.05). Additionally, empirical models were generated by means of regression analysis based on the measured responses.

Table 5. ANOVA for the clad height: *DF* – degree of freedom, *SS* – sum of squares, *MS* – mean squares

	Negative defocus				
Source	*DF*	*SS*	*MS*	*F*	*P*
Model	2	0.282	0.141	28.1	< 0.0001
-f	1	0.049	0.049	9.67	0.0080
V	1	0.234	0.234	46.53	< 0.0001
Residual	13	0.065	0.005		
Total	15	0.347			
Positive defocus					
Model	2	0.317	0.158	60.48	< 0.0001
+f	1	0.172	0.172	65.47	< 0.0001
V	1	0.145	0.145	55.49	< 0.0001
Residual	13	0.034	0.003		
Total	15	0.351			

Table 5 represents ANOVA for the clad height. *F*-values 28.1 and 60.48 indicate that the models are statistically significant, particularly high value is for *PD* plan. *P*-values of less than 0.05 indicate that focal distance (f) and velocity (V) are significant model terms. Concerning *PD* plan terms are nearly equivalent, meanwhile for *ND* plan cladding speed has much greater effect. Regression analysis gives the predictive equations for *ND* plan (2) and for PD plan (3) respectively. Coefficient of determination (R^2) for *ND* equals to 0.81 and R^2 for *PD* equals to 0.9 and proves high convergence between experimental and predicted results. Empirical model for *ND* plan (2) demonstrates that clad height increases by increasing of focal length and decreasing of cladding speed. The model for *PD* plan (3) indicates clad height increase by decreasing both of these factors.

$$H_{C(-f)} = 0.892 + 0.0493\, f - 21.6\, V, \tag{2}$$

$$H_{C(+f)} = 0.763 - 0.0926\, f - 17.1\, V. \tag{3}$$

Table 6 shows ANOVA for clad width, which represents extremely high models significance: *F*-value for *ND* plan was 87.96 and for the *PD* plan model *F*-value was 51.4. As it is seen from both model terms *F*-values, cladding speed has considerably the largest effect on clad width.

Table 6. ANOVA for the clad width

	Negative defocus				
Source	*DF*	*SS*	*MS*	*F*	*P*
Model	2	1.669	0.834	87.96	< 0.0001
-f	1	0.194	0.194	20.47	0.0010
V	1	1.474	1.474	155.44	< 0.0001
Residual	13	0.123	0.009		
Total	15	1.792			
Positive defocus					
Model	2	1.087	0.543	51.4	< 0.0001
+f	1	0.057	0.057	5.42	0.0370
V	1	1.029	1.029	97.38	< 0.0001
Residual	13	0.137	0.011		
Total	15	1.224			

As it can be seen from predictive equation (4), which correspond to *ND* plan, clad width increases by decreasing both of model terms. In the case of *PD* plans equation (5), clad width increases by increasing of focal length and by decreasing of cladding speed. R^2 had also high values: for *ND* it equals to 0.93 and for *PD* – to 0.89.

$$W_{C(-f)} = 2.52 - 0.0985\, f - 54.3\, V, \tag{4}$$

$$W_{C(+f)} = 2.44 + 0.0535\, f - 45.4\, V. \tag{5}$$

Analysis data concerning the clad depth is shown in the next Table 7. ANOVA represents also very high significance of the models: *F*-value for *ND* plan was 61.46 and for the *PD* plan *F*-value was 102.72. In this case the main effect showed focus distance, this was considerably higher than the cladding speed.

Table 7. ANOVA for the clad depth

	Negative defocus				
Source	*DF*	*SS*	*MS*	*F*	*P*
Model	2	1.672	0.836	61.46	< 0.0001
-f	1	1.474	1.474	108.37	< 0.0001
V	1	0.198	0.198	14.55	0.0020
Residual	13	0.177	0.014		
Total	15	1.849			
Positive defocus					
Model	2	3.508	1.754	102.72	< 0.0001
+f	1	3.22	3.22	188.84	< 0.0001
V	1	0.284	0.284	16.60	0.0010
Residual	13	0.222	0.017		
Total	15	3.730			

The below given equation (6) for *ND* plan represents that the clad depth decreases by decreasing of the focus distance and by increasing of cladding speed. In the case of *PD* plan (7) clad depth decreases by increasing of both of model terms. R^2 for these models showed very high values: for *ND* it equals to 0.90 and for *PD* – to 0.94.

$$D_{C(-f)} = 2.77 + 0.272\, f - 19.9\, V, \tag{6}$$

$$D_{C(+f)} = 2.74 - 0.402\, f - 23.8\, V. \tag{7}$$

The next one analysis carried out for the clad contact angle showed in the next Table 8 represents that more significant model was for *PD* plan. Generally *F*-value for ND plan was 14.02 and for the *PD* plan *F*-value was 64.69. The focus distance is again appearing as a dominant factor. Velocity in case of *ND* plan revealed insignificance of model term.

Table 8. ANOVA for the clad contact angle

	Negative defocus				
Source	*DF*	*SS*	*MS*	*F*	*P*
Model	2	1,385.45	692.72	14.02	0.0010
-f	1	1,361.25	1,361.25	27.54	0.0002
V	1	24.2	24.2	0.49	0.5000
Residual	13	642.55	49.43		
Total	15	2,028.0			
Positive defocus					
Model	2	3,372.1	1,686.1	64.69	< 0.0001
+f	1	2,916.11	2,916.11	111.89	< 0.0001
V	1	456.01	456.01	17.50	0.0010
Residual	13	338.81	26.06		
Total	15	3,710.94			

Predictive equation for the *ND* plan (8) showed that contact angle decreases by decreasing of focus distance and by increasing of cladding speed. In the case of *PD* plan (9) this response decreases by increasing of both of model terms. R^2 for these models was as following: for *ND* plan it equals to 0.68 and for *PD* plan – to 0.91.

$$\theta_{(-f)} = 67.7 + 8.25\, f - 220\, V, \tag{8}$$

$$\theta_{(+f)} = 72.9 - 12.1\, f - 955\, V. \tag{9}$$

In order to analyze process parameters influence on to porosity ANOVA was performed in the same way as for studying of geometry characteristics. As it can be seen in the next Table 9 model significance can be seen just in case of *ND* plan, where *F*-value was 5.22, but for *PD* plan *F*-value was 1.47, which showed insignificance of model to this response. However in case of *ND* plan the analysis defined that only defocus had an effect on degree of porosity.

Table 9. ANOVA for the porosity

	Negative defocus				
Source	*DF*	*SS*	*MS*	*F*	*P*
Model	2	23.125	11.563	5.22	0.022
-f	1	23.113	23.113	10.43	0.007
V	1	0.0125	0.0125	0.006	0.941
Residual	13	28.813	2.216		
Total	15	51.938			
Positive defocus					
Model	2	26.500	13.250	1.47	0.266
+f	1	0.05	0.05	0.005	0.942
V	1	26.45	26.45	2.93	0.11
Residual	13	117.25	9.019		
Total	15	143.75			

As it is seen from the predictive equations (10) and (11) that pores content decrease by increasing of focus distance in case for both of defocusing plan. R^2 was equal to 0.45 in case of *ND* plan and for *PD* plan equal to 0.18, and it represents too weak conformity of the calculated and measured values.

$$P_{(-f)} = -\ 0.09 - 1.07\, f - 5.0\, V. \tag{10}$$

$$P_{(+f)} = -\ 1.83 - 0.05\, f + 230\, V. \tag{11}$$

ANOVA analysis of the effects of parameters on the total amount of alloy elements (Cr, W, Mo, V) is presented in the next Table 10. The models *F*-values of 5.68 for *ND* plan and 8.45 indicated significant statistical relationships. It was found out that in case of *PD* plan both the model terms were significant. The analysis indicated only insignificance of defocus for *ND* plan.

Table 10. ANOVA for the content of AE

	Negative defocus				
Source	*DF*	*SS*	*MS*	*F*	*P*
Model	2	9.567	4.783	5.68	0.017
-f	1	2.705	2.705	3.21	0.096
V	1	6.862	6.862	8.15	0.014
Residual	13	10.944	0.842		
Total	15	20.511			
Positive defocus					
Model	2	8.949	4.474	8.45	0.004
+f	1	4.068	4.068	7.68	0.016
V	1	4.88	4.88	9.21	0.010
Residual	13	6.89	0.530		
Total	15	15.835			

Predictive equations demonstrate EA content increase by focusing laser beam towards the focal plane. Velocity has a negative effect; thereby its increase leads to minimization of EA in the clad. R^2 had very close values, which for *ND* plan were equal to 0.47, in case of *PD* plan – to 0.56 and by converting these values to the correlation coefficients (R) 0.69 and 0.75 respectively; so they present appreciable relationship between the experimental and predicted results. Therefore, for the further research the optimal regime can be determined by relying onto created model:

$$EA_{(-f)} = 6.69 + 0.368\, f - 117\, V, \quad (12)$$

$$EA_{(+f)} = 6.06 - 0.451\, f - 98.8\, V. \quad (13)$$

CONCLUSIONS

The quality of laser cladding coating first of all depends on ability to create a single clad with the necessary characteristics. The tool steel clad beads were deposited using different combinations of process parameters including laser beam focus displacement and cladding speed. The produced clads have been evaluated by geometrical parameters, content of alloying components, degree of porosity and the results have been statistically analyzed. The examination of the obtained results shows the following:

- Solid clad with good fusion bond and fine microstructure has been achieved in this research, but porosity is still a problem; presumably due to a high power intensity and keyhole behavior effect.
- It was assumed that by creation of the first layer of laser cladded coatings with keyhole in penetration could ensure smooth gradient of mechanical properties of the coating-substrate system to provide better resistance to external stress during tool operation in the press working process.
- The maximal value of combination of clad height and width (wh) was achieved at the lowest cladding speed (0.01 m s^{-1}) and by defocusing laser beam at -2 to -1 mm.
- The minimal depth of penetration corresponds to the highest cladding speed and the largest focusing distance (+3 mm) – when the focus plane was displaced below the treatable surface.
- The contact angle of the produced clads was varying in range from 17° to 67°, the smallest values correspond for +3 mm defocus and by the highest velocity.
- The maximal content of alloy elements (Cr, W, Mo, V) was discovered by defocus at -1 mm and by the lowest cladding speed (0.01 m s^{-1}).
- Porosity had irregular distribution order, but nevertheless the largest average value corresponds to the highest cladding speed. The largest value of 9% was detected by defocus at +1 mm, but relatively to all the studied clad beads the average index was 2%. Meanwhile by processing with laser beam defocus at -1; 0 and +3 mm, clad beads were free of pores.
- ANOVA showed significant relationships between the process parameters and characteristics of clad beads geometry for both defocus directions with the exception of cladding speed and contact angle correlation in case of negative defocus.
- Statistical analysis of porosity showed that only focus displacement in negative direction correlates with measured data.
- The analysis of alloy elements content indicated significant relationships of all of model terms except of defocus in negative direction.

– The developed empirical models are found to be able to predict the geometry of clad beads and alloy element content in it within a confidence level more than 95%. In the following research the optimal regime can be determined by relying onto created models. To determine nature of the pore-formation the extended studies are required.

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Effect of drill machine operating speed on quality of sowing and biomass yield

J. Maga and K. Krištof*

University of Agriculture in Nitra, Faculty of Engineering, Department of Machines and Production Biosystems, Tr.A. Hlinku 2, SK949 76 Nitra, Slovakia
*Correspondence: koloman.kristof@uniag.sk

Abstract. The paper is focused on the study and evaluation of quality of the seeding of seeds and its effect on the biomass yield. The aim was to evaluate the space arrangement of the seeds by using of polygon method on one field with the repetition for different forward speeds of the drill machine. For the evaluation there were used digital photographs, which were taken during repeated measurements of the each value of the forward speed after sprouting of crop. These images have been used in order to determine the shape and size of the surface area belonging to the plant. Own software TfPolyM was used for the image analysis. The shape of the polygons belonging to the individual plants was expressed by values of the shape factor T_f. This factor characterises the suitability the shape of polygon surface related to the individual plant. By comparing of the values of the shape factors for different forward speeds of the drill machine we can determine the optimal value of the forward speed from the point of seed placement uniformity in horizontal level. During harvest of the crop there was analysed the variability of the biomass yield in relation to values of the forward speed used during seeding. The most suitable values of shape factor T_f (0.8519) was recorded for speed of drill machine set on 12 km h^{-1}. For other tested speeds 8, 10, 15 km h^{-1} were recorded lower values of shape factor 0.7994, 0.8173 and 0.8449, respectively. In determination of biomass production for drill machine speed 12 km h^{-1} the greatest yield from 1 m^2 was observed. Subsequently, for speeds 8 and 10 km h^{-1} was lower about 4.26% and 1.83%, respectively. For tested speeds of drill machinery 15 km h^{-1} and above was observed only a small descent of yields about 0.6%. Fluctuation in yields affected by working speed then demonstrates fluctuation in sowing rate. It was also observed that the working speed of sowing machinery also affect the amount of yield directly. However, in case of lowest yield of straw recorded it was observed even 20% decrease in yield of grains.

Key words: drill machine, sowing quality, biomass, operating speed, yield.

INTRODUCTION

The quality of sowing is affected by a various number of factors (Findura et al., 2005; Findura et al., 2006; Jobbágy et al., 2007; Turan et al., 2014; Turan et al., 2015). During the evaluation of seeds placement in the soil is needed to take into account the depth of its placement (Rusu et al., 2009) but also the spatial (horizontal) distribution of seeds in the sowing area (Maga et al., 2015). This spatial distribution of seeds in soil affects not only field germination of plants but also further development of plants and therefore yields in the results. Blackmore et al. (2009) concluded that optimization of the area location of the seeds during seeding process and subsequently of the emerged plants is very important for the increasing of the field emergence rate, for further plant grows and yield obtained. In the same time the competitive effects of growth factors among plants (light, water and nutrients) are decreasing with increasing distance between plants. However, Ramseier & Weiner (2006) concluded, there is a negative linear relationship between the relative growth rate of target plants over an interval and the biomass of their neighbours at the beginning of the interval. The size of the target plant itself did not make a significant additional contribution to predicting its growth rate. There is a limit on the growth in biomass of the population (target + neighbours), and growth of individuals occurs within this constraint. Local biomass density, which can be primarily determined by neighbouring individuals, can be much more important for an individual's growth than its own size. There was no evidence of size-asymmetric competition. The size of neighbours was the primary determinant of a target plant's relative growth rate, but the effect of a given amount of neighbour biomass was the same for neighbours larger and those smaller than the target plant.In addition, Korres et al. (2016) stated that crop ability to suppress weeds can be considered in two ways, namely (a) the ability to tolerate weed competition which can be measured by the ability of the crop to maintain high yields under weedy conditions and (b) the ability of the crop to suppress the growth of weeds, usually determined by comparing different biological characteristics in mixtures with that in pure stands, known as weed suppression ability or competitive ability (Callaway, 1992; Korres & Froud-Williams, 2004; Andrews et al., 2015).

Spatial distribution of seeds in soil then represents an essential production and technical measures which affects directly into the process of crop yields production. A polygon method is one of the possible evaluation forms of spatial distribution of seeds assessment (Griepentrog, 1999). This method allows to evaluate the spatial distribution of seeds by distribution of polygons and definition of areas occupied by individual plants, an individual growing spaces (Griepentrog et al., 2005a; Griepentrog et al., 2005b). It was further found that the spatial distribution of seeds in soil is dependent on quality of longitudinal distribution of seeds along with spacing of rows and also on specific quantity of seeds per area unit (Griepentrog & Nørremark, 2001; Hanzlik & Gerowitt, 2011). Moreover, Findura et al. (2005) and (2006) concluded that the seeders do not sow seeds at the same distance even within the same row.

As a criterion for description of longitudinal distribution quality can be considered also evaluation of the spatial distribution of seeds even indirectly. In addition, the distribution of seeds in the same row do not fit into normal distribution (Gauss distribution) but most often fit into exponential distribution (Maga et al., 2015; Torres et al., 2017). Disadvantage in this kind of assessment procedures is decommissioning of other and essential parameters such as the inter-row distance and specific quantity of seeds per area unit while quantity of seeds also affects living area per plant, inter-row distance and also the shape of living area per plant (Jha et al., 2017). Nevertheless, these assessment criteria of the quality of seeders work will be used, although direct comparisons should be fair and meaningful only when the same inter-row distances and equal quantity of seeds per area unit will be applied (Maga et al., 2015). Subsequently, Heege & Feldhaus (1997) suggested and later Nørremark et al. (2007) expanded that with lower inter-row distances usually also improves the spatial distribution of seeds in the soil. Based on this conclusions, it appears to be competitive to aim for a lower inter-row distances in the seeding processes.

Criteria which characterize only the mean distance of seed to neighbouring seed (plant) are able to describe the spatial distribution of seeds only limited due to its low level of explanatory and are not suitable for further analyzes or modelling of images. These methods of evaluation are still in progress of development. One of the reason of this low level accuracy is namely eccentricity which can be defined as a specific (real) position of plant (seed) in produced polygon and therefore its distance to another plant inside neighbouring polygon also affected by this eccentricity in another level. These criteria however, are applicable as a first assumption and formulation for inscription of spatial distribution of seeds (Bechar & Vigneault, 2016; 2017).

The main focus of the study was to evaluation of quality of the placement of seeds and its effect on the biomass yield. To achieve this, the main objectives were to evaluate the space arrangement of the seeds by using of polygon method on one field with the repetition for different forward speeds of the drill machine.

MATERIALS AND METHODS

Since the aim of the study was the evaluation of spatial distribution of seeds (plants) by polygon method the variety of winter wheat was selected and used along with commonly used Väderstad Rapid RD – 800 A seeding unit. In order to determine the dependencies (namely: effect of drill operational speed on placement of seeds, dynamic proportions of seeds impact on the soil and distances of seeds inside the same row) a various operation speeds of seeding units was applied.

Identification of plants and methods of picture analysis

In order to facilitate the description and evaluation of competitive situation among crop plants it was established so called 'specific area' which represents the living area for a single plant. This area is bordered from all sides by areas occupied by neighbouring plants and it has the multi-angle shape or polygon.

For calculation of polygon areas values is therefore critical which plant is neighbouring with those evaluated and for polygon creation is essential. In this case as suitable appears to be a Denaunays triangulation or Thienssens distribution of polygons (Kashyap et al., 1983; Tüceryan & Jain, 1990; Okabe et al., 2008).

Denaunays triangulations can be understood as the: there are 3 visible points as neighbours which form the circuit together and do not contain any other point at the same time (Fig. 1, A). Point 'B' is not a neighbour to point 'O' since the common circuit does not contain point 'B'.

Voronois method can be explained as the: as a neighbouring point is considered those which polygons as a result of polygon decomposition show the common polygon edge (Fig. 1, A). Point 'A' is not a neighbour to point 'O' since a half of distance 'OA' is greater than 'a'. As it is showed at Fig. 1 identification of the neighbouring seeds (which seed is a neighbour to which) by both methods are equal and the difference is only in the resulting shapes of geometric patterns. It means that both procedures are suitable as a solution of selected issue.

As it is showed in Fig. 1, B, area attributable to the plant and defined by a specific polygon is characterized by: (i) size of the area (ii) shape of the area and (iii) location of plant (eccentricity). There is no doubt that the most important factor among all is the size of area for a single plant. Accordingly, the same quantity of seeds per area results in the same size of area attributable to one plant. It was proven that longitudinal distribution of seeds, row spacing and size of area per plant affects the final yields. In addition, shape of the polygon area also affects the plant development. The ideal would have been round shaped area however it is not achievable in common practise. When balanced precise sowing is applied the area have the shape of rectangle while triangular sowing results in hexagonal shape of the area.

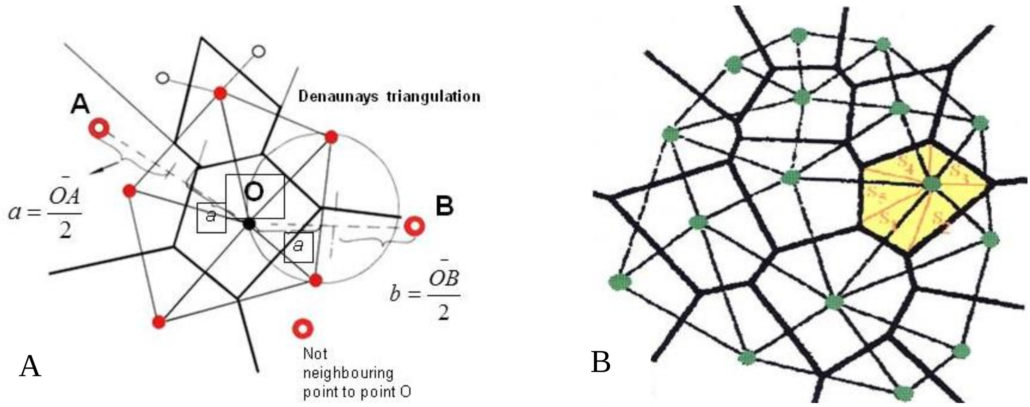

Figure 1. A: The example of Denaunays triangulation and Voronois polygon (where A, B and O are individual plans/seeds); **B:** Polygon on sown seeds (where the area of single polygon is defined as a sum of areas S_1 to S_n).

For evaluation of area shape Griepentrog (1999) introduced so called shape coefficient T_f which is calculated by following equations:

$$\bar{T}_f = \frac{1}{n}\sum_{i=1}^{n}\frac{O_{ideal}i}{O_{real}i} \tag{1}$$

$$O_{ideal} = 2\sqrt{\pi S_i} \tag{2}$$

where $O_{ideal}i$ – ideal perimeter of polygon i; $O_{real}i$ – real perimeter of polygon I; n – number of polygons; S_i – area of polygon i (as a sum of areas $S_{1\text{-}n}$ – see Fig. 1, A).

For the described concurrence between individual plants contingent by plant location is the distribution of polygons particularly significant due to high similarity of the size and shape of real polygon areas. The method of polygon distribution is dependent on the selected method of sowing. It is applicable on the line sowing, strip sowing or even wide sowing when the position coordinates of seeds are known. At the same time, measurements of seed distances in case of seeding machines studies can be used as a base for calculation of polygon distributions. Optimization of spatial distribution of seeds during process of seeding and subsequent plant emergence should be of value in improving the plant field emergence but also in improvement of following plant development and subsequent yields while competing effects of growth factors between plants (light, water and nutrition) should decrease.

It is obvious that besides the size and shape of polygon attributable for one plant the inside position of plant in polygon (eccentricity) will play an important role (Jiang et al., 2013).

Machinery and conditions of field study

Field measurements were conducted at the fields of PD Gemerská Ves, agricultural company (48°28'13.1"N 20°16'14.3"E). Winter wheat was sown, variety Antoniusz, specifically. Soil type of selected field was determined as loamy clay which belongs to hevier soil types. Väderstad Rapid RD – 800 A seeding unit was used which consist of disk heel coulters with a pitch of 125 mm. The seeding machine was set to apply the quantity of seeds at 220 kg ha^{-1} along with seeding depth at 30 mm (confirmed by measurements after seeding at value 29 mm ± 2 mm). The sowing mechanism of selected seeding machine works on pneumatic principles, overpressure specifically with cylindrical roller dosing system. The crossings of sowing assembly was realised with various speeds 8, 10, 12 and 15 km h^{-1}, respectively. Those different crossings were then labelled for later identification when plans emerged. For every sowing speed (factor) a multiple (5 × 10) pictures (samples) were taken diagonally to crossing vector.

Description of used software

It was used the evaluation software TfPolyM developed at Department of Machines and Production Biosystems. Software was developed in development environment of Delphi. It is designed for determination of polygon distribution of plants in the horizontal plane in relation with distribution of neighbouring plants. Program is able to process digital pictures which were taken after the plant emergence (Fig. 2, A). Algorithm of this program can be divided into 3 phases which follow each other and are executed in following order: (i) determination of individual points – identification of plants on the pictures (Fig. 2, B), (ii) determination of neighbouring points (Fig. 2, C) and (iii) production of polygons (Fig. 2, D).

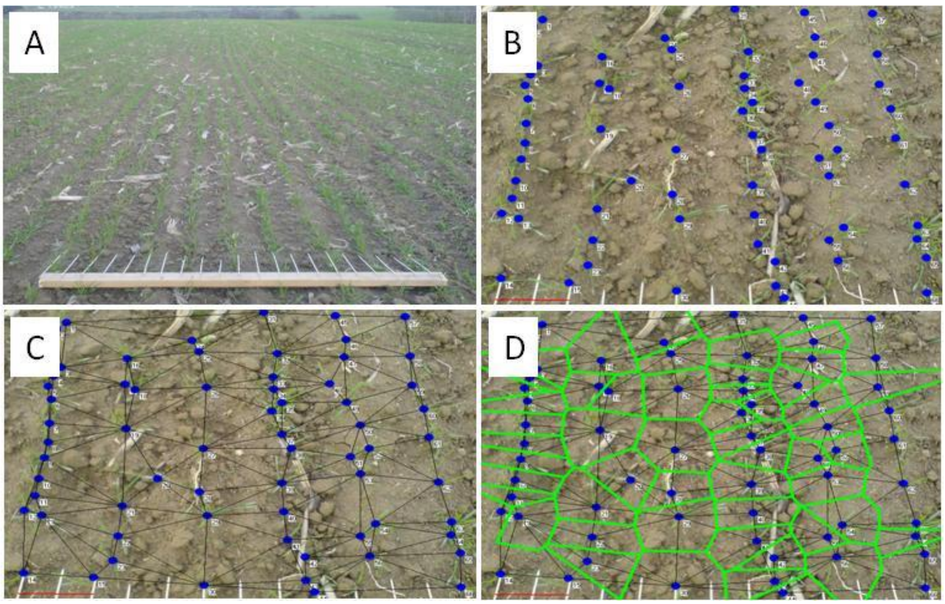

Figure 2. Picture of the field after plant emergence: A – measurement frame; B – Plant identification; C – Determination of neighbouring points; D – Production of polygons.

RESULTS AND DISCUSSION

Results of image analysis

Digital pictures were used in the evaluation which was taken from repetitive measurements of all selected speeds of seeding machinery assembly and full emergence of all plants. Those pictures were taken when all of the plants were visible and fully emerged, the crop were not involved into full cover and were easy to identify. The evaluation was then carried out by specific software TfPolyM defined in above chapter. These pictures were then used for determination of the shape and size of area attributable for selected single plants. The shape of polygons defined for plants was then expressed as the shape factor value 'T_f' (Table 1). This factor serves as a tool to identify the suitability of shape polygon for selected plant and its proper development (Findura et al., 2005; Findura et al., 2006).

Table 1. Forward speed effect of the drill machine on the seeding parameters, *n = 10*

Forward speed, Km h^{-1}	Mean value of the shape factor, T_f					Average, T_f	s.d.
8	0.7779	0.7899	0.8316	0.7875	0.8101	0.7994^a	± 0.0215
10	0.8070	0.8392	0.8113	0.8057	0.8235	0.8173^a	± 0.0141
12	0.8553	0.8322	0.8684	0.8398	0.8640	0.8519^b	± 0.0155
15	0.8727	0.8942	0.7679	0.8328	0.8570	0.8449^b	± 0.0485

Different letters $^{(a,b)}$ denotes statistically significant difference, α = 0.05.

By comparison of those shape factors in relation with selected working speed of seeding machinery (Fig. 3) it can be concluded and determine the most suitable speed of seeding machinery from the perspective of distribution uniformity of seeds in horizontal direction (Griepentrog et al., 2005a; Griepentrog et al., 2005b).

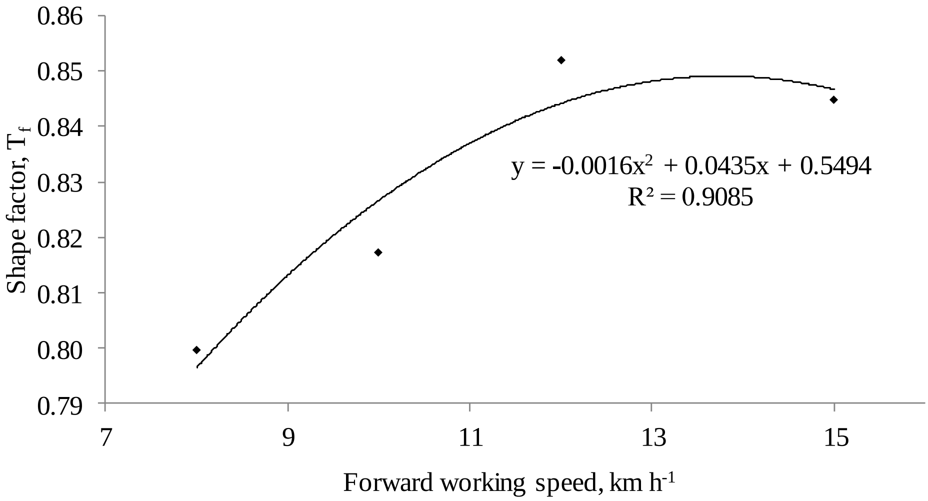

Figure 3. Forward speed effect of drill machine on the values of the shape factor.

The most suitable values of shape factor T_f (0.8519) was recorded for speed of drill machine set on 12 km h^{-1}. For other tested speeds 8, 10, 15 km h^{-1} were recorded lower values of shape factor 0.7994, 0.8173 and 0.8449, respectively. This phenomenon represents that decreasing and increasing values of drill machinery speed (below and over 12 km h^{-1}) results in decreasing T_f value which therefore means the lower work quality of seeding machinery assembly. The effect of operation speed of drill machinery on seeds placement was also observed by Nørremark et al., 2007 in their study. It was also pointed out that inclusion of seeders altitude data in the data processing significantly improved the accuracy of the estimation of geo-referenced plant positions and therefore it was concluded that a dual axis tilt sensor should be a required part of the instrumentation. Furthermore, it was shown that high accuracy of the estimation of geo-referenced plant positions required a zero horizontal velocity of the seed released from the seeding mechanism. In general, the overall accuracy of the estimation of geo-referenced plant positions was satisfactory to allow subsequent individual plant scale operations (Nørremark et al., 2007).

Also the average sizes of polygons were observed (Fig. 2). Based on the results obtained it can be concluded that increasing working speed resulted in increased average size of polygons up to 12 km h^{-1} and then is relatively stable till the speed of 14 km h^{-1} even has a gradual decreasing trend. There are some indications that this phenomenon is connected with physical attributes of individual seeds. Specifically, with increasing speed of drill machinery it gives to individual seed a different momentum which then affect final placement of seeds. This momentum then affect the distance where the individual seed is able to roll in row till finally placed. This rolling force is dependent on the shape of individual seeds, physical (e.g. dimensions, shape, and weight) and mechanical properties of individual seed (Ren et al., 2001). Perfect & McLaughlin (1996) also observed the effect of soil properties on final seed placement in the row.

As it was mentioned before, placement of the seed in produced polygon is also highly effected by eccentricity phenomenon (Griepentrog & Jørgensen, 2008) and therefore all of these variables have the final effect of T_f. As Krzaczek et al. (2006) concluded, working speed of seeders affects the quality of sowing procedure due to its high impact on the precision of seed distribution in a row. This phenomenon could be also explained by non-ideal feeding of sowing mechanism which works on the gravity basics (Turan et al., 2014).

Results of biomass production

The samples of biomass yield were harvested in full ripeness of plants straight before harvest of whole crop (Fig. 4). The samples (ale 1 m^2) were harvested from the same locations where the digital pictures were taken for the evaluation of shape factor (T_f) in above chapter. The samples were analysed (Table 2) and values represents fresh biomass before drying process. Moisture content of grains and for all samples taken was determined at 15% ± 0.5%.

An above-ground portion of plants was cut roughly 10 cm above ground. Every sample was collected individually for all of selected drill machine speed 8, 10, 12 and 15 km h^{-1}. Samples were taken in 10 replications. For evaluation of samples it was needed do separate ears from straw and subsequently grain from straw. Efficient threshing was performed manually.

Figure 4. Biomass samples – harvested from 1 m^2.

In determination of biomass production for drill machine speed 12 km h^{-1} the greatest yield from 1 m^2 was observed (Table 2 and Fig. 4). Subsequently, for speeds 8 and 10 km h^{-1} was lower about 4.26% and 1.83%, respectively. For tested speeds of drill machinery 15 km h^{-1} and above was observed only a small descent of yields about 0.6%. Fluctuation in yields affected by working speed then demonstrates fluctuation in sowing rate. In this case it means negative performance. Also Guberac et al. (2000) suggested the same phenomenon which was later supported by Carr et al. (2003a; 2003b) and finally proved by Schillinger (2005).

Table 2. Forward working effect of speed of the drill machine on the biomass yield, *n = 10*

Parameter	*Unit*	*Values* (± *s.d.*)			
Speed of the drill machine	km h^{-1}	8	10	12	15
Average weight of the sample	g m^{-2}	1,570^a ± 4.01	1,610^b ± 3.30	1,640^c ± 6.39	1,630^c ± 4.18
Average weight of the straw	g m^{-2}	650^a ± 7.76	630^a ± 5.70	590^b ± 6.43	570^b ± 4.75
Average weight of the weight of ears	g m^{-2}	920^a ± 2.07	980^a ± 5.89	1,050^b ± 8.32	1,060^b ± 7.58
Average weight of the grains	g m^{-2}	760^a ± 6.35	786^a ± 4.43	810^b ± 6.18	805^b ± 4.13

Different letters $^{(a,b,c)}$ denotes statistically significant difference, α = 0.05.

In the whole experiment there was observed an unbalanced number of (seeds/plants) individuals in greater extent. The reason of unbalance in number of individuals (seeds/plants) could be affected also by the impact of seeds on soil during sowing process as also suggested Botta et al. (2010). In addition, individual seeds were falling very close to each other which results in insufficient space for plants growth and further development as it was stated by Maga et al. (2015). Working speed of drill machinery 15 km h^{-1} is not efficient even does not comply the conditions while it was observed that increasing working speed resulted in extrusion of sowing coulters which results into violations of necessary sowing depth.

As it is showed in Table 2 and Fig. 5, working speed of sowing machinery also affect the amount of yield directly. In addition, it was observed that for speed of drill machinery 15 km h^{-1} the average yield was 805 g from 1 m^2. However, in case of lowest yield of straw recorded it was observed even 20% decrease in yield of grains. The conclusion that the working speed of drill machinery, quality of sowing and even sowing mechanism affects the individual plants performance and therefore final yields was also supported by various researchers in their studies, however by a different levels (e.g.: Arvidsson et al., 2000; Naresh et al., 2011; Kahloon et al., 2013).

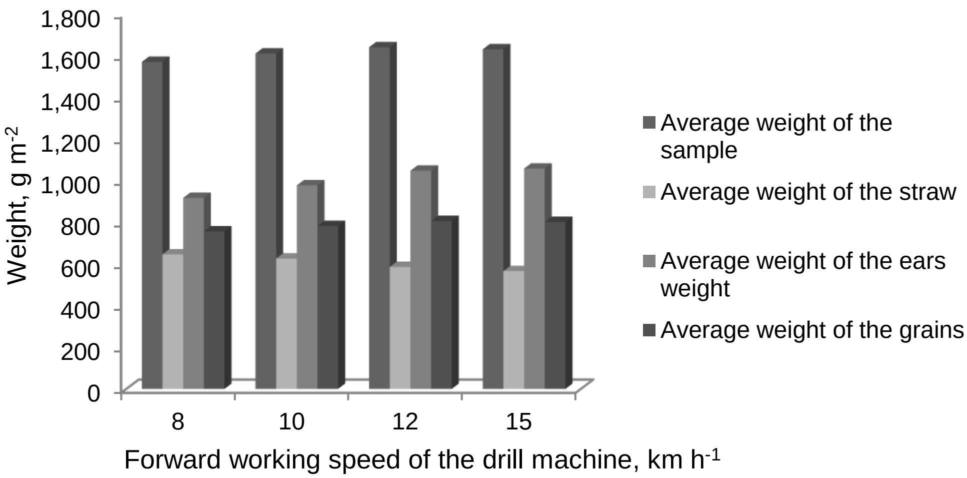

Figure 5. Relationship of yield (weight) of biomass (straw, ears and grains) and working speed of sowing machinery assembly.

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CONCLUSIONS

It can be concluded that the relationship between shape factor (T_f) and working speed of drill machinery was found. As an optimal value of shape factor is considered 0.952 however this value is not achievable in practice. In our experiment, the best possible values of shape factor were recorded for working speed of drill machinery 12 km h^{-1}. For lower and higher tested speeds the decrease in value of shape factor was observed. The lowest value of shape factor was recorded for working speed 8 km h^{-1} and working speed 15 km h^{-1} was found to be even not applicable due to violation of other requirements for quality of sowing process, e.g. sowing depth.

As it is apparent from the results, with increasing working speed of drill machinery the average size of polygons is also increasing until speed 15 km h^{-1} and then decrease by moderate trend. However, average size of polygon in dependence with working speed of drill machinery should not fluctuate because it result into fluctuation of specific amount of seeds for area unit which should be stable. This phenomenon could be caused by insufficient filling rate of sowing mechanism or insufficient seeds amount and following the lower gravitational force exerted by seeds on the sowing system.

In determination of biomass production was observed that working speed of drill machinery 12 km h^{-1} result in the highest yields from 1 m^2. Other tested speeds, 8 and 10 km h^{-1} resulted in decreased yields. In case of working speed 15 km h^{-1} was observed only small decrease in yields (0.6%) however other parameters of sowing quality was violated due to extrusion of sowing coulters from the soil.

It was also observed that the working speed of sowing machinery also affect the amount of yield directly. However, in case of lowest yield of straw recorded it was observed even 20% decrease in yield of grains.

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Occupational diseases among agricultural workers in the Russian Federation: review of statistical data

N. Mazitova[1,*], N. Simonova[2], E. Adeninskaya[3] and M. Trofimova[4]

[1]Research and Clinical Center of Otorhinolaryngology of Federal medical and biological agency, Department of Occupational diseases, Volokolamskoye hgw., 30, build. 2, RU 123182 Moscow, Russia
[2]Klinsky Institute of occupational safety and working conditions,Department for Science, Berezovoy roschi str., 4, RU125252 Moscow, Russia
[3]Central Clinical Hospital of Civil Aviation, Department of Occupational Health, Ivankovskoye hgw., 7, RU125367 Moscow, Russia
[4]Administration of the Federal Service for Supervision of Consumer Rights Protection and Human Welfare in the Republic of Tatarstan, B.Krasnaya str., 30, RU420111 Kazan, Russia
[*]Correspondence: mazitova@otolar-centre.ru

Abstract. The aim of the study is to analyze the epidemiological situation of occupational diseases among agricultural workers in Russia. To address this task, the analysis of occupational diseases incidence was carried out.
Conclusions.For the last decades the proportion of rural working population in Russia is gradually decreasing, but remains noticeably higher than in other industrialized countries. There is a huge difference between entities of the Russian Federation in occupational illnesses incidence rates among agriculture workers, which can be explained by: (a) the distinction of health care availability; (b) lack of occupational physicians in rural areas; (c) the high level of the incidence of non-communicable diseases, which can disguise occupational illnesses among agricultural workers. The improvement of the health care regulatory legal framework, development of evidence-based clinical practice guidelines, quality improvement in postgraduate education of medical doctors in rural areas, increasing in the number of occupational health physicians in rural areas, and implementation of long-term health promotion programs are necessary in order to maintain the heath of agricultural workers in the Russian Federation. This list of priority measures is not sufficient, as it highlights only the main issues in the field of occupational health.

Key words: agricultural workers, occupational diseases, diagnosis.

INTRODUCTION

Agriculture in both industrialized and developing countries is one of the most hazardous industries (Donham & Thelin, 2006). Agricultural workers are usually at risk for wide range of occupational diseases and injuries (Lessenger, 2006). However the incidence of occupational diseases among agricultural workers is considered to be underestimated (Solomon et al., 2007). The underdiagnosis of occupational diseases among agricultural workers is a common problem: the number of reported occupational diseases in sphere of agriculture is low and reflects obvious underreporting (Kurppa et al., 2006).

The most common and costly occupational illness of agricultural workers are musculoskeletal disorders (MSD), which can be caused by work-related (i.e., ergonomic) and individual-related risk factors. The prevalence of MSDs in farmers is greater than in non-farmer populations (Osborne et al., 2012).

In Russia agricultural workers is one of the most numerous groups among patients with occupational diseases. But the level of occupational diseases incidence appears to be underestimated as well. Among the causes of the underdiagnosis there are: (1) low availability of medical care for rural population (particularly in occupational health), (2) lack of knowledge among health professionals. Currently the challenge ahead Russian specialists on occupational health is not only to restore lost priorities of Russian medicine that was aimed at prevention and the continuity of health care, but also create medical monitoring system of rural workers, as in Soviet Union health care policymakers were primarily focused on industrial workers.

The aim of this study is to analyze the epidemiological situation of occupational diseases among agricultural workers in Russia. To address this task, the analysis of occupational diseases incidence has been carried out.

MATERIALS AND METHODS

The analysis included all cases of agricultural workers' occupational diseases, which were reported to the Russian Federal Service for Supervision of Consumer Rights Protection and Human Welfare over the years 2012–2014. For more detailed analysis we used all available data on agricultural workers' occupational diseases from Registry of Occupational Diseases of Tatarstan Republic over the years 2012–2014, as All-Russian Federal Registry of Occupational Diseases with total data, suitable for analysis, has been not created yet.We analyzed the level and structure of occupational incidence, as well asthe number of cases among different occupations. For data obtained from the Register of Occupational Diseases, we assessed the sex-age structure of patients and the length of service in harmful working condition.

We also used Russian service of state statistics to obtain the official statistical data about number of rural population and key indicators of agriculture development (Russian Federal Service of state statistics).

Due to the lack of published large epidemiological studies, concerningeither agricultural workers' healthor quality of occupational health services, we used other available statistical data as a main comparison (Organisation for Economic Co-operation and Development, US Bureau of Labor Statistics, World Bank Open Data).

The software STATISTICA 8 (Statsoft Inc., USA) was used for the statistical data analysis. The data are presented as the arithmetic mean. The basic characteristics were processed using descriptive statistics. The difference between variables was evaluated by Student′s t-test. The level of statistical significance was set at $p < 0.05$.

RESULTS AND DISCUSSION

For the last three decades the percentage of agricultural population of Russia remains stable (Table 1). Decrease of the weight of agricultural population which took place in the middle of 20th century was caused by the country's industrialization and withdrawal of rural inhabitants to cities. The absolute number of rural population in Russia is also in slow decline. At the same time the number of employees in the agricultural sector decreased from 6.5 to 4.8 million people, i.e. by 25% over the period of last 10 years.

Table 1. Trends in number and proportion of rural population in the Russian Federation

Years	Number of inhabitants	Rural population	
		Number, million people	Proportion in the total population, %
1897 (in modern borders)	67,5	57,6	85
1914 (in modern borders)	89,9	74,2	83
1926	92,7	76,3	82
1939	108,4	72,1	67
1959	117,2	56,1	48
1970	129,9	49,3	38
1979	137,4	42,5	31
1989	147,0	**39,0**	**27**
2002	145,2	**38,8**	**27**
2010	142,9	**37,5**	**26**
2014	143,7	**37,1**	**26**

Nevertheless, compared to other industrialized countries, the share of agricultural population of Russia remains rather high, both against larger countries, such USA, and as well as against former Soviet republics. At the same time country's level of agriculture remains very low, i.e. poor level of production organization, insufficient mechanization, outdated agricultural technologies, high proportion of manual unskilled labor, etc. Most of agricultural machinery is domestic technique of old models, operated 10 years or more, amortization degree of which reaches 75% or more. Therefore, the added value per agricultural worker in Russia is much lower not only than in major industrialized countries, but also than in former Soviet republics, such Estonia (Table 2).

Table 2. Agriculture and rural development data in Russia, US and Estonia

	USA		Russia		Estonia	
	Absolute data	%	Absolute data	% to USA	Absolute data	% to USA
Employment in agriculture (% of total employment), data for the year 2014	**1.6**	100	**6.6**	412.5	**3.9**	243.7
Agricultural machinery, tractors per 100 sq. km of arable land, data for the year 2006	**272.3**	100	**27.1**	9.9	**604.7**	222.1
Agriculture value added per worker (constant 2010 US$), data for the year 2014	**78,223.9**	100	**10,941.6**	13.9	**13,196,7**	16.9

In Russia mandatory monitoring of working conditions with quantitative evaluation of occupational exposures is being conducted since 1997 (i.e. toxic substances, noise, vibration, dust, physical stress, etc.). According to official statistical data, 30% of workers in agriculture have working conditions that do not meet safety requirements (Russian Federal Service of state statistics). The refore farmers are expected to be exposed to high occupational risks. However, in Russia the number of reported occupational diseases does not correspond to the level of anticipated occupational risk. Total incidence rates of nonfatal occupational illnesses is almost 19 times less than in United States, and almost three times less than in Estonia. With country's basic health status indicators comparedto those inboth the US and Estonia, occupational incidence rates are also expected to be significantly higher, especially under poor working conditions. Nevertheless, mortality and disability rates in the Russian Federation are higher than in compared countries (Table 3). Given the high level of prevalence of musculoskeletal diseases in adult population of the Russian Federation, these diseases could be considered to disguise occupational illnesses, particularly among agricultural workers.

Table 3. Health status indicators in Russia, US and Estonia, for the year 2014

	US		Russia		Estonia	
	Absolute data	%	Absolute data	% to USA	Absolute data	% to USA
Incidence rates of nonfatal occupational illness (all industries), per 10,000 full-time workers	**18.8**	100	**1.1**	5.9	**3.2**	17.0
Death rate, crude (per 1,000 people)	8.1	100	13.1	161.7	11.7	144.4
Disability prevalence (WHS, 2002–2004)	12.6	100	16.4	130.2	11.0	87.3
Life expectancy, Total population at birth, Years	78.8	100	70.6	89.6	77.0	97.7

The incidence rates of occupational illness among agriculture workers in Russia are lower than those for all occupations. However in Republic of Tatarstan, one of the most stable and developed regions in the Russian Federation, the incidence rates of occupational illnesses among agriculture workers are three times as much (Table 4). Other regions of Russia with higher level of occupational health care availability showed similar occupational incidence rates among agriculture workers (Bakirov et al., 2015).

Table 4. Incidence rates of occupational illnesses in Russian Federation and Republic of Tatarstan

	Russian Federation			Republic of Tatarstan		
	2012	2013	2014	2012	2013	2014
Incidence rates of nonfatal occupational illness (all industries), per 10,000 full-time workers	1.11	1.14	1.1	0.82	1.07	1.00
Incidence rates of nonfatal occupational illness (agriculture), per 10,000 full-time workers	0.86	0.83	0.69	2.71*	3.29*	2.78*

The difference between variables was evaluated by Student's t-test.
Marked difference ($p < 0.05$) is between compared data of Russia and Tatarstan.*

In Russia's agricultural sector more than half cases of occupational diseases were found among tractor drivers (53.0–59.7%), about one third – among livestock keepers(33.3–35.1%), there are a relatively large numbers of occupational diseases among veterinary officers (5.0–11.3%) due to brucellosis cases in southern regions of Russia, and the smallest number of occupational diseases registered among plant breeders (1.0–2.6%).

In Republic of Tatarstan the structure of occupational incidence is slightly different. The most numerous group of affected workers are livestock keepers (56.5–61.1%), and then tractor drivers (27.7–43.5%). The number of plant breeders 6–8%. Cases of occupational diseases caused by biological agents are very seldom – one case in several years. This difference in incidence structure can be explained by a higher level of hygienic control measures, which can help manage the risk of occupational diseases caused by biological agents. Most of big farms in Tatarstan are well-equipped with modern agricultural machinery, which resulted in lower levels of occupational diseases among tractor drivers. Unfortunately, levels of mechanization and proportion of manual labor remain the same. Therefore, the amount of occupational diseases among livestock keepers is quite high.

The structure of occupational morbidity among agricultural workers such as age-sex distribution in Russia cannot be analysed using only official statistical data of Russian Federal Service for Supervision of Consumer Rights Protection and Human Welfare. All-Russian Registry of Occupational Diseases there is still no in the Russian Federation. This is why we used the data from Registry of Occupational Diseases of Tatarstan Republic, where one of first Registries was founded. In Tatarstan Republic over the years 2012–2014 the most frequent occupational illnesses among agricultural workers were MSDs which amounted 65.2%; whole-body vibration syndrome and noise induced hearing loss turned out to be less frequent; other occupational diseases (one case of brucellosis and two cases of occupational chronic obstructive pulmonary disease) amounted only 2.9% (Table 5).

Table 5. Basic characteristics of occupational diseases among agricultural workers in Tatarstan Republic (2012–2014)

	Number / %	Age, mean (95% CI)	Length of service, mean (95% CI)	Gender, male/female
Whole-body vibration syndrome	27 / 19.5	52.4 (51.0–53.8)	30.2 (28.1–32.3)	27/0
Noise induced hearing loss	17 / 12.3	54.1 (51.9–56.2)	30,7 (27.3–34.1)	17/0
Bursitis and tenosynovitis	36 / 26.1	51.4 (50.2–52.6)	28.3 (26.3–30.3)	6 /30
Low back pain	18 / 13.0	49.6 (47.5–51.7)	26.5 (23.2–29.9)	2/16
Neck pain	36 / 26.1	50.3 (48.7–51.8)	26.7 (24.4–29.0)	6/30
Other diseases	4 / 2.9	47.3 39.6–54.9)	11.5 (8.2–14.7) *	2/2
In total	138 / 100.0	27.9 (26.4–29.3)	51.2 (50.4–52.2)	65/73

The difference between variables was evaluated by Student's t-test.
Marked difference (p < 0.05) is between compared group and all the others.*

Analysis of age distribution among agricultural workers with newly diagnosed occupational diseases reveals that the most likely reasons of underreporting of occupational diseases are both the fear of losing job and the lack of access to occupation health services. The overwhelming majority of occupational diseases are diagnosed at the age 50 or over with the length of service of 26 years and more years with any statistically significant differences among groups of diseases, i.e. several years to retirement.

Undoubtedly, the reasons for under-diagnosis may include also a well known shortage of medical doctors, even occupational health physicians, in rural areas of Russia. The other reason may be a lack of awareness of medical doctors in occupational health due to absence of evidence-based clinical practice guidelines of MSDs diagnosis.

Furthermore, some of smallholder farmer often are uninsured in system of compulsory social insurance, that denied them the right to receive as the disability payment as medical rehabilitation measures, that does not help to consult a doctor.As a result, late diagnosis of advanced forms of occupational diseases among rural workers has made all the treatment and rehabilitation measures inefficient and increased disability level of working population in rural areas of Russia.

CONCLUSIONS

In the Russian Federation the proportion of rural inhabitants among employed population has been gradually decreasing for the last decades, but still remains noticeably higher than in other industrialized countries. Level of added value per agricultural worker in Russia is lower than in major industrialized countries due to obsolete equipment, high rate of low-skilled manual labour, etc. As a result, approximately one-third of agricultural workers in Russia are forced to work under harmful working conditions. Therefore, the level of occupational diseases among agricultural workers is expected to be higher. However, over the past years in Russia the incidence rates of occupational illnesses among agriculture workers are significantly lower than those for all occupations. Given the fact that the total incidence rates of nonfatal occupational illnesses in Russia is almost 19 times less than in United States and almost three times less than in Estonia, we can conclude that there is considerable occupational diseases underdiagnosis also among rural workers.

The structure of occupational incidenceof agricultural workers is different both in Russia and Republic of Tatarstan. In Russia's agricultural sector more than half cases of occupational diseases were diagnosed among tractor drivers, but in Republic of Tatarstan – among livestock keepers, which can be explained by higher level of hygienic control measures and agricultural equipment in Tatarstan. Proportion of manual labor remains the same, resulting in a quite high rate of occupational diseases among livestock keepers both in Russia and Tatarstan.

In general, underdiagnosis of occupational diseases in agriculture sector can be explained by: (a) low level of health care availability; (b) lack of occupational physicians in rural areas; (c) lack of awareness of medical doctors in occupational health; (d) high level of non-communicable diseases incidence, which can disguise occupational illnesses among agricultural workers; (e) lack of social security of smallholder farmers.

The improvement of the health care regulatory legal framework, development of evidence-based clinical practice guidelines, quality improvement in postgraduate education of medical doctors in rural areas, increasing in the number of occupational health physicians in rural areas, and implementation of long-term health promotion programs are necessary in order to maintain the heath of agricultural workers in the

Russian Federation. This list of priority measures is not sufficient, as it highlights only the main issues in the field of occupational health.

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Fodder galega (*Galega orientalis* Lam) grass potential as a forage and bioenergy crop

H. Meripõld*, U. Tamm, S. Tamm, T. Võsa and L. Edesi

Estonian Crop Research Institute, J. Aamisepa 1, EE48309 Jõgeva, Estonia
*Corresponding author: heli.meripold@etki.ee

Abstract Fodder galega (*Galega orientalis* Lam.) is a forage legume that has been grown in Estonia for almost forty five years. Pure galega is known to be persistent, high-yielding crop and rich in nutrients, in particular crude protein (CP), neutral detergent fibre (NDF) and acid detergent fibre (ADF). Galega is usually grown in a mixture with grass in order to optimize its nutrient concentration, increase dry matter (DM) yield and improve fermentation properties. The trial plots were established on a typical soddy-calcareous soil. There are certain grass species suitable for the mixture. In this study galega mixtures with reed canary grass cv. 'Marathon', timothy cv. 'Tika', red fescue cv. 'Kauni' and festulolium cv. 'Hykor' were under investigation in three successive years (2013–2015). In order to increase competitiveness of grasses and the yield of the first cut, two N fertilization levels were used: N0 and N50 kg ha^{-1}. Two cuts were carried out during the growing season in all three years. The total dry matter yield varied from 9.1 to 12.8 t ha^{-1}. The NDF concentration in the DM varied from 495−559 g kg^{-1}. Both DM-yield and NDF were dependent on the year, mixture, cutting time and fertilization. Nitrogen fertilization (N50 kg ha^{-1}) favoured grass growth and reduced the role of galega in the sward.

Key words: Fodder galega, goat's rue, yielding ability, galega-grass mixtures, fertilization.

INTRODUCTION

In recent decades, renewable energy production has become the focus of energy policy. Increasing the share of renewable energy has been set a target also in EU strategies. For example, Directive 2009/28/EC sets a target of reaching a 20% share of energy from renewable sources in the EU by 2020.

Estonia, like most countries, has ratified the Kyoto Protocol, which requires us to reduce our greenhouse gases emissions. This can only be done by combining different measures: reducing overall energy consumption and using more local energy sources, especially renewable ones.

The most common cultures in warmer climates meant for burning are the plants using the C_4 carbon fixation (Miscanthus, Panicum; Florine et al., 2006). These plants cannot survive low temperatures and soil freezing in northern regions, which is why C_3 carbon fixation reed canary grass is grown in Sweden and Finland (Hadders& Olsson, 1997; Larsson, 2006). Production of biofuels is worth the effort only if it will not cause additional fossil energy consumption. One of the major fossil fuel consumer is the production of mineral fertilizers. The usage of these fertilizers on grasslands reduces compellingly the energy conversion efficiency (MJ MJ^{-1}) of the energyhay (Tonn et al., 2009). Crude oil price is also important aspect for succession.

Organic dry matter yields obtained from galega-grasses mixed swards were higher by 2.3% to 10.7%, compared with pure galega swards at the same soil, fertilization and climate conditions. Average biogas yield per unit of degraded organic matter (DOM) was 533 m^3 Mg_{DOM}^{-1} and average methane yield was 31 m Mg_{DOM}^{-1} (Adamovics et al., 2011).

Different crops have been investigated as raw materials for energy production (Lewandowski et al., 2006; Jasinskas et al., 2008). Most research points out that although harvested yield can be used as energy raw material, economic feasibility of this may be questionable. Using grasses as a source of bioenergy has not been thoroughly studied in Estonia so far. The finnish technology (first cut harvest early in the spring from the frozen soil) is not suitable, because soil will not freeze through on every year and repeated melting periods weakens stems so they lodge (Noormets et al., 2007; Raave et al., 2009). The heat of combustion of grasses and wood are similar but the disadvantage of grasses, compared to wood, is their greater content of potassium and total ash. This complicates using grasses in furnaces as the ash melts at lower temperatures and sticks to the walls of the chamber wherefrom it cannot be easily removed (Hovi, 2006). Preliminary burning tests in a big bale furnace in Nurmiko garden resulted pure galega energy yield 1.6 kWh kg^{-1} (moisture content 16.7%).

Along with other legumes, fodder crops like lucerne and clovers, goat's rue, i.e. fodder galega have been grown in Estonia for almost forty five years. Galega is very persistent with a high yielding ability. Results have shown that the yields can reach to 10.5 tons of dry matter (1.7 to 1.8 tons of crude protein per hectare) with CP concentration of 200–220 g kg^{-1} DM (Viiralt et al., 1998; Raig et al., 2001; Lillak et al., 2007; Võsa et al., 2008). The nutritive value is the highest when the 1st cut was made at budding or at the beginning of flowering. In order to connect the need for nitrogen fertilizer with biologically bounded nitrogen, it is favourable to grow galega in a mixture with grass.

Of plant nutrients nitrogen has the highest effect on yield and quality of forage crop. When choosing grasses for mixtures, the species development speed, duration and the effect on nutritive value should be considered. Earlier results have shown that growing galega in mixtures with grasses improves the nutritive value and ensiling properties of forage crop (Lättemäe et al., 2005; Meripõld et al., 2014). The total dry matter yields of the three-cut systems varied from 7.6 to 13.7 t ha^{-1}. The CP concentration in the DM varied from 156 to 186 g kg^{-1}. Both DM-yield and CP concentration were dependent on year, mixture and fertilization. A more detailed description of the three-cut system experiment is presented in the article by Meripõld et al. (2016). The aim of the two-cut system investigation was to assess galega and galega-grass mixtures potential as a bioenergy crop.

MATERIALS AND METHODS

The experimental field was established in 2012 in Saku Estonia (local latitude 57° 25'). The study includes a three (2013–2015) years data. The soil type of the experimental area was *Calcaric cambisols* according to the World Reference Base classification (EAO 2014) where the agrochemical indicators were as follows: pH_{KCl} 6.3 (ISO 10390); soil carbon content C_{org} 3.3% (Tyurin method) and concentration of soluble P and K being 114 and 161 mg kg^{-1} (Mehlich III method) respectively. Four galega-grass mixtures were used. The galega cv. 'Gale' (*Go*) was sown in binary mixtures with reed canary grass cv. 'Marathon' (*Pa*) (7 kg ha^{-1}), red fescue cv. 'Kauni' *(Fr)* (10 kg ha^{-1}), timothy cv. 'Tika' (*Pp*) (8 kg ha^{-1}) and festulolium cv. 'Hykor' (*Fe*) (15 kg ha^{-1}) respectively. The sowing rate of the seed of 'Gale' was 15 kg ha^{-1} in all mixtures and pure seeding. A pure fodder galega *(Go)* was included in the trials as a control. The seeds were treated just before seeding with nodule bacteria *Rhizobium galegae.*

In order to increase competitivity of grasses and yield of the first cut, two N fertilization levels were used: N0 and N50 kg ha^{-1} (April or May, depending year conditions). The trials were established in split-plot design in 4 replicates and the size of the harvested plot was 7 m^2. The crop was cut by a scythe MF-70, then weighed and samples were taken for analyses. The botanical composition of crop was determined prior to sampling by comparing the dry matter yield proportion of different species. A two-cut system was used during harvest years and four replicates of the plots of each treatment. The first cut was made after the galega flowering, in the beginning of July. The second cut was made in the beginning of October.

The data determined in this experiment are: dry matter yield (DM), crude protein (CP), neutral detergent fibre (NDF) and acid detergent fibre (ADF) contents. Accumulated effective temperatures over 5 °C for the first cut in 2014 was 241 °C, 2013 291 °C and 2015 year was 178 °C. Effective temperatures of 2015 (Apr–May) were the lowest in the last ten years. The trial results were processed statistically by the method of dispersion analysis (Excel for Windows 2003).

RESULTS AND DISCUSSION

The results indicate that galega-grass mixtures ensured high DM yields since the trial field was established. In the years 2013–2015 the yields varied from 6.6 to 15.5 t ha^{-1} (Table 1). The best DM yield of the three experiment years was obtained from 'Gale'-'Hykor' mixture at N50 fertilizer level.

Table 1. The DM yield (t ha^{-1}) of fodder galega-grass mixtures in 2013–2015

Species	Variety	2013		2014		2015		Average	
		N0	N50	N0	N50	N0	N50	N0	N50
Go	Gale	7.6	7.8	10.0	13.5	10.5.	9.9	9.4	10.4
Go/Pa	Gale/Marathon	8.6	12.1	10.5	15.4	10.6	9.7	9.9	12.4
Go/Pp	Gale/Tika	7.5	8.5	12.8	14.2	8.7	10.5	9.7	11.0
Go/Fr	Gale/Kauni	6.6	8.5	10.6	13.2	10.2	10.9	9.1	10.9
Go/Fl	Gale/Hykor	7.3	11.9	10.9	15.5	9.7	11.0	9.3	12.8
		LSD 0.05 = 1.42		*LSD 0.05 = 2.02*		*LSD 0.05 = 2.2*		*LSD 0.05 = 2.2*	

The yields were higher in 2014 and varying from 13.2. to 15.5 t ha^{-1}. Application of N fertilizer changed the botanical composition of the sward. N fertilizer increased grasses and reduced 'Gale' proportion in the all mixtures. The highest average DM yields of the three experiment years were obtained from 'Gale'-'Hykor' and 'Gale'-'Marathon' mixture supplied with N fertilizer while 'Gale'-'Maraton' and 'Gale'-'Tika' mixtures provided the highest DM yields (9.9 t ha^{-1} and 9.7 t ha^{-1}) without the ferilizer. The yields of two-cut system mixtures were high enough, except 'Gale'-'Hykor' because 'Hykor' is an intensive variety and needs higher N supply during the growth period. The productivity of the 'Gale'-grass mixture is affected by the botanical composition and N fertilization of the mixture. In the N50 variant the yields of 'Gale' pure seeding are generally overcome by the mixtures in the three experiment years.

The ratio of the average (2013–2015) DM yield of the first cut to the average DM yield of the second cut with N fertilizer and without fertilizer was accordingly 1:0.43 and 1:0.48 in case of mixtures and 1:0.51 and 1:0.47 in case of pure 'Gale' (Table 2).

Table 2. The ratio of the first and the second cut (average of 2013–2015)

Variety	Galega	Galega-grass mixtures
N50	1:0.51	1:0.43
N0	1:0.47	1:0.48

In the N fertilizer variant the mixtures exceed pure 'Gale' yield by average in 2013–2015. In the mixtures of 2015, 'Gale' proportions had grown to 66–89%.

In 2013 the average 'Gale' proportion in all mixtures at N50 was 17%, in the second year it was 39% and in the third year were 51%. At fertilization level N0 the red fescue cv. 'Kauni' and festulolium cv. 'Hykor' less competitive (Fig. 1).

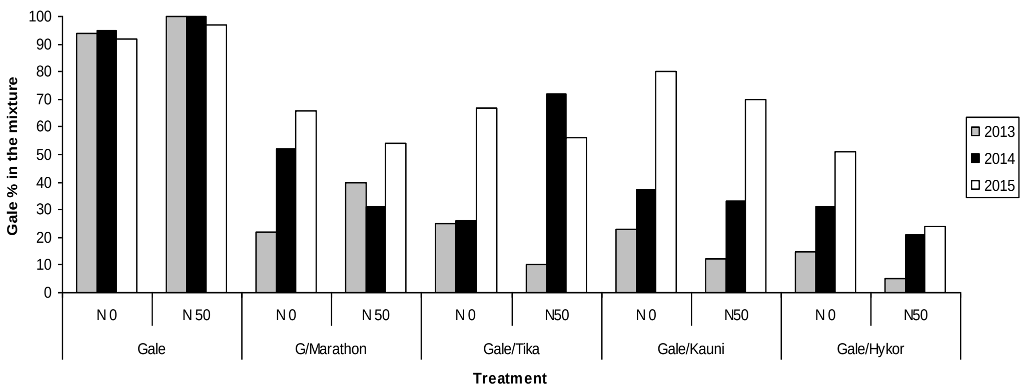

Figure 1. The botanical composition of galega-grass mixture (DM yield) of the first cut in 2013–2015.

In the second cut the highest competitivity was shown by the festulolium cv. 'Hykor' and the reed canary grass cv. 'Marathon' at N50 fertilization level.The red fescue cv. 'Kauni' and timothy cv. 'Tika' were less competitive (Fig. 2).

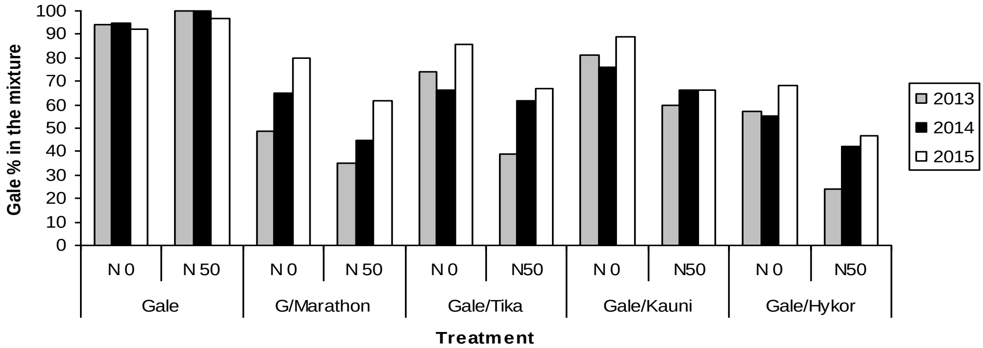

Figure 2. The botanical composition of galega-grass mixture (DM yield) of the second cut in 2013–2015.

The yield of galega harvested at the end of flowering (in the beginning of July) is less valuable, due to the high fiber content. Therefore, it is suitable for baling to produce bioenergy. Earlier results have shown (Meripõld et al., 2016) that growing galega in mixtures with grasses three-cut system improves the nutritive value and ensiling properties of forage crop. In general, the chemical composition of mixtures was mainly dependent on fertilization level and 'Gale' proportion (Table 3). Lower CP concentrations in mixtures (94–105 g kg^{-1} DM) were found in treatments when N fertilizer was not used. The fertilization level N50 increased the CP (100–134 g kg^{-1} DM) concentration. The NDF concentration in the DM varied from 495–554 g kg^{-1}. Both DM yield and NDF were dependent on the year, mixture, cutting time and fertilization. Therefore, the ADF and NDF concentrations were higher in treatments where 'Gale' proportion was higher and in 'Gale'-'Marathon' treatment, obviously due to high fibre concentration of reed canary grass. N50 fertilization favoured grass growth and reduced the role of galega in the sward. As a result of the experiment, it can be concluded that if the first cut was made at the end of flowering period of galega and the second cut in the beginning of October, it is advisable to use the first cut as a bioenergy crop and the second cut as forage.

Table 3. The chemical composition of the fodder galega-grass mixtures of first cut (DM) in 2013–2015

Mixture	Average of 2013–2015			
(Varieties)	N rate, kg ha^{-1}	CP, g kg^{-1}	NDF, g kg^{-1}	ADF, g kg^{-1}
Gale	N0	178	495	439
	N50	170	489	408
Gale/Marathon	N0	99	545	396
	N50	118	553	384
Gale/Tika	N0	96	524	391
	N50	105	544	369
Gale/Kauni	N0	105	541	424
	N50	134	520	387
Gale/Hykor	N0	94	509	392
	N50	100	554	371

'Gale' inclusion in mixtures stabilized summer yields due to the better growth of 'Gale' during summer months.

CONCLUSIONS

The galega-grass mixtures maintained high yielding ability and nutritive value over several years. The chemical composition of mixtures was mainly dependent on fertilization. N fertilization rate 50 kg ha^{-1} favoured grass growth but reduced the role of galega in the sward. On the basis of these results, fertilization rate of N50 should be recommended in order to avoid grasses being lost from the sward and to prevent N deficiency in the spring. The higher yielding ability and similar higher NDF was obtained in 'Gale'-'Hykor' and 'Gale'-'Marathon' mixtures. As a result of the experiment, it can be concluded that if the first cut was made at the end of flowering period of galega and the second cut in the beginning of October, it is advisable to use the first cut as a bioenergy crop and the second cut as forage.

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Risk analysis regarding a minimum annual utilization of combine harvesters in agricultural companies

M. Mimra* and M. Kavka

Czech University of Life Sciences Prague, Faculty of Engineering, Department of Machinery Utilisation, Kamýcká 129, CZ165 21 Prague 6–Suchdol, Czech Republic
*Correspondence: mimra@tf.czu.cz

Abstract. This article presents the results of entrepreneurial risk analysis concerning a minimum annual utilization of harvesters in a company providing agricultural services where a group of combine harvesters is used. Furthermore, this article presents the following analysed key operating parameters with the greatest influence on reaching the minimum annual utilization and performance: the changing market price of mechanized work, the volatile purchase price of the machines, average maintenance costs).

Partial profit which an enterprise can reach through operating combine harvesters is directly affected by the level of their annual utilization. Not reaching the minimum annual utilization of combine harvesters would create losses that could result in termination of business activity in the specific field or even insolvency of the company. It is therefore necessary to monitor the key factors which influence the minimum annual usage and in case of negative developments to take timely corrective actions.

Key words: combine harvester, data modelling, key parameters, profit, business risk, agriculture, machinery utilization, business profitability.

INTRODUCTION

Accomplishment of minimum annual utilization of combine harvesters is always associated with some risk and uncertainty, which is caused by natural, biological, technological and technical parameters.

Based on the on-farm time motion studies Sørensen (2003) stated harvesting costs make up 30% of overall in-field machinery costs. The machinery performance (field efficiency) varies from 63 to 81% and is influenced by a number of technical and biological factors. These factors include the basic theoretical capacity as determined by the machinery size and the working speed, the shape and size of smaller fields, the traveling pattern in terms of subdivisions of the field, combine maneuverability, crop conditions, operator skill, etc. An increase in the field efficiency from, for example, 0.5 to 0.9 in terms of a combine with improved maneuverability, better reliability of the technical components, increased field size and more regular field shape, etc. implies a 30% reduction in costs, all other things being equal. Undercapacity is 50% more costly than overcapacity.

As mentioned by Edwards & Boehlje (1980) whatever the farm type, field machinery capacity should be large enough to complete operations on time not only under ‘average weather conditions’ but also in difficult seasons, without incurring excessive costs. However, establishing the ‘appropriate’ size of single machines in a machinery system is a difficult question as specific machinery costs are closely related to timeliness costs, which in turn are linked to available field workdays, the most uncontrolled and unpredictable variable affecting field operations.

Jánský et al. (2012) discovered that at the production of silage from perennial fodder plants the following factors account for the highest part regarding the average primary costs: employment of machinery operation (25.7%), labour costs (22.2%), overhead (17.7%) along with other direct costs and services (10.1%). Kavka et al. (2010) stated that the size of the fixed costs is also influenced by the service life of the machines. There is a decrease in fixed costs at the same annual performance (e.g. 1,000 ha per annum) when the period of usage of the machinery is extended (one machine is in operation for e.g. 10 years instead of 6 years only).

Gleissner & Berge (2004) defined an algorithm of random-numbers generation based on predetermined conditions and statistical distribution in order to model the risky situation. Montaser & Moselhi (2014) stated that most forecasts concerning use of machines use deterministic or stochastic approaches, which are based on historical data. Therefore, according to Koenker & Hallock (2001), it is necessary to establish 1) a pessimistic 2) an expected and 3) an optimistic estimate of the analysed situation. Only then can the data be used for modelling a triangular distribution. In view of the complexity of this issue, which is clear from the previous literature review, the main aim of this article is to perform a risk analysis using stochastic simulation methods and to assess the impact of key parameters to achieve a minimum annual utilization of combine harvesters.

MATERIALS AND METHODS

Key parameters are determined based on the results of the cost analysis. The analysis of the operational area is used in order to determine the break-even point. The results of these analyses carried out showed that the following factors had the greatest impact on both the average annual gain from the partial operation of combine harvesters and the unit costs of the combine harvesters:

– a change in the price of services provided by combine harvester,
– the annual performance of combine harvesters,
– combine harvesters purchase price, and
– the cost of fuel.

For these key parameters, a risk analysis was conducted focused on the achievement of a minimum annual utilization of combine harvesters. To calculate the minimum annual utilization of combine harvesters, calculations were done according to Kavka (1997) and Rataj (2005). The annual costs (see Eqs 2 and 3) reflect the change of the annual performance combine harvesters, purchase price and the cost of fuel and lubricants. Based on the above findings, an analysis of the risk of achieving minimum annual utilization of combine harvesters was carried out (see Eq. 1).

$$aWmin = \frac{aCf}{Ph - uCv}\ [\text{ha year}^{-1}] \quad (1)$$

where

$$aCf = aCd + aCioc + aCibl + aCai + aCci + aCg\ [\text{CZK year}^{-1}] \quad (2)$$

$$uCv = uCm + uCfl + uCp\ \ [\text{CZK year}^{-1}] \quad (3)$$

$aWmin$ – minim annual performance [ha year^{-1}]; aCf – annual fixed costs [CZK year^{-1}]; Ph – price of harvest [CZK ha^{-1}]; uCv – unit variable costs [CZK ha^{-1}]; aCd – annual depreciation costs [CZK year^{-1}]; $aCioc$ – annual costs on interest of own capital [CZK year^{-1}]; $aCibl$ – annual costs on interest of bank loan [CZK year^{-1}]; $aCai$ – annual cost of accident insurance [CZK year^{-1}]; $aCci$ – annual cost of compulsory insurance [CZK year^{-1}]; aCg – annual cost of garaging [CZK year^{-1}]; uCm – unit maintenance costs [CZK ha^{-1}]; $uCfl$ – unit cost of fuel and lubricants[CZK ha^{-1}]; uCp – unit personal costs [CZK ha^{-1}].

The paper is based on the principle of the neoclassical economic theory. It considers maximisation of the company's annual profit as the main criterion for enterprise decision making. This criterion is extended to take account of the risks to the business. The risk analysis uses the stochastic Monte Carlo simulation method for generating random variables with the probability distribution of criterion variable using a triangular distribution at a significance level of 0.05. Random variables of the operating parameters are generated for one million high-risk situations. The key parameters are the lilting of ± 10% of the most common value (with regard to the analysis for risk factors, the triangular distribution is utilized). This defines the boundaries of the pessimistic and optimistic value of variables (annual usage, cost of mechanised labour, variable unit costs and fixed annual costs). Modelling is carried out in MS Excel. Performance and operating parameters were monitored during the period 2009 to 2012 with a group of three combine harvesters: John Deere model 9880i STS (hereinafter referred to as 'JD 9880i STS'), John Deere model S 9660 WTS ('JD S 9660 WTS') and John Deere model S 690i ('JD S 690i'). Data obtained from this monitoring is used in the analysis.

RESULTS AND DISCUSSION

The analysis of the sensitivity of the individual combine harvesters showed that the greatest impact on achieving minimum annual utilization at the desired profit resulted from the cost of mechanized work (this factor ranged from 63.8 to 65.8%), followed by the unit variable costs (this factor ranged from 27.3 to 31.7%) and the annual fixed costs (the effect ranged from 4.5 to 6.9%).

Risk analysis with regard to achieving a minimum annual utilization of a group of combine harvesters

In the next step, the risk analysis for all three combine harvesters was carried out based on average risk parameters and the annual performance required for all three combine harvesters. In this case, the three combine harvesters made up one investment unit. Combine harvesters are used in the enterprise as individual units and in combination with machine lines.

Fig. 1 depicts a graph of the probability of distribution of frequencies necessary to reach a minimum annual utilization in connection with the generated random variable risk factors and the probability of achieving them. The probability distribution of the output variable is interspersed with the most appropriate type of theoretical distributions. Here we see the most effective binomial distribution (green curve in the graph). The parameters of theoretical probability distributions are given in the Table 1. The graph shows that the highest value regarding the probability of achieving a minimum annual utilization is 3.7%. Furthermore, the basic average annual utilization of 697 ha year^{-1} is achieved with a probability of 50.48%.

The results of the sensitivity analysis show conclusions similar to the results of analysis individual combine harvesters. That is, the greatest impact on achieving minimum annual utilization has mechanized labor costs of 64.6%, followed by the unit variable costs of 29.8% and fixed costs by 5.6%.

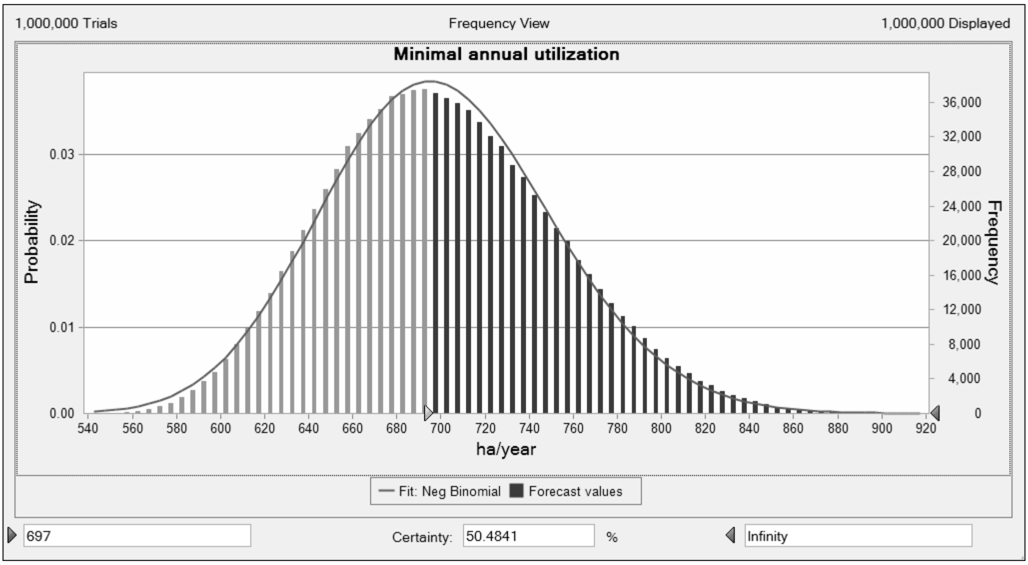

Figure 1. The distribution curve shows the risk probability with regard to achieving a minimum annual utilization for the John Deere group combines.

Table 1 presents basic statistical characteristics of theoretical binomial distribution. Further, the statistical characteristics of the simulated values are indicated. As can be seen from the values in table 1, the minimum annual utilization of combine harvesters is 540 ha year^{-1}, maximum 919 ha year^{-1}, the arithmetic average of 700 ha year^{-1}, median of 697 ha year^{-1} and modus 691 ha year^{-1}. Scattering is 2,695 ha year^{-1}, standard deviation of 52 ha year^{-1}, the variation coefficient of 0.0742, skewness 0.2573 and kurtosis 2.81. Kurtosis exceeds 1, so the probability is distributed around a mean value denser and steeper than it is outside the normal distribution. Graph is slightly deflected to the right when the average value is higher than the median. Harvester operated jointly as an investment unit should probably not achieve the required minimum annual usage even when there is a negative development of risk factors within a defined range.

Table 1. Statistical processing of risky situations concerning the average minimum annual utilization and parameters of theoretical probability distribution

Statistic	Fit: Neg Binomial	Forecast values
Trials	---	1,000,000
Base Case	---	697
Mean	700	700
Median	698	697
Mode	695	691
Standard Deviation	52	52
Variance	2,701	2,695
Skewness	0.1678	0.2573
Kurtosis	3.04	2.81
Coeff. of Variation	0.0743	0.0742
Minimum	144	540
Maximum	Infinity	919
Mean Std. Error	---	0

Fig. 2 shows a graph of cumulative frequency risks with regard to achieving minimum annual utilization. The graph shows that the value of the basic minimum annual utilization of 697 ha $year^{-1}$ will be achieved with a probability of 50.48%. Group of combines should probably achieve a basic minimum annual utilization and negative developments in risk factors within a defined range.

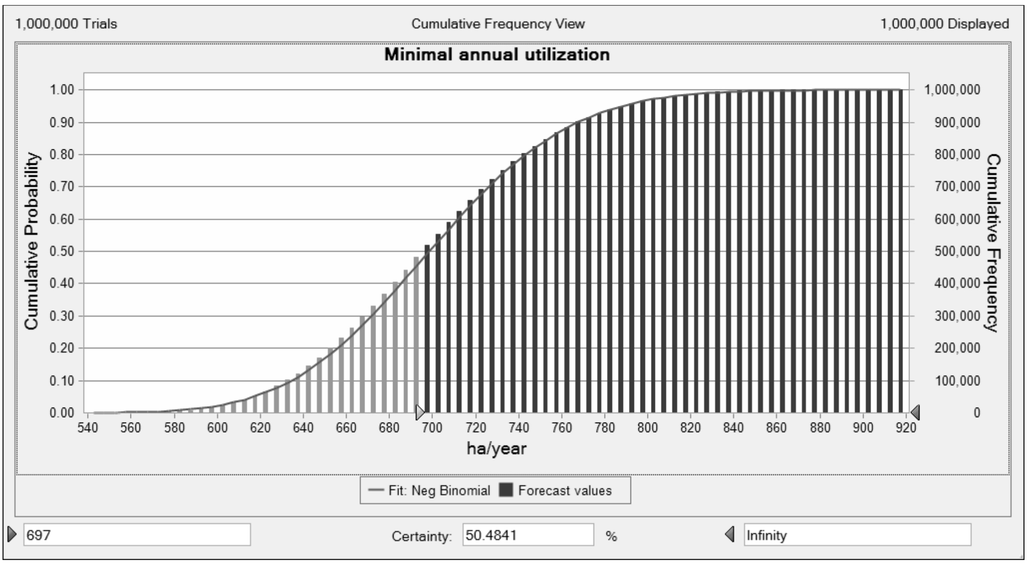

Figure 2. Graph depicts the cumulative frequency distribution of risk probability of achieving an average value of the minimum annual utilization of combine harvesters.

Table 2 presents the probabilities for different values in increments of 10% of the predicted extent of achievement of a minimum annual utilization for the whole group combines. From this table it can be determined with a specific degree of probability which values result when the minimum annual utilization is achieved by a group of combine harvesters.

Price of mechanized work is influenced by many factors, among others: competition from other service providers in a given place and time, supplier-customer relationships, weather conditions, type of combine harvesters, the size and slope of the land, humidity and vegetation, whether straw is crushed or not, as well as the type of crop being harvested. Therefore, it is necessary to look for possible savings in cost items and increase the annual use of combine harvesters in order to avoid generating negative partial profit.

Table 2. The probability of achieving annual minimum extent of utilization of the group combines

Percentile	Fit: Neg Binomial	Forecast values
100%	144	540
90%	634	634
80%	656	655
70%	672	670
60%	685	684
50%	698	697
40%	712	711
30%	726	726
20%	743	744
10%	767	769
0%	Infinity	919

Purchase prices of combines in the period 2006–2015 are based on the catalog prices that machinery dealers provided (in Table 3). The prices are affected by inflation, exchange rate, competition among manufacturers, technological advances and numerous other factors. The following table 6 shows the evolution of the purchase price of the combine harvester JD 9880i STS until 2007, when it ceased production. Subsequently, since 2008 harvester JD S 690i has been the successor model. The purchase price of the combine harvester JD 9660 WTS in 2006, when it ceased to produce, has been replaced by the price of the combine harvester JD W650, which became its successor since 2007. As table 6 shows, development of the purchase prices is quite variable. The largest annual decline occurred between the years 2012–2013 with JD S 690i by -6.44% (i.e. in total -570 thousand CZK), while the largest increase occurred between 2011–2012 by 18.16% (i.e. in absolute terms by 1,360,000 CZK). When comparing the change in the purchase price of the combine harvester JD S 690i between the years 2008–2015, we see a growth of 24.29%. Concerning the combine harvester JD W650, the purchase price in 2015 increased compared to 2007 by 27.31%. Therefore, every agricultural company must pay close attention to this parameter.

Table 3. The development of the purchase prices of combine harvesters in the years 2006–2015

Year	Purchase price of JD 9880i STS/ JD S 690i [mil. CZK^{-1}]	Annual change in purchase price [%]	Change in the purchase price compared with 2006 [%]	Purchase price of JD WTS 9660/ JD W650 [mil. CZK^{-1}]	Annual change in purchase price [%]	Change in the purchase price compared with 2006 [%]
2006	6.790			4.640		
2007	7.070	4.12	4.12	4.650	0.22	0.22
2008	7.370	4.24	8.54	4.560	-1.94	-1.72
2009	7.610	3.26	12.08	4.780	4.82	3.02
2010	7.800	2.50	14.87	5.610	17.36	20.91
2011	7.490	-3.97	10.31	5.580	-0.53	20.26
2012	8.850	18.16	30.34	5.330	-4.48	14.87
2013	8.280	-6.44	21.94	5.290	-0.75	14.01
2014	8.800	6.28	29.60	5.577	5.43	20.19
2015	9.160	4.09	34.90	5.920	6.15	27.59

Source: Catalog prices of dealers.

CONCLUSIONS

An economic model was created in order to emulate the minimum annual utilization of the combine harvesters using MS Excel. Based on the results of the sensitivity analysis, the key factors were determined. For these factors, the risk of not achieving the desired minimum annual utilization was subsequently determined. For the simulated situation, the key factors were activated within the range of ± 10% using a triangular distribution of these values. The result of this analysis showed that the most frequent value of the basic minimum annual utilization of 697 ha year^{-1} is achieved with a probability of 50.48%. The overall outcome of the combine harvesters should be profitable.

There is a risk with regard to the probability of achieving or failing common values set for an annual performance. In order to avoid financial losses, it is important in advance to assess properly the risk of not reaching an annual performance and the planned income. Minimal annual utilization has serious effects on achieving positive economic results. Szuk & Berbeka (2014) reported on the basis of the analyses, that for a business which does not reach the required minimum usage, it is more economical to buy a used combine harvester.

Therefore, in acquiring combines, it is necessary to pay attention to those parameters that may affect it. As the sensitivity analysis showed, the price of mechanized work, variable unit costs and fixed unit costs had the greatest influence on the desired economic result. These parameters affect revenues and costs which determine the break-even point. Given the seasonality of the deployment of combine harvesters, it is necessary for the company to attempt to maximize the annual utilization. Zacharda and Pepich (2002) discovered in their research that the performance of combine harvesters operated in the services is up to 99% higher (834.8 hectares, while in agricultural enterprises it is only 419.4 hectares per year). In addition, it is necessary to seek further opportunities to increase the annual use of combine harvesters. When creating a business strategy, it is important to decide how much risk is acceptable for the company. Doing business in the agricultural sector is always associated with some risk and uncertainty. In view of its biological nature and the number of influential factors, agribusinesses are very risky. Based on our experience, we can state that the company can accept a risk in the range of 0–60%. The sub-profit of the enterprise arising from the operation of the combine harvesters is directly influenced by their accomplished annual utilization.

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Influence of raw material properties on the quality of solid biofuel and energy consumption in briquetting process

A. Muntean[1], T. Ivanova[1,*], P. Hutla[2] and B. Havrland[1]

[1]Czech University of Life Sciences, Faculty of Tropical AgriSciences, Department of Sustainable Technologies, Kamýcká 129, CZ 16500 Prague, Czech Republic
[2]Research Institute of Agricultural Engineering, Drnovská 507, CZ 16101 Prague, Czech Republic
[*]Correspondence: ivanova@ftz.czu.cz

Abstract. The present paper is related to a pressing process research of raw materials with different density in order to investigate impact of biomass density on a formation of monolithic structure and the briquette's strength. Another focus of the study is an influence of raw materials particles' size on agglomeration process and quality of final product. Different biomass materials like two varieties of miscanthus, industrial hemp and apple wood were selected for experimental purposes of this research. Mechanical durability which represents one the main indicator of briquettes' mechanical quality (strength) was determined. The research was conducted using hydraulic piston briquetting press. For assessment of briquetting efficiency during the whole process energy consumption was measured. One of the most important factors that can affect briquetting process is the temperature of pressing chamber which was registered as well. The main goal of the research was practical study of possibilities for increasing production efficiency and quality of briquettes on hydraulic piston briquetting press with respect to optimization of particles' size of raw materials and use of raw materials the most appropriate density.

Key words: briquettes, bulk density, densification process, initial fraction, mechanical durability, piston press.

INTRODUCTION

In comparison with liquid and gaseous biofuels, today, densified solid biofuel in the form of briquettes gained wider application. This has happened primarily due to the fact that above mentioned type of biofuel is easier to produce and also thanks to an attractive price (Havrland et al., 2011). Solid biofuels market is developing rapidly year by year. The growing trend of solid biofuels' consumption will continue to increase, and not only in EU countries but also around the world. Nowadays, because of large quantities production of briquettes a number of problems associated with their quality and high energy consumption of the production process have been identified (Ivanova et al., 2013). The reason is a lack of sufficient information about an impact of raw material properties on the quality of solid biofuels (briquettes) as well as on energy consumption.

There are different factors that can have direct impact on the quality of final product. For example, quality can be influenced by moisture content of used raw material

(Guo et al., 2016). In some studies it was found that the working pressure of briquetting equipment affects formation of the bonds between particles of a material and as a result it has influence on the density of briquettes (Ndiema et al., 2002; Križan et al., 2014).

Temperature in a certain extent represents an important factor in the process of forming the dense structure from biomass material during pressing (Rynkiewicz et al., 2013; Križan et al., 2014).

Fraction size of feedstock material can be also considered as an important factor with influence on the durability of densified solid biofuel (Kaliyan & Morey, 2009).

Possibly, the most suitable and reliable way, which might significantly affect quality of briquettes and reduce energy consumption within briquettes' production is an optimization of fraction size of used raw material and utilization of raw materials with optimal density for a certain briquetting technology.

An important aim of the research was to investigate influence of raw materials fraction size and bulk density as well as temperature within briquetting process on the quality of briquettes with a special attention to the energy consumption of the process.

MATERIALS AND METHODS

Application of raw materials with different density for production of solid biofuel can have influence not only on the costs for transportation and storage but also on the quality of a final product. For research purposes were used raw biomass materials with different densities, i.e. low, medium and high density, such as:

- Industrial hemp (*Cannabis sativa* L.) – fibrous material with low density;
- Two varieties of miscanthus (*Miscanthus x giganteus* and *Miscanthus sinensis*) – herbaceous materials with medium density;
- Apple (wood) branches obtained after pruning – marital with high density.

Determination of bulk density of selected raw materials was performed in accordance with International standard EN ISO 17828 (using measuring container with stated volume) and calculated by following Eq. (1):

$$BD_{ar} = \frac{(m_2 - m_1)}{V}, \text{ kg m}^{-3} \quad (1)$$

where m_1 – mass of the empty container, kg; m_2 – mass of the filled container, kg; V – net volume of the measuring container, m^3.

The final result of bulk density for each type of tested material was calculated as the mean value of the duplicate determinations (performed within a short period of time, but not simultaneously), and with repeatability precision equal to a maximum 3.0%.

One of the most important parameter of raw material that can have influence on the briquetting process and the quality of solid biofuel is moisture content. Determination of moisture content was done in accordance with standard EN ISO 18134–3 (oven drying method under the temperature of 105 °C performed on general analysis test samples prepared by EN 14780:2011) using drying oven Memmert UFE 500 and determined by Eq. (2):

$$W = \frac{(m_2 - m_3)}{(m_2 - m_1)} \cdot 100, \% \quad (2)$$

where m_1 – the mass of the empty dish plus lid, g; m_2 – the mass of the dish with lid plus sample before drying, g; m_3 – the mass of the dish with lid plus sample after drying, g.

The resulting moisture content was found as the mean of duplicate determinations with respect to repeatability precision, i.e. difference between two individual results of each material was not more than 0.2% absolute.

All raw materials used for briquetting was grinded by the hammer mill SV 15 in three different fractions: 12 mm, 8 mm and 4 mm. Grinding of raw materials into fractions was performed in order to study influence of material's rheology and impact of various fractions' size on the agglomeration process. The briquetting itself was conducted using hydraulic piston briquetting press Briklis HLS 50.

During the briquetting process the temperature was measured by digital thermometer THERM 2246 in three different points (inside the pressing chamber, temperature of die and temperature of briquette). And energy consumption of briquettes' production process was determined through measuring the electric energy by electricity meter.

The main indicator of briquettes quality (strength) is mechanical durability, which was determined according to standard EN ISO 17831–2:2015 with respect to EN ISO 16559:2014, by using rotation drum and calculated as (3):

$$DU = \frac{m_A}{m_E} \cdot 100, \% \tag{3}$$

where m_A – the mass of sieved briquettes after the drum treatment, g; m_E – the mass of pre-sieved briquettes before the drum treatment, g.

Mechanical durability for each type of briquettes obtained from the studied materials grinded into different fractions was reported as the mean value from the results of the five replications.

RESULTS AND DISCUSSION

Fig. 1 below presents the values of bulk densities of four studied materials and different fractions.

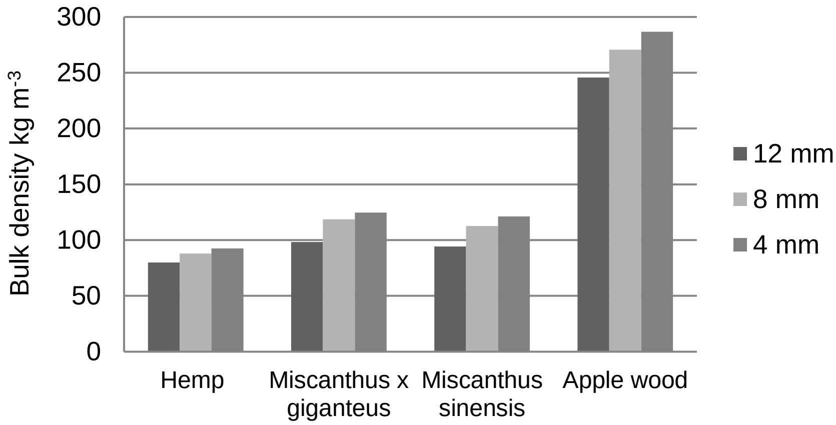

Figure 1. Bulk density of selected raw materials grinded into three different fractions.

As it is visible from the Fig. 1, the study has found that the raw material with the lowest bulk density is hemp, which shows the minimum density 79.9 kg m^{-3} for fraction 12 mm and maximum density 92.7 kg m^{-3} for fraction 4 mm. Material crushing to smaller fraction can increase the bulk density but in the same time will need more expenses for more steps of crushing (Guo et al., 2016). The highest bulk density from the studied materials has apple wood with a minimum density 245.7 kg m^{-3} for fraction 12 mm and maximum 286.8 kg m^{-3} for fraction 4 mm.

Raw materials with low bulk density applied for production of solid biofuels require more expenses for processing in comparison with raw materials with high bulk density (Havrland et al., 2011). Grinding and densification can significantly decrease volume and as a result costs for storage, transport and utilization of biomass (Guo et al., 2016). It must be also mentioned that initial bulk density of feedstock has influence on the density of final product, i.e. briquettes.

According to Havrland et al. (2011) moisture content can have significant effect on solid biofuel's proprieties, for example high moisture content of produced briquettes will decrease the calorific value, as well as high moisture content may negatively impact on densification process and briquettes storage. Moisture content of studied biomass materials is presented in Fig. 2.

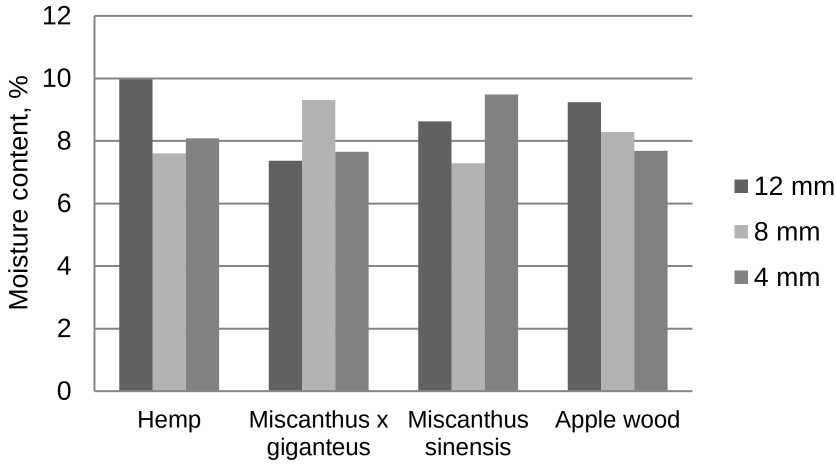

Figure 2. Moisture content of researched raw materials.

The results showed that the moisture content of raw materials used for briquetting purposes was varying between the lowest one 7.29% for *Miscanthus sinensis* with fraction 8 mm and the highest one 9.97% for hemp with fraction 4 mm (see Fig. 2). These values of moisture content are suitable for biomass briquetting (usual moisture content recommended by the producers must be not more than 12–14%, it depends on the applied briquetting technology (Havrland et al., 2011)). Moderate amount of moisture in a feedstock can positively affect the binding mechanism of biomass particles (Kaliyan & Morey, 2009). All raw materials used in the research were dried under natural conditions. Additionally, according to EN ISO 17225–3:2014 and EN ISO 17225–7:2014 in correspondence with EN ISO 17225–1:2014 moisture content of wood briquettes as well as non-woody briquettes should be 12% for A class and ≤ 15% for B class briquettes.

The briquettes of poor mechanical quality are characterised by high crumbling and that contributes to the losses during handling and transportation (Ivanova et al., 2014). The results of the main parameter of mechanical quality (mechanical durability) of obtained briquettes are illustrated in Fig. 3.

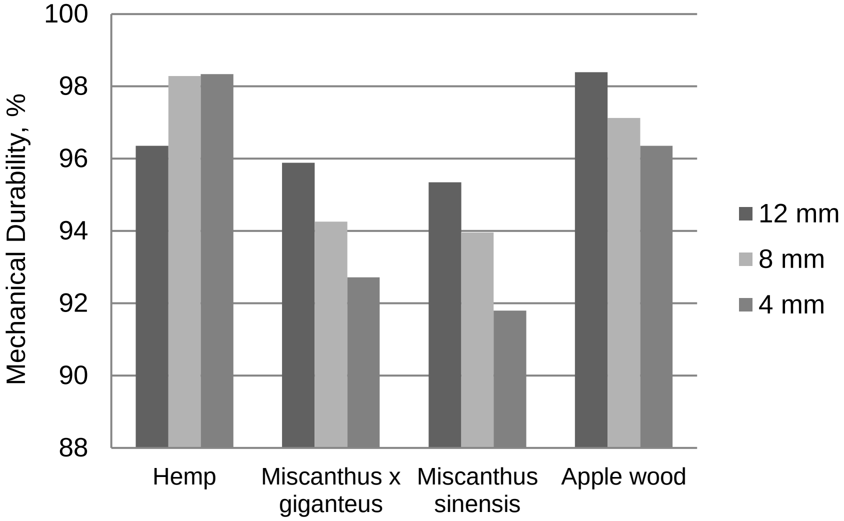

Figure 3. Mechanical durability of produced briquettes.

Based on the mechanical durability test results it was found that the briquettes obtained from hemp and apple tree wood represent the briquettes with the highest strength. The briquettes produced from *Miscanthus x giganteus* and *Miscanthus sinensis* showed lower mechanical durability. Relatively low mechanical durability of Miscanthus was also shown in another scientific works (Ivanova et al., 2014). However, as it may be seen from the Fig. 3 all the obtained briquettes had mechanical durability higher than 91%. In most cases, briquettes made from raw material with the largest fraction of 12 mm proved to be much durable than the briquettes obtained from a biomass crushed into a smallest fraction. But not in the case of hemp, which have showed an opposite trend. Different agglomeration mechanism and high strength of briquettes made of hemp can be probably explained by fibrous structure of this biomass material.

Energy consumption in the process of biomass densification is an important factor which can have an influence on the price of a final product. Today, many studies are performed in the field of briquetting in order not only to improve the quality of the final product, but also for reducing the energy consumption of the process (Kaliyan & Morey, 2009). Specific energy consumption for production of briquettes from different feedstock and fraction size is presented in Fig. 4.

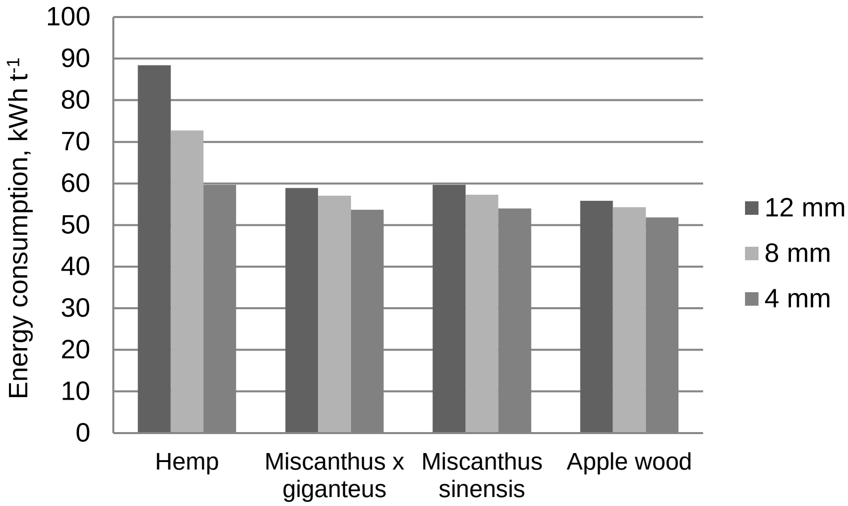

Figure 4. Energy consumption for production of 1 t of briquettes from each type of material.

Assessment of specific energy consumption has showed that pressing of all raw materials with a fraction size of 12 mm requires more energy in comparison with energy consumption for the factions 8 mm and 4 mm. Various scientific studies, for example Guo et al. (2016) proved that this may be related to lower density of the feedstock. Another factor that can hinder the effective pressing process is the effect of relaxation of the pressed material (Ndiema et al., 2002).

By some research results of densification process, specifically Kaliyan & Morey (2009) and Križan et al. (2014) it was found that the temperature produced in the briquetting process can have impact on the quality of solid biofuel. For analyzing the influence of temperature on the quality of the briquettes' formation during the briquetting process the temperatures of the pressing chamber, die and briquettes were measured. Only maximum achieved values of temperatures were registered. The research results are presented in the Table 1 below.

According to Havrland et al. (2011) increasing of the temperature values in the briquetting process happens due to the friction which appears in the process of biomass movement through the channel of the die. In the present research the highest registered temperature was 59 °C. This temperature was achieved during the briquetting of apple tree wood. This is probably related to the high density of wooden material and as a result appearance of higher friction force between densified biomass and the wall of the die.

Another important parameter of briquetting process is a working pressure developed by briquetting press. It must be mentioned that with an increasing pressing pressure increases not only density of solid biofuel (Wrobel et al., 2013; Zvicevicius et al., 2013), but also energy consumption (Havrland et al., 2011). The working pressure of hydraulic briquetting press used in the research is low (12 MPa) in comparison with another types of presses that can develop pressing pressure of 130 MPa.

Table 1. The measured temperatures in the process of biomass densification

Type of raw material	Temperature of pressing chamber, °C	Temperature of die, °C	Temperature of briquette, °C
Hemp with fractional size:			
-12 mm	29.3	44.1	31.1
-8 mm	31.9	46.6	36.5
-4 mm	34.5	51.0	40.0
Miscanthus x giganteus with fractional size:			
-12 mm	30.3	48.4	38.0
-8 mm	32.4	50.0	39.6
-4 mm	33.8	51.9	42.7
Miscanthus sinensis with fractional size:			
-12 mm	31.0	50.2	39.1
-8 mm	33.9	51.9	41.0
-4 mm	34.9	52.0	41.8
Apple wood with fractional size:			
-12 mm	30.4	54.7	41.2
-8 mm	33.7	57.7	46.2
-4 mm	39.7	59.0	47.6

CONCLUSIONS

Densified solid biofuel in the form of briquettes represents an advantageous fuel with big potential of use, but in the same time it requires more attention and further study in order to increase quality and improve the energy efficiency of its production.

In the frame of research it was found, that bulk density of initial raw material can have influence on the quality of final product and on increasing values of temperature in the process of briquetting. With decreasing particles' size of raw material (fraction) by grinding with hammer mill the bulk density increases. Also an essential can be the reduction of energy consumption in the process of biomass densification by optimization of feedstock fraction size. But in the same time grinding of biomass into very small fraction is associated with additional costs in the briquettes' production process and the quality of briquettes (mechanical durability) may be relatively low. The research showed that the durability of briquettes produced from *Miscanthus x giganteus*, *Miscanthus sinensis* and apple tree wood with fraction size 12 mm are of better quality than briquettes made from the materials with smaller fraction size 8 mm and 4 mm. Utilization of raw material with smaller fraction size affected positive only mechanical durability of briquettes made from hemp.

At the end it can be mentioned that for better understanding of an influence of initial raw material's fraction size and its proprieties on the quality of briquettes and energy efficiency of the production process much more factors should be studied.

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Verification of mathematical model of pressure distribution in artificial knee joint

V. Novák[1], D. Novák[2], J. Volf[1,*] and V. Ryzhenko[1]

[1]Czech University of Life Sciences Prague, Faculty of Engineering, Kamýcká 129, CZ165 21 Prague, Czech Republic
[2]Matej Bel University, Faculty of Natural Sciences, Department of Technology, Tajovského 40, SK974 01 Banská Bystrica, Slovakia
[*]Correspondence: volf@tf.czu.cz

Abstract. The paper deals with pressure distribution measurement in knee arthroplasty, which is an artificial replacement of human knee joint. The scope of the article is to verify the accuracy of a mathematical model by real measurements. The calculated pressure values basing on the mathematical model are compared with actually measured pressure values in the contact area of the joint. Hereby maximal load the in the contact area, the distribution of the pressure and any potentially dangerous pressure deviations during the walk cycle are checked. To enable accurate pressure distribution measurement without interfering into human's body, a sophisticated measuring setup was created: the contact area of the joint was equipped with several pressure sensors and a machine simulating the human walk cycle was used. The measured pressure data are finally compared with those from the mathematical model and with the strength limit of the used material, to verify the accuracy of the mathematical model experimentally.

Key words: knee arthoplasty, force sensor, artificial joint, pressure distribution, strain gage, tibial plateau.

INTRODUCTION

In some cases of a serious injury, joint disease or poor functionality of a human knee joint it is necessary to perform a total replacement of the joint with an artificial one – so called knee arthoplasty. The knee joint itself is the most complex one in human body due its complicated anatomic structure and multi-dimensional motion. To prevent a direct contact of two metallic parts within the artificial joint and to enable reasonable friction between individual parts, a polymer layer is placed within the joint, which comes into contact with the metallic part, for more information see Zach et al. (2004). As the polymer layer is especially susceptible to mechanical wear, it is necessary to check the actual pressure distribution in the contact layer and compare it with the strength limit of the material. The second scope of the measurement is to compare the measured pressures with calculated theoretical values, according to mathematical model by Zhu & Chen (2004).

In order to maintain the functionality of the leg, the replacement should meet the kinematical requirements on a healthy joint, and – as an implanted part of human's body

– it should exhibit excellent reliability to avoid repeating interventions into the body of the patient. Measurements of an already implanted arthroplasty would be virtually impossible as it would represent an excessive intervention into the patient's body. To enable measurements under nearly real conditions, a specific machine which simulates human step cycle with prescribed load was used. This way the actual pressure within the artificial joint may be determined without interfering into the body of the patient, so that a potential danger or malfunction of the artificial joint may be discovered before implanting the artificial joint into human's knee.

Unlike the previous work as presented in Volf et al. (2005), where only the maximal pressure in four points was measured, this measurement covers the entire contact area between the femoral component and tibial plateau with 22 probe positions. The scope of this work is not only to determine the possible pressure peaks, but to verify the pressure distribution in the contact area during the entire walk cycle, i.e. under changing knee angle flexion and thus under changing knee geometry.

There are possible alternative measuring techniques using a plate with matrix of capacitive pressure sensors or using a pressure sensitive foil that changes its colour according to the pressure. The advantage of relative easiness of such measurements is connected with necessarily influencing of the actual contact area, which yields unavoidable errors of the measurement. Therefore this measurement is performed without putting any material into the contact area, which ensures no geometry changes of the contact area.

MATERIALS AND METHODS

Composition of the knee arthoplasty

Most of the vital parts of the knee arthoplasty are made from metallic material (cobalt alloy – Vitalium), however, to prevent a direct contact between two metallic parts and to enable friction in the contact area between the femoral and the tibial part, the tibial plateau itself is made from Ultra-High Molecular Wide Polyethylene (UHMWPE).

New femoral components from oxide ceramic (Zirconium dioxide ZrO_2 and Aluminium dioxide AlO_2) are being developed. Metal materials are used because of their strength and elasticity, but they are not abrasion-proof and their life-cycle is shorter. Ceramic materials are bio-inert and exhibit good friction characteristic; however, their disadvantage is their enhanced fragility. Ceramic femoral component has also different geometric parameters, for more information see In the measurements, the described polyethylene - metallic combination is used, i.e. UHMWPE tibial plateau and metal femoral component. The composition of the artificial knee joint is shown in Fig. 1. Konvičková & Valenta (2000).

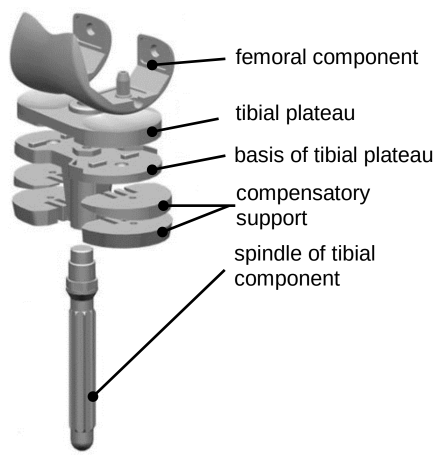


Figure 1. Composition of the knee arthroplasty.

The area which is the subject of the measurements is the contact area between the metallic femoral component and the tibial plateau made from polyethylene. This is the most vulnerable part of the artificial joint – it is the place where the most pressure concentrates, the two individual parts move relative to each and the tibial plateau is made from polyethylene which is susceptible to mechanical wear.

Mathematical model

The subject of pressure distribution in knee joint was reflected by Zhu & Chen (1999; 2004), who created a mathematical model of pressure distribution in a knee joint, more advanced model was subsequently presented by Zhu (2007). Calculations of the pressure distribution basing on the model are provided by Donát (1997) and Zach et al. (2004).

Some simulations of pressure distribution in knee joint deal with a physiologic knee, i.e. with a complete knee with muscles and fibrous apparatus. For this first verifying study, a simplified model of knee replacement which does not comprehend ligaments was used; thus the results might be slightly different according to Konvičková & Valenta (2000). The geometric model of knee replacement was created by finite element method, detailed description of this method is provided by Donát (1997).

Measurement procedure

To approximate the conditions of a real knee as much as possible and to avoid any further interventions into patient's body, a special measurement procedure was developed, consisting of two main distinctive techniques: use of movement simulator depicted in Fig. 2 and specific sensor placement.

Figure 2. Knee movement simulator machine.

The movement simulator is a PLC controlled machine that models the movements of a human knee joint under real conditions. The measurements were performed according to norm ISO 14243-3:2004(E) that prescribes exactly the movements of individual parts of the joint in relation to each other and the exerted axial force; further details about the simulation in Zhu & Chen (1999). The norm gives a relation between the walk cycle in percent with associated pressure and flexion angle values as well as the associated force value. A graphic description of individual phases of human step is depicted in Fig. 3. The measurements were carried out in steady state, gradually for each phase of the walk cycle, i.e. separately for any individual flexion angle value.

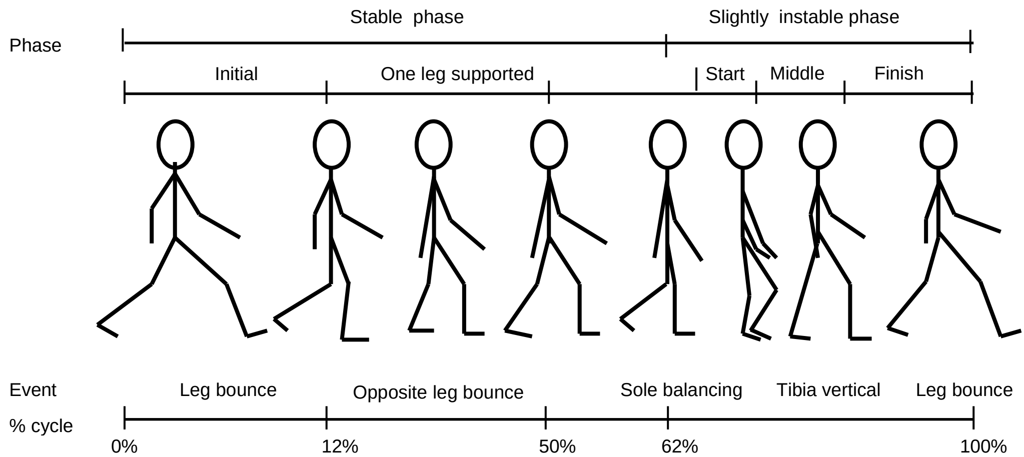
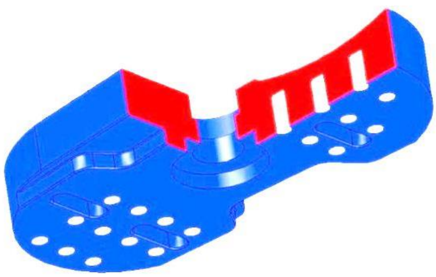


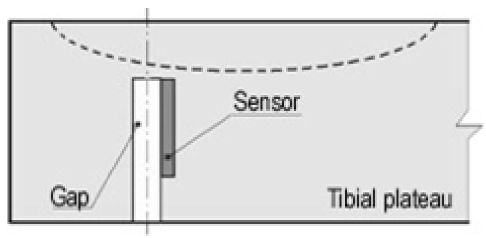
Figure 3. Phases of human step.

Sensor placement and parameters

The pressure sensors themselves placed in the artificial knee joint mustn't influence the surface shape of knee components. If sensor changes geometry of tibial plateau, it would change also the contact areas and thus contact pressures, as by Mootanah (2006) and Anderson & Lim (2006). In order to avoid any geometry changes in the contact area as discussed above, a new approach was chosen: there are bored at specified places into the polymer tibia plate several holes with 3 mm diameter and 2.9 mm bottom distance from the contact surface. A three-dimensional view on the plateau holes is displayed in Fig. 4a, and a cross-section of a hole with an attached sensor is displayed in Fig. 4b. The position of the individual holes with corresponding labeling is presented also on the top view in Fig. 5.



a)



b)

Figure 4. a) tibial plateau with bored holes for the sensors; b) cross-section of a hole with an attached sensor.

By selecting the exact number and location of individual probe holes, there are two contradictory requirements; on the one hand it was required to measure the pressure in the whole contact surface, at as many measuring points as possible. On the other hand, the number of holes and their diameter are limited in order not to influence the tension course within the material. Therefore, a compromise consisting of 22 holes spread evenly over the contact area was implemented.

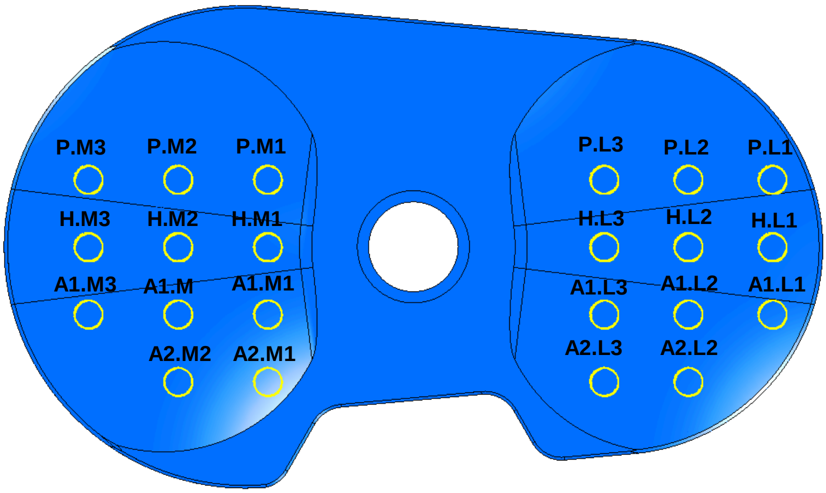


Figure 5. Position of individual holes in the tibial plateau.

For the measurements of the deformation were used monocrystalline semiconductor strain gages with N conductivity that exhibit better, more linear dependency on press deformation; further details about biomechanical measurements are in Volf et al. (2002). The used sensors were developed specially for this measurement by producer VTS Zlín, Czech Republic. This is a semiconductor strain gages of type AP120-2-12/Au/BP with a length of 2 mm.

The strain gages were placed into the prepared holes, glued and covered by silicone. Although they exhibit significant dependency of electrical resistance on the temperature and a non-linear dependency of the measured resistance on the deformation, their negatives are compensated by their accuracy and stress-fatigue resistance. The temperature error of the semiconductor was compensated by small thermometers placed into the holes.

RESULTS AND DISCUSSION

According to the output from the mathematical model by Zach et al. (2004), which is depicted in 3D view in Fig. 6, the maximal calculated pressure value is 7.04 MPa. However, the named peak pressure is concentrated in a very small area, in the close surroundings the pressure drops rapidly. Due to the setup of the experiment, where there was only limited number of probe holes, the exact point with the peak pressure cannot be hit exactly.

The mathematical model presumes static load 2,100 N and flexion angle 0°, the norm ISO 14243-3:2004(E) prescribes varying force and angle values according the actual human step cycle. Therefore, a direct comparison of the obtained data with the model is not possible; the measured values have to be recalculated. The maximal load obtained by the movement simulator is limited due to its construction to 1,730 N and the pressure values calculated by the mathematical model base on the force of 2,100 N; the force also changes during the walk cycle. And secondly, as discovered in previous experiments by Volf et al. (2005), the pressure does not always increase linearly with the force; this is given by the changing geometry of the contact area.

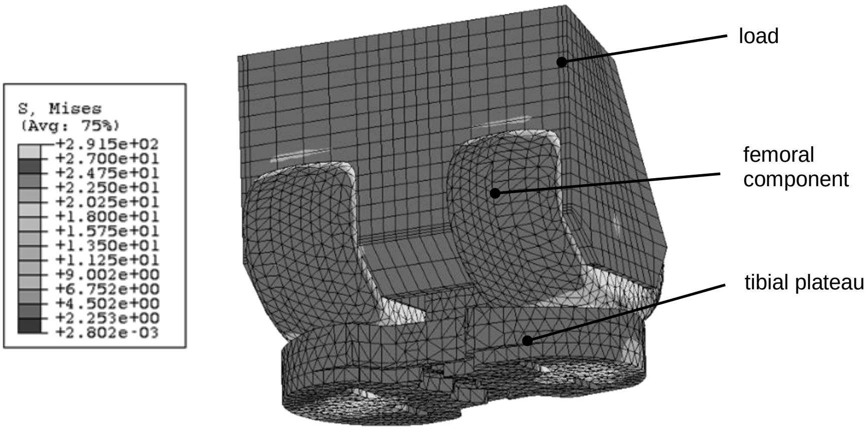


Figure 6. Geometrical model of knee arthoplasty and pressure distribution.

Considering the named limitations – varying flexion angles and exerted forces in the walk cycle vs. defined mathematical model – there have been obtained after recalculation relatively correspondent results. As the peak pressure are could not be matched exactly, the data from the nearby sensors in probe holes H.L2 and P.L3 (see Fig. 5 and Fig. 7) are presented. These recalculated pressure values are about 0.8 MPa, which is in concordance with the model that states the pressure 0.9 MPa for these points. It also has to be noted the maximal pressure values in these probe holes as seen in Figs. 7 and 8 cannot be compared with the model directly; they have to be reduced as explained above. Other probes give similar results as calculated pressure values in those points, too. Thereby the mathematical model can be considered as useful and relevant when designing joint replacements, however its accuracy is partially limited by the changing geometry of the knee joint during walk.

In the second part of our research, we focused mainly on the simulation of the movement of the joint during the walk, as the most natural and important kind of movement. The aim was to study the course of the pressure during the walk. Due to the very complex structure of the knee joint, the pressure changes significantly during the walk cycle. It is caused by combined movement of the joint, i.e. flexion, shift and rotation of the nearby parts, explained further in Zheng & Fleisig (1998). First is presented in Fig. 7 the planar distribution of individual pressure values in all sensors at 70% of the walk cycle (associated flexion is about 57.5°). The exact placement of the sensors can be seen in Fig. 5 above.

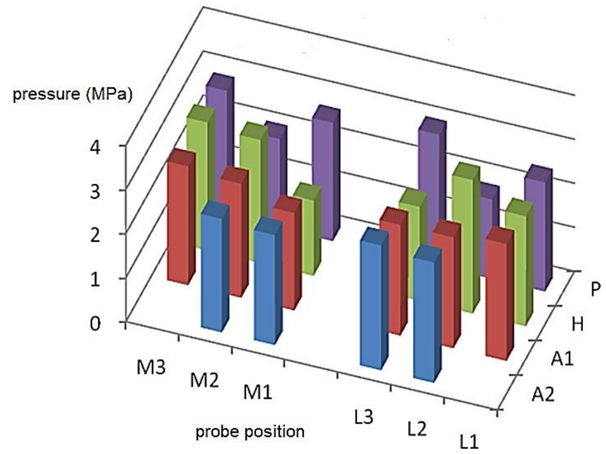


Figure 7. Measured pressure values in individual probe holes in 70% of the walk cycle.

The graph in Fig. 7 shows the planar pressure distribution over the contact area of the joint under the named conditions. The measured pressures vary from cca. 1 MPa to 2.5 MPa, the calculated pressure peak point lies between the sensors H.L2 and P.L3. The pressures are relatively high due high flexion and associated geometrical and force changes in the joint. Similar charts have been created for any individual stage of the walk according to the ISO norm, and the corresponding results are summarised in Fig. 8, which shows the course of pressure in individual probes during the walk cycle. Although the data have been measured individually for each stage of the walk cycle, because of lucidity they are connected with curves; each curve represents a data row from one sensor.

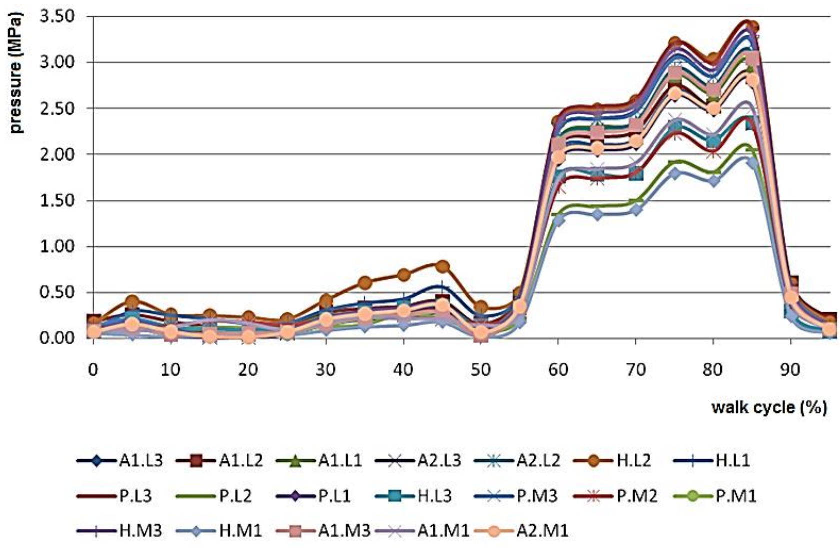


Figure 8. Measured pressure values in individual probe holes in dependency on walk cycle.

The course of pressure indicates a rapid raise at 60% of the walk cycle and a further raise at 80% of the cycle, with the peak pressure of 3.4 MPa (probe P.L3) that is the closest one to the calculated origin of force. In these stages of walk cycle the flexion increases significantly, which changes the geometry of the joint. The peak values are caused predominantly by anterior-posterior shift and by tibia rotation, which cause additional moment acting on the joint; for more detailed information see Taylor et al. (2004) and Miller & Zhang (2001).

Although the greatest load is according to ISO 14243-3:2004(E) exerted at 45% of the walk cycle (2,433.5 N), the pressure is way below its maximum at this stage. The deformation and associated pressure are compensated by low flexion angle (8.13°) and low anterior-posterior shift and tibia rotation. On the contrary, at 80% of the walk cycle, the exerted force according to the ISO norm is only 167.6 N, but the flexior reaches 47.08°, associated anterior-posterior shift is 2.38 mm and tibia rotation is 4.92°. Therefore, the peak pressure is influenced predominantly by overall kinematic changes of the joint rather than size of the force, where the flexion, shift and rotation are reflected.

According to the mathematical model, the highest calculated pressure value was 7.04 MPa, and the highest measured pressure value was 3.4 MPa, see Fig. 8. The determination of the exact point with the highest pressure would require different experiment setup and it was not the goal of our work; the aim was to determine the pressure over the entire contact area of the joint replacement components, to compare the measured values with the mathematical model and to analyse the pressure change during the walk. However, none of these values approaches to the limit stress 13 MPa of the polymer material UHMWPE from which the tibial plateau is made.

CONCLUSIONS

Pressure distribution in the knee arthoplasty – an artificial knee replacement joint, using a knee movement simulator was measured, according to the ISO 14243-3:2004(E) norm and using specific pressure sensor placement. We focused on the comparison of the measured pressure values with mathematical models developed by Zhu & Chen (1999) and calculations performed by Donát (1997) and Zach et al. (2004). The measured pressure values were in correspondence with the mathematical model given above; this mathematical model describes, with some limitations, accurately the load of knee arthroplasty and that such model can be used to design artificial joints.

Further the change of the pressure distribution in the contact area during the walk was examined. To simulate the walk a knee movement simulator was used according the norm ISO 14243-3:2004(E), which prescribes exactly the flexion and associated force values during the individual stages of the walk. Hereby were confirmed significant changes of the pressure during the walk that is given by the changing geometry of the joint.

Neither the calculated nor the measured value exceeds the limit stress of the polymer joint replacement material. Finally, no one of the sensors exhibited unexpected or unacceptable pressure peak or significant deviation from the mathematical model that could endanger the functionality of the artificial joint, and the limit stress of the material was not exceeded.

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The yield, height and content of protein of field peas (*Pisum sativum* L.) in Estonian agro-climatic conditions

M. Olle

Estonian Crop Research Institute, Department of Plant Breeding, J. Aamissepa 1, EE48309 Jogeva alevik, Estonia
Correspondence: margit.olle@etki.ee

Abstract. *Pisum sativum* L. is important protein crop in the world. The purpose of this investigation was to see whether pea varieties differ in their yield, height and content of protein. Another aim was to select the best varieties suitable for production. Field experiments with different varieties of peas ('Bruno', 'Capella', 'Clara' and 'Vitra') were carried out at the Estonian Crop Research Institute in 2014 and in 2015. Yields (t ha^{-1}) in 2014 and 2015 did not differ much, while yield from variety 'Bruno' was very different between years 2014 and 2015 and was much higher in 2015. The most suitable height of field peas is in a range of 60...100 cm, because the plants with such a height are most effectively suppressing weeds. It can be concluded that varieties with suitable height in our investigation were: 'Bruno', 'Capella' and 'Clara'. Variety 'Vitra' was too high, is lodging easily and is therefore hard to harvest. Crude protein content (% in dry matter) was lowest in 'Clara'; all other varieties had a higher content of protein, within much the same range. Based on the results of present investigation it can be concluded that out of those four varieties the most suitable varieties for production are 'Bruno' and 'Capella'. Choice of the right variety for pea cultivation is very important, but depends on the local agro-climatic conditions. As in Baltic – Nordic countries and in north of America the agro-climatic conditions are more or less similar the results are useful for those countries.

Key words: height, field pea, protein, variety, yield.

INTRODUCTION

Field peas are also known as smooth peas or specifically green and yellow cotyledon dry peas (Dahl et al., 2012). It is an herbaceous annual crop in the *Fabaceae* (formerly *Leguminosae*) family. The Mediterranean basin and the Near East are the places from where pea crop originates. Nowadays it is widely grown for its seedpod. Pea is an important human food crop (Olle et al., 2015). Dry pea production worldwide in 2014 was 11.2 Metric Tons (www.statpub.com) and in the same year pea was grown on over 7.2 million hectares worldwide (www.statpub.com). The most widely grown legume crops in the European Union are dry peas (Monti et al., 1991) and overall in Europe (Brežna et al., 2006).

Eating legumes could potentially let people live longer (Patterson et al., 2009). An increased consumption of legumes in the EU is highly desirable taking into account the high nutritional value and the beneficial health effects of legumes. Legumes contain high level of protein and adequate proportions of carbohydrates and oil making them valuable as food (Rodino et al., 2009).

The habitat quality, weather conditions during the growing season and the yielding ability of available cultivars are those factors, which influence mainly seed and biomass yields, which could vary much (Jeuffroy & Ney, 1997; Poggio et al., 2005).

Cultivar, location and environmental/growth conditions affect pulse seed quality and composition. The large variation of pea seed quality between individual samples within a year suggests a large impact of the combination of environmental conditions, agronomic practice and genetic factors. Wide ranges of protein content were noted between samples of the same variety. This suggested that, within a variety, crude protein content could be used as an indicator of a general 'environmental' effect (Wang & Daun, 2004). The protein content of field peas may vary as followed: 15.8–32.1% (Blixt, 1978), 20.5–22.1% (Jabeen et al., 1988), 21.9–34.4% (Bastianelli et al., 1998), 18.3–31% (Hedley, 2001), 20.6–27.3% (Burstin et al., 2007), 24–32.4% (Gabriel et al., 2008a; 2008b), 15.8–32.1% (Pratap, 2011), 21.4–23.9% (Saastamoinen et al., 2013). Harmankaya et al. (2010) found that the protein content for the nineteen pea genotypes ranged from 21.13 to 27.05%, with a mean of 23.89% and stated that these differences in protein content were due to a combination of genetic and environmental factors.

The purpose of this investigation was to see whether pea varieties differ in their yield, height and content of protein and to find suitable varieties for production in Estonian agro-climatic conditions.

MATERIALS AND METHODS

A field experiment with varieties of field pea (*Pisum sativum* L.) was carried out at the Estonian Crop Research Institute in 2014 and 2015. The varieties were: 'Bruno', 'Capella', 'Clara' and 'Vitra'. 'Capella' and 'Clara' are Swedish varieties, and 'Bruno' and 'Vitra' – Latvian varieties. In our experiment the leafy variety was 'Vitra' and semi-leafless varieties were 'Bruno', 'Capella' and 'Clara'. A completely randomized experiment design was used in 4 replications. Plot size was 10 m^2. Soil conditions in 2014 were followed: Soil humus content was 3.15% and pH was 5.76. Soil type was soddy-calcareous podzolic soil in Estonian system (Astover, 2005). The preceding crop was winter rye. Soil conditions in 2015 were followed: Soil humus content was 3.46% and pH was 6.29. Soil type was calcaric cambisol soil in Estonian system (Astover, 2005). The preceding crop was barley. Conventional cropping system was used with ploughing in autumn 2013 (for 2014 cultivation) and in 2014 (for 2015 cultivation), and cultivation twice before sowing both years. Seeds were sown on 28 April 2014, and on 1 May 2015 at a rate of 120 seeds per m^2 for all varieties and a depth of 4 cm. Plant spacing was 12.5×6.7 cm.

Fertilization was done with Yara Mila 7–12–25 (300 kg ha^{-1}) both years. In 2014 and 2015 weeds were controlled by Activus 330 (pendimethalin 330 g L^{-1}) EC 1.5 L ha^{-1} + Basagran 480 (bentazon 480 g L^{-1}) 1.5 L ha^{-1}, on 21 May 2014, and on 5 June 2015. No control measures against insects and diseases were applied. Disease damage on peas pods, pod spot (*Ascoshyta pisi*), pulses rust (*Uromices* ssp.) was assessed at the plant development stage 71–79 (assessment method described in Strauß et al., 1994). In 2014 followed diseases were present: Pod spot on 'Bruno' and 'Vitra' was at a very low level, and on 'Clara' and 'Capella' at a low level. Pulses rust was absent on 'Clara', 'Capella' and 'Mehis', at a very low level on 'Bruno' and at a low level on 'Vitra'. In 2015 followed diseases were present: Pod spot on 'Bruno', 'Clara' and 'Capella' was at a very low level, and on 'Vitra' at a low level. Pulses rust was either absent or on very low level on all varieties.

The weather during 2014 is shown in Fig. 1. In 2014 it was characterized by a cold spring. The temperature at the end of June was 3–4 °C lower than normal, but July was near average with a mean temperature around 18 °C. Precipitation exceeded the average in June although it was quite dry in July; nevertheless plants grew well. The weather during 2015 is shown in Fig. 2. At ECRI 2015 year weather has been very different from average (cold spring and cold summer) with some decades of too much rain and some decades of a little rain.

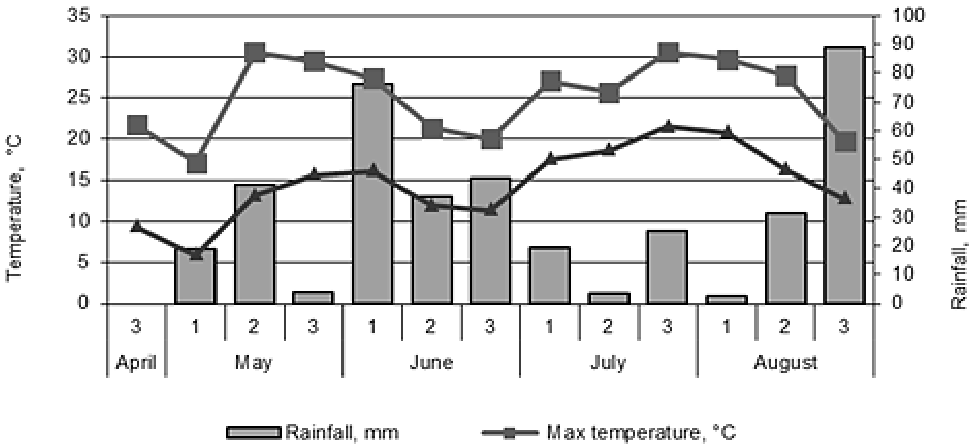

Figure 1. Weather conditions of field pea vegetation period in 2014 according to Jogeva Meteorological Station.

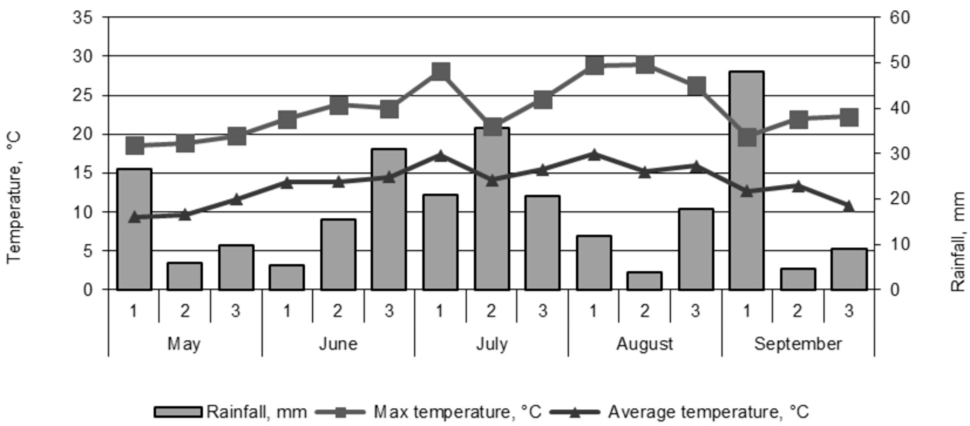

Figure 2. Weather conditions of field pea vegetation period in 2015 according to Jogeva Meteorological Station.

Peas were harvested between 6–12 August in 2014 and between 20–28 August in 2015, dried and the yield data (determined at moisture content of 14–15%) recorded for each plot and finally calculated for t ha^{-1}. Some days before harvest on both years the height of plants were measured for 10 plants (with average look in the plot) in every plot. Samples were analysed for their content of protein. Determination of protein content was by the Kjeldahl method (EVS-EN-ISO 10520:200). Analyses of variance were carried out on the data obtained using the programme *Excel*. Signs used: *** $p < 0.001$; ** $p = 0.001–0.01$; * $p = 0.01–0.05$; NS – not significant, $p > 0.05$. On figures, on columns are marked bars, which are the bars of standard deviations.

RESULTS

Yields (t ha^{-1}) in 2014 and 2015 did not differ much, while yield from variety 'Bruno' was very different between years (2014, 2015) and was much higher in 2015. In 2014 there was a tendency that the highest yield was obtained in 'Clara' and 'Vitra' (3.3 t ha^{-1}), followed by 'Capella' (2.8 t ha^{-1}) and 'Bruno' (2.6 t ha^{-1}), but differences were not statistically different (Fig. 3). In 2015 the highest yield was obtained by variety 'Bruno' (4.6 t ha^{-1}), followed by 'Vitra' (4 t ha^{-1}), 'Clara' (3.3 t ha^{-1}) and being lowest in 'Capella' (2.9 t ha^{-1}).

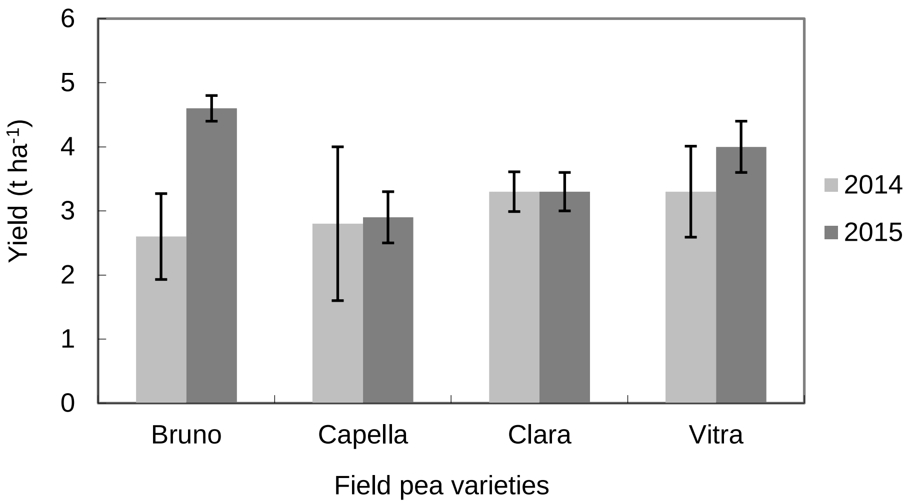

Figure 3. Dry grain yield (t ha^{-1}) of different field pea varieties (p in 2014 NS and in 2015***).

Crude protein content (% in dry matter) was lowest in 'Clara'; all other varieties had a higher content of protein, within much the same range. In 2014 crude protein content was the lowest in 'Clara' (23.6% in dry matter) and higher in all other varieties, although not ranging much from each other (26.9–27.9% in dry matter) (Fig. 4). In 2015 crude protein content was the lowest in 'Clara' (23.9% in dry matter) and higher in all other varieties. Crude protein content in all other varieties was ranging a little from each other (24.6–26.9% in dry matter).

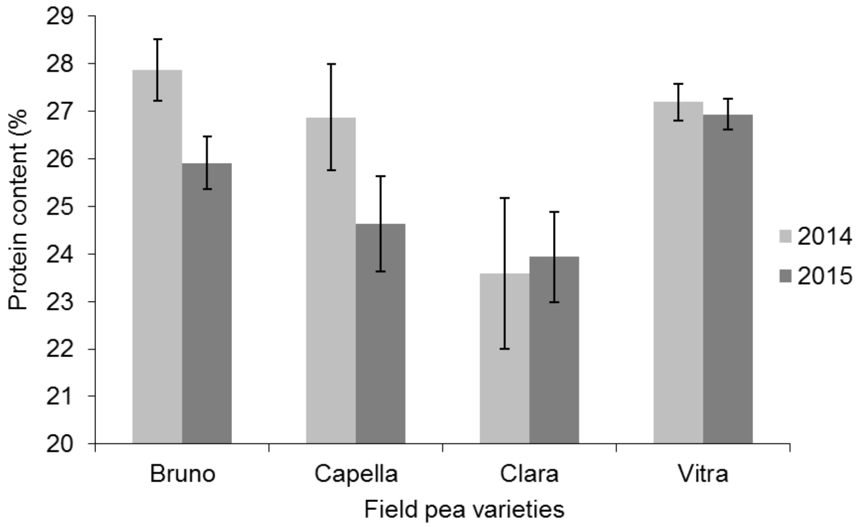

Figure 4. Average protein content (% in dry matter) of different field pea varieties (p in 2014*** and in 2015***).

The most suitable height of field peas is in a range of 60–100 cm, because the plants with such a height are most effectively suppressing weeds and they also are lodging not so easily (Olle, 2015). Results in 2014 and 2015 are showing that varieties with suitable height in our investigation were: 'Bruno', 'Capella' and 'Clara' (Fig. 5). Variety 'Vitra' was too high, is lodging easily and is therefore hard to harvest.

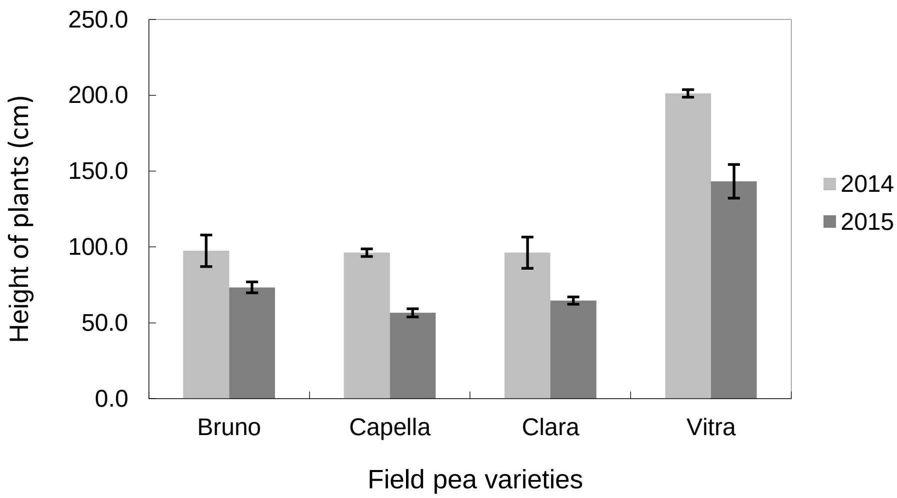

Figure 5. Average height of plants (cm) of different field pea varieties (p in 2014*** and in 2015***).

DISCUSSION

Narits (2008) reported that semi-leafless varieties have a higher seed yield, while in present investigation the seed yield from semi-leafless varieties in 2015 had both marks, the highest ('Bruno') and the lowest ('Capella'), letting leafy variety ('Vitra') to be in the middle. Probably this cold spring and quite cold summer were very suitable exactly for variety 'Bruno' growth and yielding, because just in 2014 there was a tendency that variety 'Bruno' was lowest in yield. In the years when the weather conditions favoured vegetative growth leafed types gave a higher yield and better quality than semi-leafless varieties (Kalev & Narits, 2004). They also noticed that in the year of unfavourable weather conditions the situation was the opposite. Accordingly, Kotlarz et al. (2011) reported that unfavourable weather conditions may negatively influence the crop yield.

The most suitable height of field peas is in a range of 60–100 cm, because the plants with such a height are most effectively suppressing weeds and plants are stronger against lodging, while last mentioned is differing among different varieties. In present investigation in 2014 the height of variety 'Vitra' was around 200 cm, and it in both years strongly lodged, it means this variety is hard to grow and more harder to harvest, even if yield is not bad.

Differences in climate, soil, varieties, agronomic practices may cause a different crude protein content when grown in various parts of the world. The results obtained in this study are showing us that genotype had a significant influence on the levels of crude protein in the field pea (Wang & Daun, 2004). In accordance Witten et al. (2015) describes that the variety of field peas has an influence on its crude protein content. In addition they revealed that environmental conditions and agronomic practice have strong influence on pulse seed quality. Kotlarz et al. (2011) found similarly with results from present investigation that the varieties differed in protein content. Narits (2008) concluded that when the field pea is grown for seed with the aim to get a high protein yield, then attention to the leaf type is important as leafy types usually have a higher protein content. In present investigation it was the same situation in 2015.

CONCLUSIONS

Based on the results of present investigation it can be concluded followed:

1. Out of those four varieties the most suitable varieties for production in Estonian agro-climatic conditions are 'Bruno' and 'Capella', because they have quite high yield and protein content together with suitable height. Variety 'Clara' has quite low protein content and variety 'Vitra' is too heigh and very susceptible for lodging.
2. Choice of the right variety for pea cultivation is very important, but depends on the local agro-climatic conditions. As in Baltic – Nordic countries the agro-climatic conditions are more or less similar the results could be useful also for those countries. Both varieties 'Bruno' and 'Capella' have suitable height and quite high protein content.

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Comparison of mechanical and electric drive of mulcher

M. Pexa[1,*], J. Čedík[1], F. Kumhála[2] and R. Pražan[3]

[1]Czech University of Life Sciences, Faculty of Engineering, Department for Quality and Dependability of Machines, Kamýcká 129, CZ165 21, Prague 6, Czech Republic
[2]Czech University of Life Sciences, Faculty of Engineering, Department of Agricultural Machines, Kamýcká 129, CZ165 21, Prague 6, Czech Republic
[3]Research Institute of Agriculture Engineering, Drnovská 507, CZ161 01, Prague 6, Czech Republic
[*]Correspondence: pexa@tf.czu.cz

Abstract. The contribution is focused on comparison of mechanical and electric drive of mulcher with vertical axis of rotation by means of mathematical model. The mulcher has working width of 6 m and it is usually aggregated with tractor of minimal power of 150 kW. On the test plot the torque and power transferred trough the tractor PTO, fuel consumption and the production of gaseous emissions components were monitored. This field measurement served as a basis for modelling as well as measured complete characteristics of the combustion engine of the tractor John Deere 7930. As a main base for the modelling the record of real operation of the tractor with mulcher was used. Then, in the software product MathCad the operation of the tractor with mechanical and electrical drive of the mulcher was modelled. In the case of the electrical drive of the mulcher the tractor with internal combustion engine, connected to generator was taken into consideration. Due to overall lower efficiency of the electrical drive with generator, worse values of the fuel consumption and emissions production in comparison with mechanical drive were reached in case of electric drive. At hypothetical use of batteries (100% electro-powered tractor) and when the energy mix at Czech Republic is taken into consideration, it is possible to reach the quarter values of emissions production in comparison with combustion engine.

Key words: Electric drive, emissions, fuel consumption, mulcher.

INTRODUCTION

Globally it is put the pressure on manufacturers and also operators of machinery equipped by internal combustion engines in order to achieve the lowest fuel consumption and thus as low as possible production of harmful emissions. At the same time there are discussions between producers of engines and physicians related to the harmfulness of individual components of emissions. (Hirvonen et al., 2005; Xu & Jiang, 2010; Kvist et al., 2011; Jalava et al., 2012). Harmfulness of these individual components is generally well known, but the problem is to express it financially.

Legislative regulations are forcing the manufacturers to produce ever more sophisticated machines producing minimum quantity of harmful emissions (Ryu et al., 2014). Unfortunately, the testing of these machines is usually done only during the homologation measurements (Maass et al., 2009; Lijewski et al., 2013; Cordiner et al., 2014; Liu et al., 2015). Actual measurements in operational conditions have then only informative value and do not achieve sufficient accuracy in order to be able to prove, that the internal combustion engine of an used machine remains in compliance with homologation regulations.

Widely discussed issue relates to the evaluation of emissions in operational conditions, which is not easy (Dace & Muizniece, 2015). Measurement of emissions in operational conditions brings many pitfalls, such as precision of analyzers and speed of response to the rapid change of measured variables (Pexa et al., 2016). For the practice it would be much easier to monitor the regime of machine operation and then, on the basis of overall characteristics of engine, to quantify actually produced emissions.

Within the regular operational tests it would be then specified actual overall characteristics of engine. The operators of vehicles would be then taxed not only according to what machine they bought, but also how well they care of a given machine. Which means whether the characteristics are still close to the characteristics given by manufacturer, or whether the technical state of machine has changed so much, that these characteristics differ significantly from those, which were specified by manufacturer. It is also possible to include into assessment the kind of used fuel or biofuel, which has a significant effect on emissions (Sada et al., 2012; Repele et al., 2013; Hönig et al., 2014; Čedík et al., 2015a; Pexa et al., 2015).

At the present time there is solved, in addition to the issue of biofuels, the question of electric drive of vehicles, tractors, trucks and also agricultural machinery (Usinin et al., 2013; Raikwar et al., 2015; Moreda et al., 2016). This area of research is still at the beginning, but already now it is possible to predict, how it will be with relation of these machines to the environment. Hypothetically it can be assumed, that electric drive of agricultural machinery will have worse efficiency than in case of mechanical operation (depending on a condition of generator and a combustion engine of tractor). An electric drive of tractor solved by means of batteries, when electricity is produced in a power station, seems to be very interesting alternative (hypothetically the operation of tractors can be without emissions at use of solar energy, if the disposal of the batteries, panels etc. won't be included).

The aim of this contribution is to compare the mechanical and electric drive of a mulcher with vertical axis of rotation. For comparison there is used real run of the mulcher with the tractor and for analysis of fuel consumption and emissions production there are used a model and overall characteristics of the engine.

MATERIALS AND METHODS

In order to make a comparison of mechanical and electric drive of the mulcher, it was necessary to obtain at first the **overall characteristics of combustion engine of tractor**, which was John Deere 7930 tractor with nominal output of 150 kW on the PTO, which represents a requirement for Mulcher MZ 6000 (three rotors, working width of 6 m). This measurement was carried out in laboratory with use of dynamometer

(AW NEB 400 – accuracy 2%). At first there was measured external rotation speed characteristics and on the basis of it there were determined measurement points so, that as many as possible these points cover the working range of the engine. During the measurement there were determined the fuel consumption and emission parameters. With the use of functions in MathCad programme (especially interp and spline) there were worked out continuous surfaces in coordinates of engine speed and torque. An example of continuous surfaces for carbon dioxide and hydrocarbons is shown in Fig. 1.

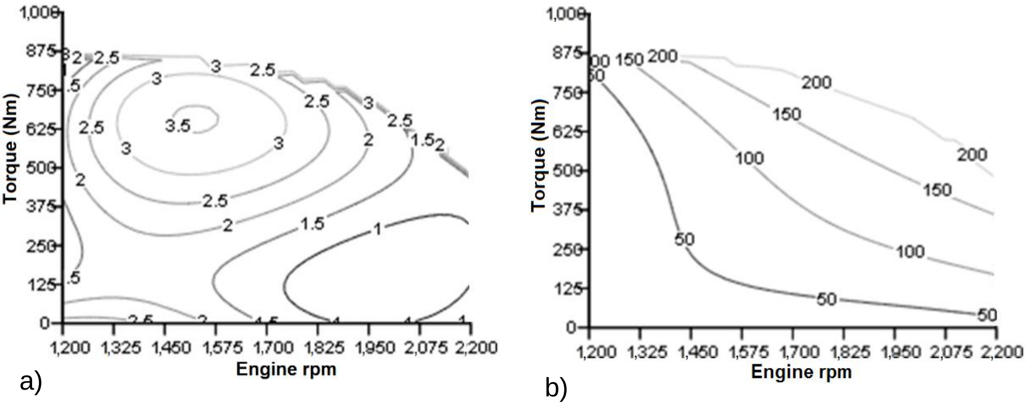


Figure 1. Continuous variable surfaces: a) hydrocarbons (g h^{-1}); b) carbon dioxide (kg h^{-1}).

Measurements in field conditions were carried out on a grassy plot. During the driving of a tractor set with mulcher there was measured the amount of consumed fuel by means of flow meter (AIC VERITAS 4004 – measurement error 1%). The amount of intake air, engine load, engine speed and tractor speed were measured by means of on-board diagnostics (on-board diagnostics system monitored by means of the device Texa Navigator TXTs – frequency 4 Hz). Performance required to drive of mulcher was measured by means of dynamometer (MANNER Mfi 2500Nm_2000U/min – accuracy 0.25%) and quantity of produced harmful emissions of carbon dioxide, carbon monoxide, hydrocarbons and nitrogen oxides by emission analyser VMK (Table 1). The movement of working set was monitored via GPS receiver (Qstarz BT-Q1000X – frequency 5 Hz) and by a drone. Recorded points are shown in external rotation speed characteristics of the tractor engine in Fig. 2. The trace of the real ride and engine parameters during this ride are shown in Fig. 3.

Table 1. Technical parameters of analyzer VMK (Kotek et al., 2016)

Measured component	Range	Resolution	Uncertainty of measurement
CO	0–10% vol	0.001% vol	0–0.67%: 0.02% absolutely, 0.67% – 10%: 3% from measured value
CO_2	0–16% vol	0.1% vol	0–10%: 0.3% absolutely, 10–16%: 3% f. m. v.
HC	0–20,000 ppm	1 ppm	10 ppm or 5% f. m. v.
NO_X	0–5,000 ppm	1 ppm	0–1,000 ppm: 25 ppm, 1,000–4,000 ppm: 4% f. m. v.

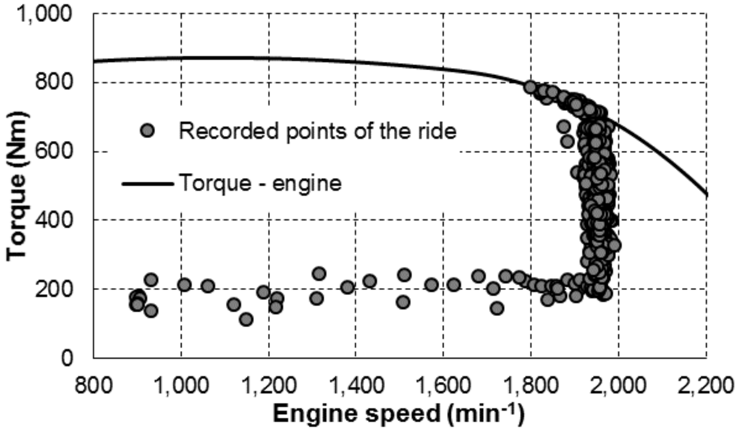
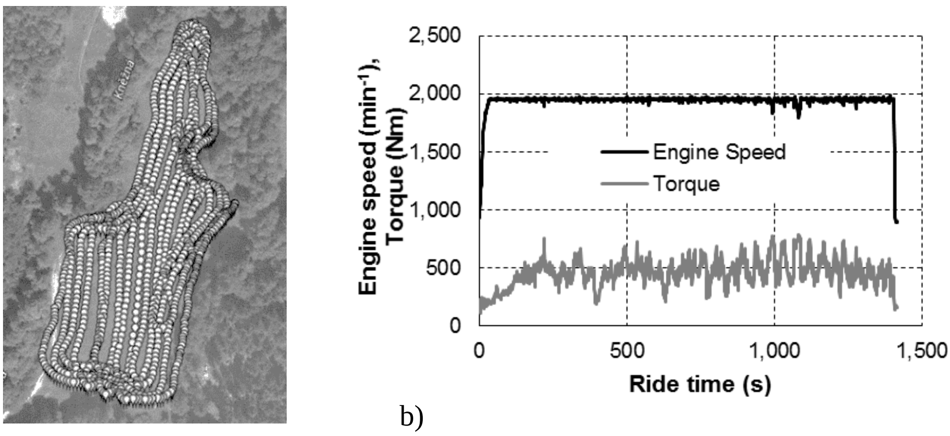


Figure 2. Recorded points of the real ride of the mulcher in external speed characteristics of the tractor engine.



a) b)

Figure 3. Field measurement: a) measured points, b) parameters of run.

The model include also **losses of mechanical drive of mulcher depending on engine speed**, which was measured over a flat surface in working height of 5 cm. For the measurement the dynamometer (MANNER Mfi 2500Nm_2000U/min – accuracy 0.25%) was used. Resulting values are described in Čedík et al. (2016) and Čedík et al. (2015b; 2015c).

In terms of electric drive of mulcher it is necessary to create dependency of efficiency of electric energy transmission from the engine to the shaft of mulcher. The transmission of electric energy takes place in the following way: At the start there is an internal combustion engine, which drives AC generator. It follows the rectification of electric energy and its transfer to mulcher. In mulcher there is a change from DC energy to AC energy. All these changes, transmission and proper electric engine are working with a certain efficiency. The overall efficiency of electric energy transmission is show in Fig. 4. Due to the parameters of electric engine (Table 2) there is used a gearbox, which reduces electric engine speed to 1,000 rpm of the PTO shaft, while the electric engine operates at 3,000 rpm, when achieves maximum torque (450 Nm) and power output (140 kW).

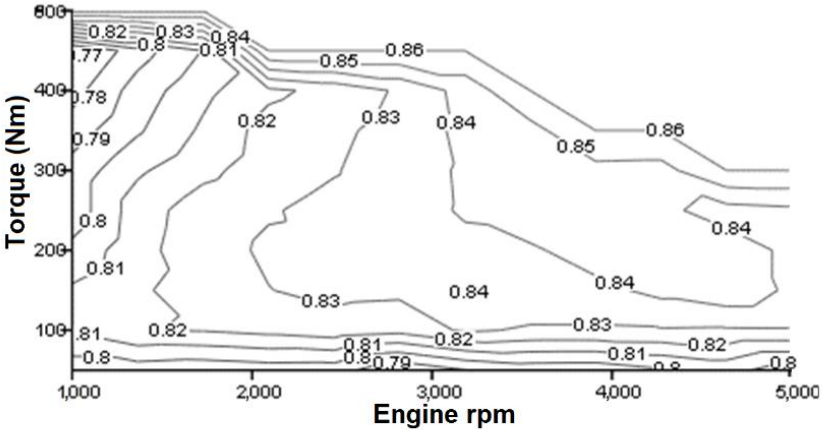


Figure 4. Overall efficiency of electric energy transmission.

Table 2. Basic parameters of the electric motor (STV Technic, 2017)

powerMELA®-C 140kW		
Nominal power	140	kW
Traction net voltage	650	V_{dc}
Traction net current	229	A_{dc}
Phases	2 x 3	-
Nominal torque	450	Nm
Nominal speed	3,000	min^{-1}
Maximum speed	6,000	min^{-1}
Maximum torque	608	Nm
Maximum power	154	kW
Efficiency	95.4	%
Weight	147	kg

Due to the substantial reduction of overall efficiency of electric energy transmission in comparison with mechanical energy transmission it was necessary to modify the parameters of really recorded run. Parameters of run were modified so, that the load of mulcher has been reduced to 70%. It could be applied, when a mulching was carried out on a plot with lower yield, however it is typical for the work of mulcher, for example in case of the ungrazed patches. If this situation didn´t occur, the engine load would be on external characteristics and consequently there would occur a considerable reduction in engine speed. The proper model comparison of mechanical and electric drive of mulcher would be by this change considerably affected.

As a second variant it is possible to utilize the easily controlled speed of the electric drive and to reduce the cutting speed of the mulcher's rotors from 105 m s^{-1} (1,000 rpm) to 84 m s^{-1} 800 rpm in order to reduce aerodynamic losses.

As another variant it could be possible to run the combustion engine of the tractor in lower rotation speed in order to increase the engine efficiency. Also, the combination of the reduction of combustion engine speed and electric engine speed was taken into consideration.In order to complete the model of electrical drive, it was removed from the run with mechanical mulcher the requirement for drive of the tractor itself. The required torque for tractor run without attached mulcher is shown in Fig. 5.

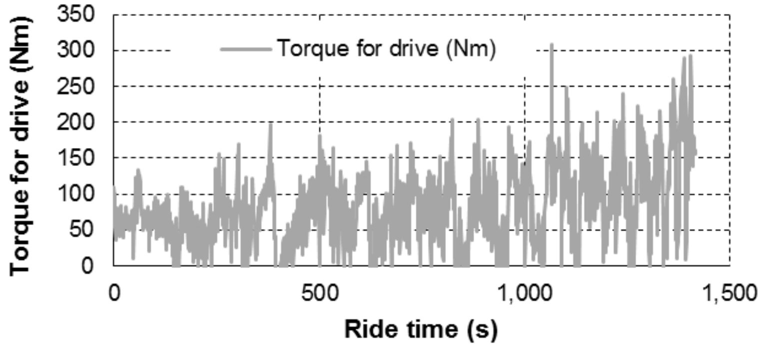


Figure 5. Requirement of engine torque for tractor run.

RESULTS AND DISCUSSION

In Fig. 6 there is shown the course of necessary engine torque in case of attached mechanical and electrical drive of mulcher. From this figure it is obvious, that for electrical drive it is necessary to have higher torque, than in case of mechanical drive.

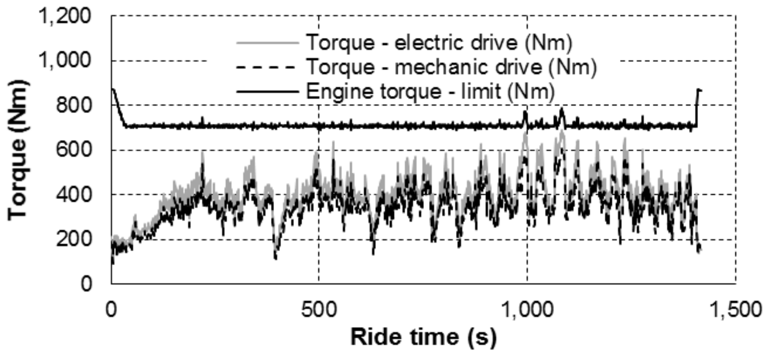


Figure 6. Course of load of the tractor engine (drive of the tractor with connected mulcher + drive of mechanism of the mulcher) in case of mechanical and electric drive of mulcher.

Owing to the need of higher torque for electric drive of mulcher, it can be expected, that the fuel consumption and emissions production of combustion engine will be also higher. In order to achieve a reduction of fuel consumption and emissions, it is possible to utilize the ability to easily regulate electric drive of mulcher and to reduce its working speed. After reduction of mulcher rotors speed from normal operating 1,000 rpm (cutting speed 105 m s^{-1}) to 800 rpm (cutting speed 89 m s^{-1}), it can be achieved the reduction of mulcher aerodynamic losses by almost 1/2 and thus also a reduction of fuel consumption and emissions production, as was already published by Čedík et al. (2016). It is also possible to reduce, as another variant, the engine speed for drive of generator (reduced by 280 rpm) so that the engine will be running with better efficiency. In this case the course of load is shown in Fig. 7.

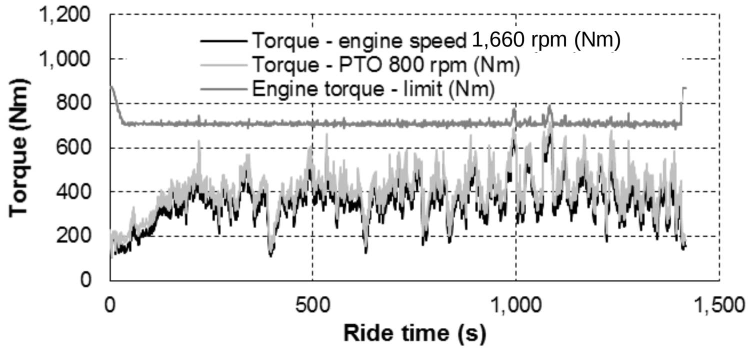


Figure 7. Course of load of the tractor engine (drive of the tractor with connected mulcher + drive of mechanism of the mulcher) in case of reduced speed of the mulcher and combustion engine.

In Fig. 8 there is shown the course of fuel consumption, NO_X production and smoke emissions from combustion engine during the run cycle, when a) represent standard mechanical drive and b) standard electric drive.

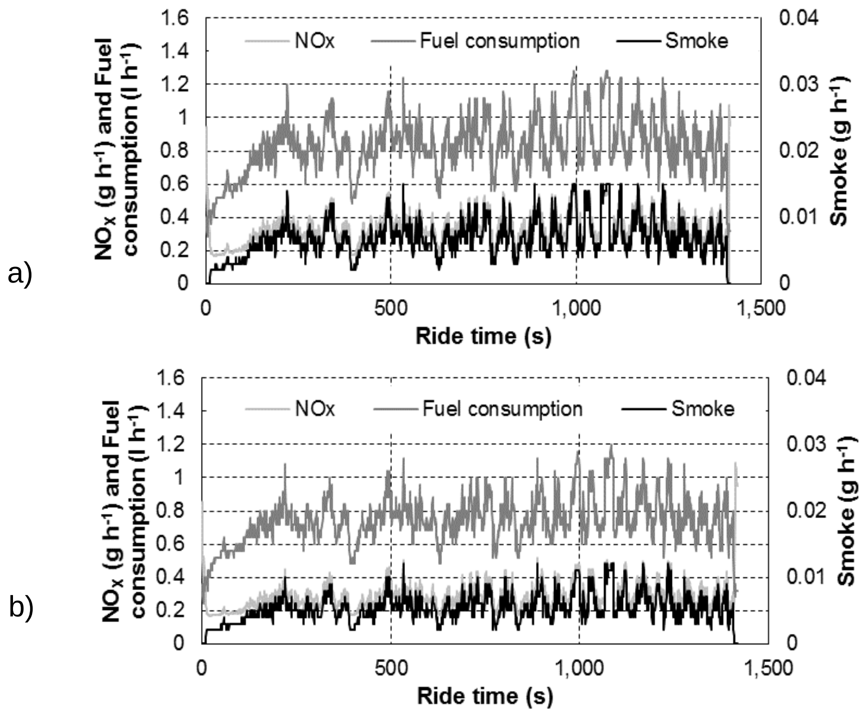


Figure 8. Course of fuel consumption, NO_X production and smoke emissions from combustion engine during the run cycle, when a) represent standard mechanical drive, b) standard electric drive.

Values for the entire run cycle are shown in the Table 3, where they are converted to one hour of tractor operation. For each of variant there are calculated two values of fuel consumption and amount of emissions. The first value is based on the sum of fuel consumption and emissions production that was calculated for each recorded point of run. The second value is based on average engine speed and average load and it is single value deducted from the overall characteristics of engine.

Table 3. Fuel consumption and production of emissions converted to one hour of operation

	Fuel consumption $l\ h^{-1}$	CO_2 $kg\ h^{-1}$	CO $g\ h^{-1}$	NO $g\ h^{-1}$	HC $g\ h^{-1}$	PM $g\ h^{-1}$
Electric drive	29.32	128.93	275.65	482.20	1.44	9.61
Electric drive - average	29.01	128.48	276.41	448.67	1.49	8.96
Mechanical drive	26.32	118.31	245.88	410.30	1.25	7.61
Mechanical drive - average	25.86	118.54	244.23	378.04	1.26	7.14
Electric drive	27.24	121.29	254.82	433.17	1.30	8.24
Electric drive - average	26.75	121.44	253.32	397.35	1.33	7.63
Mechanical drive	24.67	111.86	228.98	374.99	1.13	6.64
Mechanical drive - average	24.08	112.42	225.91	340.95	1.12	6.20
Electric drive	32.72	103.35	289.88	611.01	2.64	6.84
Electric drive - average	33.33	100.45	290.90	612.03	2.77	5.84
Mechanical drive	28.89	93.54	246.51	545.21	2.37	5.08
Mechanical drive - average	29.04	92.22	242.88	535.81	2.43	4.32
Electric drive	29.95	96.49	259.14	564.26	2.44	5.67
Electric drive - average	30.28	94.48	256.60	557.91	2.53	4.71
Mechanical drive	26.42	88.36	221.03	504.05	2.19	4.33
Mechanical drive - average	26.42	87.65	215.06	489.82	2.22	3.61

Great potential can be seen in purely electric drive of tractor. If there would be available a sufficient electric energy accumulator, into which this energy would be filled from the energy mix of the Czech Republic, in that case the produced emissions will be by 1/3 lower at least, than emissions from combustion engine. In case of the use of electric energy purely produced by coal-fired power station, the produced emissions will be comparable to the emissions produced by combustion engine.

CONCLUSIONS

This contribution is aimed at comparison of mechanical and electric drive of mulcher. Comparison is carried out by means of model in MathCad. The most important source of information is real run of tractor set along the plot.

From the results in Table 3 it is obvious, that electric drive of mulcher causes an increase in fuel consumption and production of emissions. It is caused above all by the fact, that it was used the tractor with combustion engine and only then there is attached to this combustion engine generator of electric energy. In case of electric drive of mulcher more devices is in operation, than in case of mechanical drive and therefore it decreases the efficiency of energy transfer. By this fact electric drive of mulcher is disadvantaged. In the model it was also calculated with the fact, that the reduction of mulcher rpm and also engine speed is possible both in case of mechanical drive and electric drive of mulcher. However it may not be true, especially in case of mechanical drive.

The average difference between the worst variant and the best variant, when we include both types of mulcher drive, makes approx. 40%. Three times there was achieved the best result by reduction of mulcher rpm (fuel consumption, NO_X, HC) and three times by reduction of mulcher rpm in combination with reduction of engine speed (CO_2, CO, PM). If this comparison will be related only to the electric drive of mulcher, it is possible to achieve by means of reduction of mulcher rpm, by reduction of combustion engine speed and by their combination the average reduction of fuel consumption and emissions by 15%. The greatest reduction was achieved in case of smoke by ca 40% and carbon dioxide by ca 25%.

The great potential of electric drive of mulcher and other agricultural machines can be seen in case of use of 100% electro-powered tractor without combustion engine. In this case the amount of produced emissions reaches only one third in comparison with mechanical drive of mulcher with inclusion of energy mix of the Czech Republic.

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Some factors affecting the efficiency of potato production, under Al–Ghab plain conditions, Syrian Arab Republic

P. Prochazka[1,*], A. Murjan[1], V. Hönig[2] and K. Pernica[2]

[1]Czech University of Life Sciences Prague, Faculty of Economics and Management, Department of Economics, Kamýcka 129, CZ165 21 Prague 6, Czech Republic
[2]University of Economics, Faculty of Business Administration, Department of Strategy, W. Churchill Sq., CZ130 67 Prague 3, Czech Republic
[*]Correspondence: pprochazka@pef.czu.cz

Abstract. Data were collected by a field survey of 300 farmers from Al–Ghab region (Syria) during 2014–2015. The non–parametric Data Envelopment was used in analyzing the Technical efficiency. The relationship between farm size and production efficiency was considered. Technical efficiency amounted about 53% and most of farms are operating at low level of technical efficiency. The relationship between farm size and productivity efficiency is Non–linear, it decreases from small to medium farm size and then increases as the size increase. Large farms have the higher net farm income per thousand square metersand are the most efficient technically followed by small and medium farm size. To disclose that factors causing the technical efficiency, Two–limit Tobit Regression Model was used. The calculated results showed that, Household Size, Occupation, Farm Size, Experience in Farming, Seed Type and Membership are factors that cause the technical inefficiency potato farming at Al–Ghab region. Therefore, the Syrian Planning Board and Decision Makers should take this results into account when they draw their plans to improve farmer's skills by allocating more investment in farm research and extension programmers.

Key words: Potato, Technical inefficiency, farm size, Data Envelopment Analyses, Tobit Model.

INTRODUCTION

Agriculture is one of the most important sector in the Syrian economy, as it employs about 21% of the labor force and generates about 25% of the country's gross domestic product (GDP). It has a decisive role in restoring food security, protecting natural resources, fostering economic growth and employment. Land use in Syria is divided into 45% desert and semiarid land, 32% cultivated land, 20% uncultivated, and 3% forests (Khaldoon & Berndtsson, 2012).

Agriculture is a high priority in Syria's economic development plans, as the government seeks to achieve food self–sufficiency, increase export earnings, and halt rural out–migration. Thanks to sustained capital investment, infrastructure development, subsidies of inputs, and price supports, Syria has gone from a net importer of many agricultural products to an exporter of cotton, fruits, vegetables, and other foodstuffs.

One of the prime reasons for this turnaround has been the government's investment in huge irrigation systems in northern and northeastern Syria (MAAR, 2010).

Similar situation is in other Middle East countries where governments attempt to diversify the economy by supporting other sectors by implementing different types of investments (Maitah et al., 2013; Maitah et al., 2015). Governments in the Middle East attempt to attract foreign direct investment to their countries, similar activities are done by European countries. (Maitah et al., 2014) and the same policies are applied by Russian Federation toward the sector of sugar industry (Smutka et al., 2014; Maitah et al., 2016; Maitah & Smutka, 2016).

Important agricultural products in the Syria include cereals, industrial crops (such as cotton, sugar beets, tobacco,vegetables and fruits (MAAR, 2010).

Potatoes together with rice and wheat belong among the three most important food crops in the world after rice and wheat in terms of human consumption (CBS–SYR. 2010).

With the increasing population pressure and growing environmental degradation, it becomes more and more important to increase productivity in sustainable ways. This requires access to appropriate agricultural inputs and technologies.

Mukul et al. (2013), found a significant differences in socio–economic characteristics of potato farmers and showed that majority of farmers have a medium farm size (0.34–1.0 acre), belong to young age category (20–35 years) having medium family size, illiterate, (1–10 years) farming experience, those characteristics is associated with inefficiency in potato production (Arif et al., 2012).

Khaldoon & Berndtsson (2012) investigated potato profitability in Uganda, they showed that education level is correlated positively with efficiency, indicating that public investments in education have a synergistic effects on outcomes in Uganda (Mugonola, 2007; FAO, 2008).

The relationship between farm size and production is a very controversy issue. Some author support the inverse relationship, while other authors hold that production relationship with farm area is non–linear and is U–shaped. However, this inverse relationship has disappeared, as a result of technology adjustment (Theisen, 2007).

Taking into account that, no previous studies concerning the efficiency of potato production, under Al–Ghab plain conditions were achieved in Syria, and the insufficiency of argue on inverse relationship hypothesis, it is necessary to investigate the factor that may affect the efficiency of potato production in the regioon (International Year of the Potato 2008).

This paper aimed to reveal some factors affecting the efficiency of potato production.

The specific objectives of the study are to:

- investigate technical efficiency of potato production in Al–Ghab region, under different farm size;
- disclose some factors that may affect the technical efficiency of farms in the region and;
- offer suggestions to increase the potato farming efficiency.

MATERIALS AND METHODS

The study took into consideration three major potato producing villages (Al–Jornaie, Al–Habit and Kurnaz) in Al–Ghab plain, which located in north west of Syria. This plain represents an area of 61,000 hectares of very fertile alluvial soils. The major crops cultivated in the area are wheat, sugar beet, cotton, potato as well as vegetables and legume crops.

In the countries surrounding the Mediterranean sea the potato is a crop of great significance. Due to favorable climatic conditions, it can be cultivated throughout the year where planting and harvesting dates depend on the specific area of cultivation. The Mediterranean region differs from Northern Europe not only in its environmental conditions but also in the different use of high technology and adaptation of potato cultivars. A great problem related to potato cultivation in the Mediterranean area is the availability of seed tubers at the right physiological stage (Frusciante & Ranalli, 1999).

Potato is planted twice per year, the early one in the spring (15 february–15 march) and harvested after 90–110 days of planting date, while the autumn planting is don on 15 August till 15 September.

The data were collected during July–October (2014) by a structured questionnaire designed in line with objectives of the study. Questionnaire consisted of main questions regarding potato farming practices and environment in which they grow potatoes.

Respondents selection (from each of village) was achieved by multistage sampling, based on their high participation in potato production. So, after villages selection, a list of potato producers was compiled from each village, where one hundred of potato farmers were selected using a systematic random samplings technique, so, the total selected respondents farmers accounted three hundreds (300). The respondents had to answer the following questions: the age of the farmer; the education level; the farming experience (years); the family size (number of family member's); the membership of agricultural organization; the farm size (1,000 sq meters Dunom); the seed type and the distance to farm land (kms).

The technical and allocative efficiency were estimated to point out the economic performance of potato farms in Al–Ghab region. Therefore, the Input–Oriented Data Envelopment Model (DEA) was used to determine technical and allocative efficiency by parametric and non–parametric techniques.

Technical efficiency (CRS), pure*technical efficiency* (VRS) and *scale efficiency* were determined to explore the causes of farms inefficiency. A farm with a technical efficiency between 0.90 > 1 was considered an efficient farm.

Taking into account that farmers are able to control their inputs rather than their outputs the input–oriented DEA model was used. Authors consider inputs relevant for potato production such as land, labor, fertilizers or seeds.

Technical efficiency, pure technical efficiency and scale efficiency were calculated to point out the overall status of potato productivity efficiency. In this paper we assume the same input for the three farms sizes.

The technical efficiency of a given decision making unit DMU, i.e. a farm, is the efficiency ratio equal to a weighted sum of outputs over a weighted sum of inputs. So, those weights for each DMU were calculated by solving an optimization non–linear problem. It maximizes the efficiency ratio for a DMU subjected to constraint so that the equivalent ratios for every unit in the set will be ≤ 1. In this manner, the efficiency rate will ranges from 0 to 1. solving the following mathematical programming problem will give the Optimal weights:

$$Max\ h_0 = \left[\frac{\sum_{r=1}^{S} u_r\, y_{ro}}{\sum_{i=1}^{m} v_i\, x_{io}}\right] \tag{1}$$

$$\frac{\sum_{r=1}^{s} u_r y_{r0}}{\sum_{r=1}^{m} v_i\, x_{i0}} \tag{2}$$

(j = 1, 2, ...n); $u_r \geq 0$; $vi \geq 0$.
For (r = 1, 2, 3 ……s); (i = 1, 2, 3 …….m)
where h_0 is the ratio of outputs to inputs; u_r and v_i are the weights to be determined for the output *r* and input *i* respectively; yr_0 and the xi_0 are the observed output and input values for the *DMU* to be evaluated.

The aim is to obtain u_r and v_i weights that maximizes the efficiency ratio of *DMU*. To transform this problem into linear one, a new constraint *was introduced*. The denominator was set equal to 1 and the numerator is being maximized in this model. So, the input–oriented Charnes, Cooper, Rhodes (CCR) model will be:

$$Max\ h_0 = \sum_{r=1}^{s} u_r y_{i0} \tag{3}$$

Subject to:

$$\sum_{i=1}^{m} v_i\, x_{io} = 1 \tag{4}$$

$$\sum_{r=1}^{s} u_r\, y_{ri} - \sum_{i=1}^{m} v_i\, x_{ij} \ \leq 0\ (j = 1 \ldots\ldots..n) \tag{5}$$
$$u_r \geq\ \epsilon\ (r = 1 \ldots..s),\quad v \geq \epsilon\ (i = 1 \ldots...m)$$

ε is introduced in Eq. 2, which is an arbitrarily small positive number, to have a positive weight values for inputs and outputs.

To identify slack in inputs or output and reduces the number of restrictions of the DEA model, the following dual problem of the linear program was used:

$$Min\ h_0 = \theta_0 - \epsilon\left[\sum_{i=1} s_i^- + \sum_{r=1} s_r^+\right] \tag{6}$$

Subjected to:

$$\sum_{i=1}^{m} x_{ij}\,\lambda_j + s_i^- = \theta_0 x_{i0} (i = 1 \ldots\ldots..m)$$
$$\sum_{r=1}^{m} y_{rj}\,\lambda_j + s_i^+ = y_{r0} (r = 1 \ldots\ldots..s)$$
$$\lambda_j \geq 0\quad (j = 1 \ldots\ldots, n).\ \ s_i^- \geq 0,\quad s_r^+ \geq 0$$

where θ_0 denotes the efficiency of DMU$_0$; y_{rj} is the amount of r_{th} outputs produced by DMU$_0$ using x_{ij} amount of i_{th} input; y_{rj} and x_{ij} are exogenous variables; λ_j represents the benchmarks for a specific DMU under evaluation; s_i^- and s_r^+ are the slack variables.

To identify if a farm (DMU) is operating in constant, decreasing or increasing returns to scale, the Banker, Charnes, Cooper (BCC) Model was used. Constant return to scale (CRS) linear programming problem was modified by adding the convexity constraint to Eq. 3, in order to calculate Variable.

So the BCC model become:

$$Min\, h_0 = \theta_0 - \varepsilon\left[\sum_{i=1}^{m} s_i^- + \sum_{r=1}^{s} s_{r=1}^+\right] \quad (7)$$

$$\sum_{i=1}^{m} x_{ij}\,\lambda_j + s_i^- = \theta_0 x_{i0} (i = 1 \dots\dots, m)$$

$$\sum_{r=1}^{s} y_{rj}\,\lambda_j + s_r^+ = y_{ro} (r = 1 \dots\dots, s)$$

$$\sum \lambda_i \geq 1 \;\; (j = 1 \dots\dots. n).\;\; s_i^- \geq 0,\;\; s_r^+ \geq 0$$

Estimated scores of technical and pure technical efficiency were compared to determine if the inefficiency in a DMU is caused by inefficient agricultural practices or by the operating conditions. Banker et al. (1984) considers that the DMU is fully efficient, when it operates in the Most Productive Scale Size (MPSS). The use of the CRS specification will result into measures of technical efficiency which may be confused by scale efficiencies (SE), If all DMUs are not operating at the optimal scale. To calculate a TE without SE effects, the variable return to scale (VRS) specification was used.

$$TE_{\mathrm{CRS}} = PT_{\mathrm{EVRS}}.SE \quad (8)$$

where TE_{CRS} is technical efficiency of constant returns to scale: PTE_{VRS} is technical efficiency of variable returns to scale; *SE* is scale of efficiency; and

$$SE = TE_{\mathrm{CRS}} / PTE_{\mathrm{VRS}} \quad (9)$$

where $0 \leq SE \leq 1$ since $TE_{\mathrm{CRS}} \leq PTE_{\mathrm{VRS}}$.

If SE value is equals to 1, the firm is scale efficient. Whereas values less than 1 ($SE < 1$) reflect scale inefficiency, which could be either increasing ($NI < VR$) or decreasing ($NI = VR$) returns to scale. The sum of intensity variables (i.e. *) in the CCR model shows the increasing or decreasing return to scale:

$$\sum_{j=1}^{n} \lambda_j > 1 \text{ (increasing returns–to–scale).}$$

$$\sum_{j=1}^{n} \lambda_j < 1 \text{ (decreasing returns–to–scale).}$$

The sources of inefficiency for each farmer according to the input and output variables, and the target values of these variables were defined at farm level by means of the technical efficiency scores at constant returns to scale according to the following formulae:

$$X_{i0} = \theta_i^* x_{i0} - s_i^{-*} \quad (10)$$

$$Y_{r0} = y_{r0} - s_r^{+^*} \tag{11}$$

where X_{i0} is the target input i for 0th farmer; Y_{r0} is target output r for 0th farmer; x_{i0} is actual input i for 0th farmer; y_{r0} is actual output r for 0th farmer; θ_i^* is OTE score of 0th farmer; $s_i^{-^*}$ is optimal input slacks; $s_r^{+^*}$ is optimal output slacks.

So, $\Delta x_{i0} = X_{i0} - x_{i0}$ is the quantity of input i to be reduced and $\Delta y_{r0} = Y_{r0} - y_{r0}$ represents the amount of output r to be increased, so that the inefficient farmer will be moved onto the efficient frontier. To make the farmer under evaluation efficient, the input reduction for the input i and output addition for the output r were calculated by $(\Delta x_{i0}/x_{i0}) \times 100$ and $(\Delta y_{r0}/y_{r0}) \times 100$ respectively.

Two–limit Tobit Regression Model was used to identify the determinants of farm Technical Efficiency. The empirical Tobit Model has been estimated as:

$$y_i^* = \beta_0 + \sum \beta_m \; X_{jm+\,\epsilon_i} \tag{12}$$

where y_i*is efficiency scores of farm; j is a vector of unknown parameters (increasing returns–to–scale); X_{jm} is vector of explanatory variables m (m = 1, 2... k) for farm j; ** = an error term that is independently and normally distributed with mean zero and common variance σ2.

The Tobit Regression Model can be written as:

$$Y = \beta_0 + \beta_1X_1 + \beta_2X_2 + \beta_3X3 + \beta_4X_4 + \beta_5X_5 + \beta_6X_6 + \beta_7X_7 + \beta_8X_8 + \beta_9X_9 + \beta_{10}X_{10} + \beta_{11}X_{11} + \beta_{12}X_{12} + U_i \tag{13}$$

where y_i* is efficiency scores of farm; j is a vector of unknown parameters (increasing returns–to–scale); Y is the Technical Efficiency Score (0 to 1); X_1 is the age of the farmer (years); X_2 is Education (years); X_3 is Farming Experience (years); X_4 is Experience Square; X_5 isMain occupation (1 = for farming and 0 = for other); X_6 is Family size (number of family member's); X_7 is Membership of agricultural organization (1 = if yes and 0 = if no); X_8 is Farm size (1,000 sq meters); X_9 is Farm size square; X_{10} is Household Assets Owned (value in 1,000 **Syrian Lira);** X_{11} is Seed Type (1 = improved seed verities and 0=otherwise); X_{12} is Distance to farm land (kms); U_i is the error term.

Slacks and targets were calculated to find out the ways for enhancing agricultural practices. In addition to the target values of inputs and outputs for inefficient farmers, the potential increase in outputs and potential reduction in inputs were determined, to improve the input–output activity and move inefficient farmers to the efficient frontier.

RESULTS AND DISCUSSION

In this section, results of the study are presented and discussed. Table 1 revealed that 90.7% of the respondents were men. This result mismatch with Galiè, A. (2013) who concluded that*: 'Women in the Syrian villages play substantial roles in farming and are increasingly involved in agricultural management, but they are generally overlooked or under–valued as farmers by both men and women, at the household and community levels. Men typically are considered to be the farmers' and women to be only their helpers'.*

Table 1 showed that 6.0% of the farmers are illiterate, while 94.0 have a formal study, however,52.7 have had secondary and 22.7 have higher education. Närman (1991) showed that: *'It is held that the skills transferred through the extension services for adoption by farmers would be more easily implemented by those who have acquired the ability in reading, writing and arithmetic. A consequence, if we accept this assumption, is that farmers without education may remain outside technical evolution in agriculture'.*

Results in Table 1 also shows that 82.3% of the farmers in Al–Ghab region had over ten years of experience in 'Diamond' potato production, which implies that the farmers were aware of processes involved in potato productions. Alabi et al. (2005), showed that farmers awareness increases efficiency and productivity in business.

Table 1 also revealed that 77% of the farmers had high family size ranging from seven to more than ten household members, the large family size implies availability of free family labor, thus, the reason for the lower cost of labor as compared to cost of seeds and fertilizers in the business.

Results also showed that 92.67% of farm size per farmer in the study area is less than 1 hectare (ha) which may increase unit costs and reduce benefits per ha. Also the hired labor was the smallest (28.0%) source of labor in the study area, so, family labor force would increase the profitability of potato production in Al–Ghab region.

Results in Table 1 shows that only 6.3% of the respondents were young (up to 25 years), which mean that the majority of potato farmers are aged adult, who have had several years of experience in 'Diamond' potato farming. This result agrees with the findings of Alabi et al. (2005) *'who observed that farmer's age has great influence on maize production in Kaduna state with younger farmers producing more than the older ones plausibly because of their flexibility to new ideas and risk'.*

Table 1. Socio–economic Characteristics of Diamond Potato Farmers in Al–Ghab region

Percentage	Frequency	Variable
Gender		
90.7	272.0	Male
9.3	28.0	Female
100	300	Total
Marital status		
88.3	265.0	Married
11.7	35.0	Single
100	300	Total
Educational level		
6.0	18	Illiterate
20.7	62	Primary
52.7	158	Secondary
15.0	45	Higher secondary
5.7	17	University
100.0	300	Total
Family size		
7.33	22	Up to 4
15.67	47	5–7
40.67	122	8–10
36.33	109	More than 10
100	300	Total

Table 1 (continued)

Age		
6.3	19	Up to 25
14.3	43	31–35
34.0	102	36–40
29.7	89	41–45
10.0	30	46–50
5.7	17	> 50
100.0	300	Total
Years of experience		
2.0	6	< 5
15.7	47	6–10
38.3	115	10–15
25.0	75	15–20
19.0	57	> 20
100.0	300	Total
		Farm size
40.67	122	Up to 0.4 ha
52.00	156	0.5–1 ha
7.33	22	more than 1ha
100	300	Total
		Labor
43.3	130	Family
28.0	84	Hiring
28. 7	86	family and hiring
100.0	300	Total
Primary occupation		
63.3	190	Farming
20.7	62	Public administration
16.0	48	Business
100.0	300	Total

The *technical inefficiency* could be considered the main source of inefficiencies of Syrian potato farming. As shown by the results from Table 2, around of 47% of potato production is lost due to technical inefficiency and the technical efficiency averaged only 53% of the potential output from a given mix of inputs.

Table 2. Distribution of farmers by their score of Technical Efficiency

Total Farms		Large Farms		Medium Farms		Small Farms		
%	Fre–quency	%	Fre–quency	%	Fre–quency	%	Fre–quency	Efficiency scale
15.58	50	6.3	6	30.4	35	10.0	9	0.10 < 0.30
39.84	121	33.7	32	47.0	54	38.9	35	0.30 < 0.60
24.9	73	32.6	31	16.5	19	25.6	23	0.60 < 0.90
19.67	56	27.4	26	6.1	7	25.6	23	0.90 < 1
100	300	100	95	100	115	100	90	Total
0.06		0.09	0.09	0.06		0.11		Minimum
1		1	1	1		1		Maximum
0.52950		0.5821		0.3924		0.554		Mean
0.28014		0.32546		0.16254		0.35243		Std. Deviation

Farm sizes affected the efficiency level, as it ranges between 0.11 to 1.00, 0.06 to 1.00 and 0.09 to 1.00 for small, medium and large farmers respectively. Small farms showed the highest mean of technical efficiency (0.55) as compared with medium (0.43) and large farms (0.45).

25.6% of small farms were technically efficient (0.90 > 1), however, this efficiency decreases to (6.1%) for medium size farmers at first, then it increases to (27.4%) for large size farmers. So the technical efficiency first decreases from small farms to medium farms and thereafter it increases for large farmers.

Most of farms(80.31%) were operated inefficient technically,as only 19.67% of them were technically efficient.

The averages of Pure efficiency were 86.6%, 84.3% and 80.0% for small, medium and large farms respectively.

The technical efficiency ranged between 0.40 to 1.00, 0.50 to 1.00 and 0.09 to 1.00 for small, medium and large farmers respectively. The overall technical efficiency under variable returns to scale varied between 0.33 to 1.00.

In addition 83.6% of all farmers were efficient technically under the variable returns to scale.

Scale efficiency *(SE)* equal to 1 means that the farm is operated at the *Most Productive Scale Size (MPSS)* which corresponds to constant returns to scale, whereas *SE < 1* means that the farm is inefficient technically because of the scale size (Table 3.)

Table 3. Distribution of farmers by their score of Pure Tech Efficiency

Total Farms		Large Farms		Medium Farms		Small Farms		
%	Fre–quency	%	Frequency	%	Fre–quency	%	Fre–quency	Efficiency scale
0	0	0.0	0	0.0	0	–	0	0.10 < 0.30
4.456	13	6.3	6	2.6	3	4.4	4	0.30 < 0.60
11.87	36	13.7	13	13.0	15	8.9	8	0.60 < 0.90
83.67	251	80.0	76	84.3	97	86.7	78	0.90 < 1
100	300	100	95	100	115	100	90	Total
0.33		0.09		0.5		0.4		Minimum
1		1		1		1		Maximum
0.836		0.800		0.843		0.866		Mean
0.11221		0.32546		0.16254		0.15243		Std. Deviation

The mean of SE were 55.4%, 47.2% and 43.1% for small, medium and large farms respectively (Table 4). The results showed an SE scores ranged from 0.11 to 1, 0.09 to 1 and 0.15 to 1 for Small medium and large farms respectively.

Only 24.0% of farms were operating at MPSS as they attained SE score equal to 1, so 76% of farms were operating with either increasing or decreasing returns to scale. this result suggests that scales is a major impediment for efficient potato farming in Al–Ghab region.

Table 5 showed that 14.3%, 10.7% and 75.0% of farms are operating under CRS, DRS and IRS respectively. So proper reallocation of the used resources is necessary to improve the efficiency. About 43 (14.3%) of farmers were working under MPSS, and 32 (10.2%) of farmers were working under decreasing returns to scale, while 225 (75.0%) of them farmers were working under increasing returns to scale. Therefore, farmers with decreasing return to scale should reduce their utilized resources to reduce the production unit costs, while farmers with increasing return to scale should increase their utilized resources to increase their production and achieve optimal scale.

Table 4. Distribution of potato farmers by their score of Scale Efficiency

Total Farms		Large Farms		Medium Farms		Small Farms		
%	Fre–quency	%	Fre–quency	%	Fre–quency	%	Fre–quency	Efficiency scale
19.0	57	24.2	23	22.6	26	8.9	8	0.10 < 0.30
44.7	134	36.8	35	60.0	69	33.3	30	0.30 < 0.60
12.3	37	5.3	5	10.4	12	22.2	20	0.60 < 0.90
24.0	72	33.7	32	7.0	8	35.6	32	0.90 < 1
100	300	100	95	100	115	100	90	Total
0.03		0.15		0.09		0.11		Minimum
1		1		1		1		Maximum
0.6541		0.4311		0.4721		0.5541		Mean
0.2358		0.1524		0.1754		0.2732		Std. Deviation

Table 5. Comparison of potato farmers by Various Returns to Scale

Total Farms		Large Farms		Medium Farms		Small Farms		
%	Fre–quency	%	Fre–quency	%	Fre–quency	%	Fre–quency	Scale Efficient Farms
14.3	43	21.1	20	13.9	16	7.8	7	Constant
10.7	32	13.7	13	12.2	14	5.6	5	Decreasing
75.0	225	65.3	62	73.9	85	86.7	78	Increasing
100	300	100	95	100	115	100	90	Total

So, to attain the level of efficient peers, the inefficient farmers should increase Chemical pesticides, number of irrigation and improved seeds by 18.7, 16.01 and 10.04% respectively, and decrease Labor by 24.5% and of Fertilizers by 14.1%.

Slack Output (Table 6) suggest that on average, inefficient farmers could increase their output by $ 40.47 US. by using the same inputs. The average of actual output $ 6,617 US per 1,000 sq.meters, could be increased with the same level of inputs. To reach the efficient frontier, inefficient farmers (DRS) could reduce labor by 24.51% ($258 US per 1,000 sq.meters) and fertilizer by 14.14% ($82 US per 1,000 sq.meters). Whereas, they could reduce chemicals costs by approximately $2 per 1,000 sq. Meters, irrigation by $18.6 US per 1,000 sq.meters and seed by $109.47 US per 1,000 sq.meters to reach the efficient frontier.

Table 6. Average actual and target output and input quantities for inefficient farmers

Percentage	Target	Slacks	Actual	Variables
0.61	1,427,074.3	8,676.75	1,418,397.58	Output
58.97	3.1	1.15	1.95	Cultivated area
–24.51	170,366.03	–55,322.17	225,688.20	Labor
–14.14	106,658.35	–17,577.1	124,235.45	Fertilizers
16.08	28,772.86	3,987.65	24,785.21	Irrigation
10.05	256,993.34	23,465.14	233,528.20	Seeds
18.72	2,772.39	437.18	2,335.21	Chemicals

Table 7. shows factors influencing Technical Efficiency, where F–test (0.0240) suggest that Tobit Regression Model is valid and it is distinct significant at 1% level and the pseudo R^2 is 27.8%.

Table 7. Factors Influencing Technical Efficiency (Tobit Regression Model)

Significance	Std. Err.	Coefficient	Variable
0.524	0.001233	–0.00022	Age
0.724	0.008214	0.00237	Education
0.091**	0.002088	0.008245	Experience
0.083**	6.50E–05	–0.00111	Experience Square
0.068**	0.010006	–0.0278	occupation
0.025*	0.002489	0.003144	Household size
0.076**	0.05871	0.0333102	membership
0.022*	0.0043452	–0.09872	Farm size
0.074**	0.00614	0.0065884	Farm size square
0.066**	0.03564	0.02244	Seed Type
0.175	0.01233	–0.0012	distance
0.35	0.00051	0.0000425	Household Assets
0.033	0.000323	0.350211	Constant
F(56, 212) = 1.75		Log Pseudo Likelihood = –11.228725	
Prob > F = 0.0240		Pseudo R^2 = 0.2780	

Note: *significant at 5%, ** significant at 1%.

Occupation, Membership, Farming Experience, Farm Size, Seed Type and Household Size have significant influences on technical efficiency. Farmer's age have a negative effect on technical efficiency of the farms, but the relationship is not significant.

Although no significant relationship were found between education and farm efficiency, the increase by one year of education increased the farm efficiency by 0.72%. A positive and significant (at 10% level) relationship was fond between farming experience and farm's technical efficiency. But, the coefficient of Experience Square is negative and significant (10%) which suggest an increase in technical efficiency, at first stage, with the increase in experience, thereafter in the second stage, the increase in experience would reduce the technical efficiency. This is because, farmers with more years of farming experience are aged people who are (generally speaking) more conserved towards modern farming technology.

The farm technical efficiency decreased by 2.7% with farmer's primary occupation, this may be attributed to the fact that farmers who have alternative income from employment, business or any others, are more able to finance their farming activities than those with only farming occupation.

Membership increased the technical efficiency level by 3.3% as compared their peer non–membership. The results showed a positive relationship (p = 5%) between household size and technical efficiency. This may be attributed to the increase in availabi

A negative relationship (p = 5%) was found between farm size and technical efficiency, this may be attributed to that small lands are more easy to control and manage as compared with medium and large one. However, the square of farm size showed a significant positive relation at 10% level, which mean that the efficiency decreases up to a certain point, thereafter it increases with increase of farm size.

The household assets have a positive impact on the technical efficiency, but this insignificant at p = 10%. A positive relationship was found between seed type and farm efficiency but insignificant at 5% level. Which mean that the use of improved varieties of seeds increased the level of farm efficiency.

The relationship between technical efficiency of farm and the distance from the farm to farmer's home was negative but insignificant at p = 10%. The increase in distance by one kilometer will decrease the farm technical efficiency by 1.2%. The farther the farm the greater cost of inputs and outputs transport, management, supervision, etc.

CONCLUSIONS

In this paper, economic analysis of potato production in Al–Ghab region, Hama–Syria, weas provided. The data collected from farmers by questionnaires were analyzed by using the Non–parametric Data Envelopment Analysis (DEA) to determine the technical efficiency of Syrian potato farms.

The main findings are that farmers obtain 47% of potential output from a mix of inputs. At the same time, they lose 53% of their production due to the technical inefficiency. Non–linear relationship was found between farm size and productivity efficiency, so the efficiency is reduced when moving from small to medium size and then raised with the raise in farm size. The highest net farm income per area and highest technical efficiency were shown at Large farms followed by small and medium farm size.

The Scale Inefficiencies (SIE) in Al–Ghab region amounted 53% which suggest that potato farming could be improved substantially.

The highest productivity were recorded in large farms followed by small and medium farms, this is due to technically efficient. So in addition to technical efficiency, the farm size is a major source of farming inefficiency. Therefore, medium farm should be integrated in such a way that eliminate this technical insufficiency.

The technical efficiency level was affected significantly by farmer's experience, occupation, household size, membership, farm size and seed type, as shown by the results from Tobit Regression. This could be taken into account by authorities when plans are proposed to improve farmer's skills by allocating more investment in farm research and extension programmers.

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Effectiveness of simulation models on technical skills among surgeons. A critical review

R. Raimla* and E. Merisalu

Estonian University of Life Sciences, Institute of Technology, Husbandry Engineering and Ergonomics, Fr.R. Kreutzwaldi 56/1, EE51014 Tartu, Estonia
*Correspondence: riin.raimla@emu.ee

Abstract. Based on simulation models the surgeons can train technical skills and improve their functional status of musculoskeletal state. Work in good ergonomic position could reduce and prevent musculoskeletal disorders. The aim of this review is to carry out critical analysis of research on simulation techniques analysing the effectiveness of simulators on technical skills among the surgeons. The search of the articles based on the databases EBSCO, Science Direct and Web of Science. The articles published in 2011–2016 years and not the literature reviews of simulator models in surgery were the selection criteria. Most often the simulator models have used for training of laparoscopic operations, choosing new instruments or introducing new methodologies. Some articles have paid more attention to ergonomic equipment layout in practice to prevent musculoskeletal disorders. It is important to use simulators in the university hospitals, where the young surgeons and medical students are practicing.

Key words: ergonomics, simulator, surgeon, skills.

INTRODUCTION

Many researches have shown that simulators are effective technical devices for training professional skills and test new tools, and good strategy to promote the effectiveness of students and young surgeons. When surgeons use the simulator for training it is needful to pay more attention on workplace ergonomics.

Technical skills means that the person who use simulator can practice more before practicing in patients. With simulator the surgeons can train psychomotor skills, camera navigation and objects transfer. Also, they can train for 2D to 3D perception, two hands coordination and needle suture as well as knots training, organ placing and total needling (Xiao et al., 2013). When professional skills have achieved, the simulator training enables to focus on the special aspects of a surgical procedure (Debes et al., 2012).

The simulators are good to test working on the new tool before buying and using it in operation. Often the instruments in one size used in laparoscopic surgery but the manner of using them varies according to the surgeon's hand size (Gonzalez et al., 2015).

Simulation method is a safe and accessible way to learn surgical procedures outside the operating room. Simulator training programs for surgical trainees have been developed using special simulation laboratories (Buckley et al., 2014). However, the simulation training can never replace practical training, but it does provide a cost-effective and safe environment for surgeons to train their laparoscopic skills (Xiao et al., 2014). Easily and low cost use of the simulator are two important qualities that could be considered by individual trainees in the training programs (Gromski & Matthes, 2011).

The most often problem of testing laparoscopic simulators is that the participants do not realize the importance of the ergonomic factors and till today there is no standard questionnaire and no consensus on how many participants should be included in a study (Jalink et al. (2015). The ergonomic factors are important for posture training, but seldom participants are thinking about them theoretically (Xiao et al., 2013). Work place ergonomics must consider monitor height between the operating surface and surgeon's eye-level height. The operating surface has set to 80% of elbow height, where the optical axis could be perpendicular to the target plane and box could tilt with angle of 20° (Van Veelen et al., 2002; Xiao et al., 2012).

The purpose of our study is to carry out critical analysis of research on simulation techniques to identify effectiveness of simulators on technical skills among the surgeons.

MATERIALS AND METHODS

We searched through the data basis of ScienceDirect, EBSCO and Web of Science to identify scientific papers related to 'ergonomics' and 'simulator' (Fig. 1).

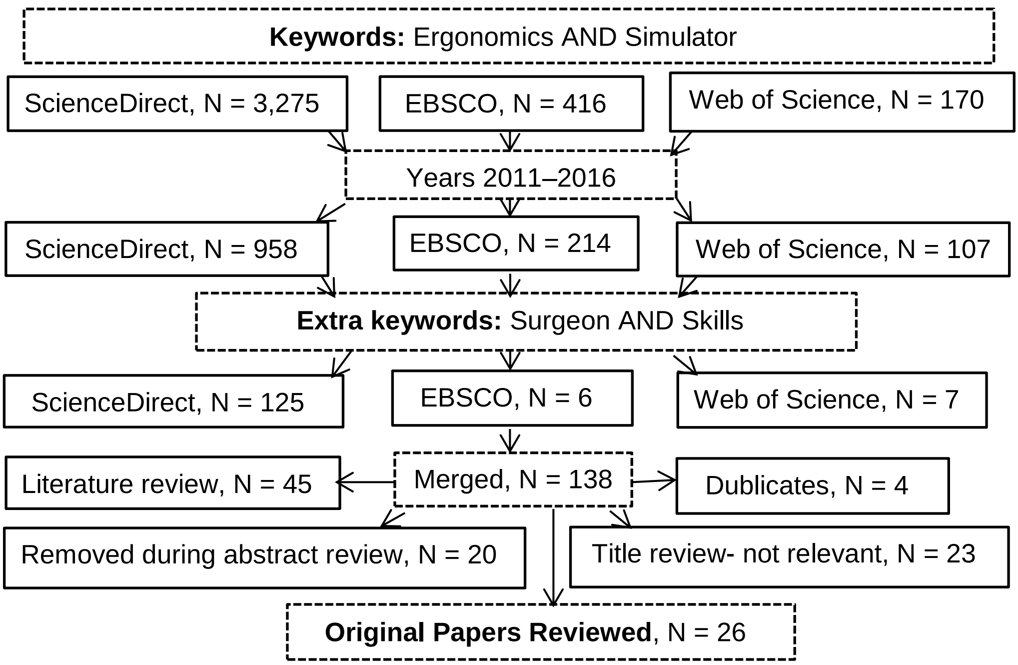

Figure 1. Review of studies flow chart.

Our search strategy yielded 3,275 journal articles in ScienceDirect, 416 in EBSCO and 170 of them in Web of Science. We selected the articles in period 2011 to 2016. When to focus on clinical simulation method and skills' trainings we added the keywords ‘surgeon’ and ‘skills’. After that we removed from list the repeated articles and literature reviews.

Based on the abstract information, we removed the articles not focused on ergonomic aspects, simulator principles or simulator in use, clinical background or not published in English. For critical analysis we yielded 26 studies. The topics included in the results Table 1 and Table 2 are: study, aim, sample, skills’ training, number of sessions, duration of sessions and outcomes.

RESULTS AND DISCUSSION

Our review covers the following outcomes of the studies: ‘new simulator and testing of technical skills’ (n = 8; Table 1) and only ‘testing of technical skills’ (n = 18; Table 2).

There were 8 articles about testing ‘new simulator and technical skills’ (Table 1). Low cost was one principle to make the new model (Xiao et al., 2013; Xiao et al., 2014). The cost difference depends on the components have used. The cost of the simulation model in the study of Tunitsky-Bitton et al. (2016) was 180 $, in Xiao, et al. (2014) – it was 300 € – new Ergo-Lap Simulator was used, and in Burdall et al. (2016) study the cost was 900 £. In latter it was used Selective Laser Sintering printer to carry out 3D printing.

Most the simulators were constructed in the box, the exercises were covered and the camera was showing the results. The demo of video game was used in testing technical skills by Jalink et al. (2015). The video game is showing the results on an acceptable level, but usually it takes more time than a traditional simulator.

In the ‘new simulator and technical skills’ studies, all the used simulators showed acceptable results. Only the question arise, are these articles mutually comparable and statistically confident, when the participant numbers are quite different? For example, 82 surgeons were under the observation in the video game study (Herbert et al., 2015), and only 13 participants were included in the other study (Horeman et al., 2015)

There were 18 articles under the analysis about ‘testing of technical skills’ (Table 2). In addition some studies tested simulator effectiveness (Letouzey et al. 2014; Jalink et al. 2015) and some studies assessed the educational value (Botchorishvili et al. 2012; Enciso et al., 2016a, Enciso et al., 2016b, Enciso et al., 2016c).

Origin of the studies

From a total 18 studies of ‘technical skills’ testing’, five of them were conducted in Netherlands (Luursema et al., 2012; Xiao et al., 2012; Luursema et al., 2014; Groenier et al., 2015; Jalink et al., 2015), four in Spain (Sánchez-Margallo et al., 2014; Enciso et al., 2016a, Enciso et al., 2016b, Enciso et al., 2016c), three in France (Botchorishvili et al., 2012; Letouzey et al., 2014; Morineau et al., 2016), three in United States (Rinewalt et al., 2012; Thawani et al., 2016; Viriyasiripong et al., 2016), one in United Kingdom (Bharathan et al., 2013), and one in Denmark (Vedel et al., 2015) and Hungary (Lukovich et al., 2016).

Table 1. 'New simulator and technical skills' testing' studies

Study	Debes et al. (2012)	Xiao et al. (2013)	Xiao et al. (2014)	Herbert et al. (2015)
Aim	To develop a standardized, graduated, and evidence based D-box.	To develop an inexpensive simulator to help surgeons to improve their skills under ergonomic conditions.	To verify the construct validity of 4 innovative tasks on the Ergo-Lap simulator for training basic laparoscopic skills.	To adapt the paediatric laparoscopic surgery simulator for paediatric single-port laparoscopy.
Sample	Medical and surgical interns (n = 20) and experienced surgeons (n = 10).	Medical students, surgeons, and experienced laparoscopic surgeons (n = 53).	Medical interns and junior surgical residents and laparoscopic specialists (n = 46).	Novices (n = 18), intermediates (n = 16) and experts (n = 7) participants (total = 41).
Simulator	D-box trainer.	Ergo-Lap simulator.	Ergo-Lap simulator.	Pediatric laparoscopic surgery simulator was modified to accommodate a SILS™ port.
Skill training	Peg transfer, sorting pegs, donkey stack, running gut, rubber plate, labyrinth.	Camera navigation and objects transfer; 2D to 3D perception; two hands coordination; pass needle suture and chenille wire through rings, ligation loop.	Transfer beads (coordination skills), transfer tubes (use of graspers), stretch band (both hands coordination), pass needle suture (bimanual coordination skills).	Peg transfer, pattern cut, ligating loop and intracorporeal suturing.
Number of sessions	6 tasks, 8 sessions.	Several tasks, 1 session.	Four tasks, 2 sessions.	4 tasks, 1 session.
Duration of sessions	30 to 60 min.	Not specified.	Different in every task and group (~150–1,200 s). Depended on participant skills.	Different in every task and group (~53.5 – 600 s).
Outcomes	Significant learning curves were obtainned for all construct valid parameters for tasks 4 and 5 and reached plateau levels between the 5 and 6 session.	Insignificant differences were found between the 2 groups. Only 50% of participants paid attention to the ergonomics factors.	Experienced group completed tasks faster than Novice group ($p < 0.001$) and did more errors in tasks.	Outcomes were significantly different between groups in all 4 tasks evaluated; There were no significant differences in outcomes between intermediates and experts for all tasks.

Table 1. Continues

Study	Horeman et al. (2015)	Burdall et al. (2016)	Maricic et al. (2016)	Tunitsky-Bitton et al. (2016)
Aim	To develop a trainer who can quantitatively measure task time, force and motion data.	To develop and trial a model of laparoscopic choledochal cyst excision.	To develop a model that could be used in simulation scenarios and brought experience and training as much as possible in practice.	Design a surgical model for training in laparoscopic vaginal cuff closure and to present evidence of its validity and reliability as an assessment and training tool.
Sample	Thirteen participants.	Senior paediatric surgical trainees (n = 20).	International faculty or paediatric surgeons (n = 39).	Gynaecology staff (n = 19) and trainees (n = 21).
Simulator	New box trainer.	3D printed laparoscopic choledochal surgery model.	A common rubber dummy, oesophagus and lungs model.	FLS box trainer.
Skill training	Laparoscopic multiport (MP), laparoscopic singleport (SP).	Active traction and division; dissection; internal visualization of the upper limit of the cyst and the duct level and transection of the cyst and hybrid anastomosis with porcine esophagus.	Thoracoscopic correction of Oesophageal atresia with tracheaoesophageal fistula (TEF/EA) repair training.	Laparoscopic suturing and specifically vaginal cuff closure. Needle loading, stitch placement, knot tying.
Number of sessions	3 tasks MP and 3 tasks SP, 1 session.	Four key steps, 1 session.	1 session.	3 tasks, 1 session.
Duration of sessions	Different in every task and group (MP – 61+/-16 s; SP – 122 +/-34).	20 min.	Different in groups (40 min vs 81 min).	Different in every task and groups (~8–250 s).
Outcomes	The task, maximum abdominal force, tissue manipulation force, and tilt angles of the left handle are significantly higher in SP.	The 10 delegates that trialled the simulation felt that the tactile likeness was good, was not too complex, and generally very useful.	Time in minutes and number of errors was significantly lower in the high experience group ($p < 0.0001$).	For the construct validity, the participants in the expert group received significantly higher scores in each of the 3 added items than did the trainees.

In total, eight ‘new simulator and skills’ testing’ studies have taken under analysis. Three studies were conducted in Netherlands (Xiao et al., 2013; Xiao et al., 2014; Horeman et al., 2015), two in United Kingdom (Herbert et al. 2015; Burdall et al., 2016), one in United States (Tunitsky-Bitton et al., 2016), and one in Norway (Debes et al., 2012) and Argentine (Maricic et al., 2016).

Period and Duration

In Table 1 and 2 the studies with different duration for every task or group or session have shown (Debes et al., 2012; Luursema et al., 2012; Xiao et al., 2012; Groenier et al., 2015; Jalink et al., 2015; Burdall et al., 2016¸ Enciso et al., 2016a; Enciso et al., 2016c; Morineau et al., 2016) and in other studies were different duration in every task or group or session and depends on participant previous skills (Botchorishvili et al., 2012; Rinewalt et al., 2012; Bharathan et al., 2013; Letouzey et al., 2014; Xiao et al., 2014; Herbert et al., 2015; Horeman et al., 2015; Vedel et al., 2015; Enciso et al., 2016b; Lukovich et al., 2016; Maricic et al., 2016; Tunitsky-Bitton et al., 2016; Viriyasiripong et al., 2016) and some studies did not specify duration (Xiao et al., 2013; Luursema et al., 2014; Thawani et al., 2016). In some studies, the time of tasks have pointed out to achieve the best skills (Debes et al., 2012; Luursema et al., 2012; Groenier et al., 2015; Jalink et al., 2015; Burdall et al., 2016; Morineau et al., 2016). One study had no time limit (Sánchez-Margallo et al., 2014).

Simulation

In total eight ‘new simulator and skills’ testing studies’ have taken under the analysis (Table 1). The box trainer for laparoscopy was constructed to train laparoscopic skills. Ergo-Lap simulator was used in two studies (Xiao et al., 2013; Xiao et al., 2014) and Herbert, G.L. et al. (2015) study was the existing simulator modification. The simulator was printed out with 3D printer (Burdall et al., 2016) and a common rubber dummy was used and constructed simulation model was placed in it (Maricic et al., 2016).

In the ‘technical skills’ testing studies’ the different conditions and technical equipment have used. The box trainer have used in different studies: Surgical Science’s LapSim simulator was used in four studies (Luursema et al., 2012; Luursema et al., 2014; Groenier et al., 2015; Vedel et al., 2015). LAPMentor virtual reality simulator was used in four studies (Bharathan et al., 2013; Enciso et al., 2016a; Enciso et al., 2016b; Enciso et al., 2016c) and a Covidien box trainer was used in two studies (Xiao et al., 2012; Lukovich et al., 2016). Also, the simulator room (Morineau et al., 2016), Nintendo Wii U game console plus Underground game (Jalink et al., 2015) and validated video-trainer suturing model (Botchorishvili et al., 2012) have introduced.

Outcomes

Xiao et al. (2012) have paid an attention on ergonomics. In the ergonomic simulation setting the proper distance of the monitor has included, the optical axis was perpendicular to the target plane, the operating surface was set as 80% of elbow height, and box trainer was tilt as an angle of 20°. Xiao et al. (2012) was doing the experiment with optimal and non-optimal ergonomic simulation setting.

Table 2. 'Technical skills' testing' studies

Study	Botchorishvili et al. (2012)	Luursema et al. (2012)	Rinewalt et al. (2012)	Xiao et al. (2012)
Aim	To evaluate prospectively the educational value and responsiveness of a large series of residents.	To add knowledge of the relation between the development and visuospatial ability of laparoscopic skills.	To measure the amount of improvements over time by residents at different levels of training.	To investigate the influence of ergonomic factors on task performance during laparoscopic training with a box trainer.
Sample	Residents (n = 191).	Students (n = 24).	Surgery residents (n = 20).	Twenty subjects.
Simulator	Validated video-trainer suturing model similar to that used in the MISTELS skill set.	Surgical Science's LapSim.	Laparoscopic box trainers.	A Covidien box trainer.
Skill training	Suture with each hand and porcine nephrectomy.	Grasping and instrument navigation.	Bead drop and rope drill, precision cutting and endo-loop, checker-board, endostitch, intracorporeal suture/ knot tying.	Optimal ergonomic simulation setting (A) and non-optimal ergonomic simulation setting (B). Tasks were suturing.
Number of sessions	Not specified.	2 tasks, 4 sessions, 8 weeks.	5 tasks, 1 session.	2 tasks, 1 session.
Duration of sessions	Different in every day and hand (~114.7–299 s).	30 min.	Different in every task (5–10 min).	Timing score were defined based on the completion time and a cut-off time of 900 seconds.
Outcomes	Significant improvement in time and technical scores for both laparoscopic suturing and porcine nephrectomy was noted.	Correlations for all performance measures over all sessions showed the motion efficiency to correlate highly with both damage and duration.	Scores improved in all the categories ($p < 0.05$) except for the bead drop/rope drill, which improved on objectively measured tasks only.	The mean score of G1A was significantly higher than G2B. Both groups performed better under condition A than under B.

Table 2. Continues

Study	Bharathan et al. (2013)	Letouzey et al. (2014)	Sánchez-Margallo et al. (2014)	Groenier et al. (2015)
Aim	To validate a virtual reality simulator for the training and assessment of laparoscopic tubal surgery.	To evaluate the value of a box trainer simulator in laparoscopy training.	To assess the usefulness of the evaluation system of surgical skills based on motion analysis of laparoscopic instruments.	To examine the influence of cognitive and psychomotor ability on the training duration and learning rate.
Sample	Gynaecologists (n = 34).	Residents and gynecology (n = 12).	Surgeons (n = 6).	Novices (n = 98).
Simulator	LAP Mentor VR laparoscopic simulator.	da Vinci1 surgical robot.	SIMULAP.	Surgical Science's LapSim v.3.0.10.
Skill training	Salpingectomy and salpingotomy.	Timing of the hands, movement through space, cutting in a defined plane and suture of synthetic material.	Synthetic fabric cutting task, organic tissue dissection task, organic tissue suturing task.	Hand-eye coordination.
Number of sessions	2 tasks, 1 session.	4 tasks, 1 session.	3 tasks, 1 session.	6 sessions.
Duration of sessions	Different in every task and group (~170–313 s).	Different in every task and sessions (60–300s).	No time limit.	30 min.
Outcomes	Both tasks revealed significant differences among 3 group times and total number of movements.	Technical performance was significantly higher after the training.	Regarding the dissection activity, experienced surgeons need less time (p = 0.006) and less length with both instruments (p = 0.006 for dissector and p = 0.01 for scissors).	Participants with better psychomotor ability, shows better results across all sessions on all outcome measures.

Table 2. Continues

Study	Jalink et al. (2015)	Luursema et al. (2014)	Vedel et al. (2015)	Enciso et al. (2016a)
Aim	To face validity of the game.	To develop the method for generating intermediate performance variables and investigate the development of laparoscopic skills.	To examine does medical students can facilitate laparoscopic procedural tasks to residents using a virtual reality simulator.	To evaluate a structured training model for laparoscopic gynaecologic surgery skills.
Sample	Surgeons (n = 77).	Beginner group (n = 16) and experienced group (n = 9).	Residents (n = 51).	Novice gynaecologists (n = 21).
Simulator	Nintendo Wii U game console plus Underground game.	LapSim laparoscopic simulator.	LapSim from Surgical Science.	LAPMentor virtual reality simulator.
Skill training	It is supposed to train eye-hand coordination, depth perception, inverse movements, and bimanual operation.	Suturing, camera navigation and coordination, precision and speed skills, handling intestines, fine dissection task.	Camera navigation, coordination, lifting and grasping, cutting, clip applying, fine dissection, tubal occlusion, salpingostomy, and salpingectomy.	Eye-hand coordination, hand-hand coordination, cutting tissue, dissection and intracorporeal suturing.
Number of sessions	1 session.	5 sessions.	Unlimited attempts.	5 tasks, tasks were repeated until they achieved a predetermined proficiency level.
Duration of sessions	5–15 min.	Not specified.	Different in every task and group (~200–230 min).	7 hours.
Outcomes	The majority of the participants (93.1%) said that The Underground game is a useful tool for learning basic laparoscopic skills.	Damage performance differentiated the most between groups and proficiency values; Motion performance variables differentiated the least.	The first group spent significantly longer time training basic modules ($p = 0.001$) but significantly fewer attempts to pass the upgraded salpingectomy module.	After the receiving training the participants performed all the tasks faster, using fewer movements.

Table 2. Continues

Study	Enciso et al. (2016b)	Enciso et al. (2016c)	Lukovich et al. (2016)	Morineau et al. (2016)
Aim	To validate a structured training model for efficient development of urological laparoscopic surgical skills.	To assess a laparoscopic training model for general surgery residents.	To compare the acquired skills in using straight vs. curved instruments in a laparoscopic training box and underline their importance in the laparoscopic curriculum.	To test framework qualitatively, as a methodological tool for identifying task management deficiencies.
Sample	Urology residents (n = 16).	Residents (n = 12).	Five-year medical students (n = 20).	Nurses (n = 13).
Simulator	LAPMentor virtual reality simulator.	LAPMentor virtual simulator.	The Single Incision Laparoscopic Surgery port by Covidien.	Simulation room.
Skill training	Balanced combination of simulation and animal training. Eye-hand coordination, hand-hand coordination, transference of objects.	Eye-hand coordination, hand-hand coordination, the transfer of objects, placing clips and cutting.	Peg transfer, curved peg transfer, loops and string.	A case of respiratory failure and cardiac arrest.
Number of sessions	3 tasks, 2 sessions-before and after the course.	4 exercises, session number are not specified.	3 tasks, 7 sessions.	2 tasks, 4 sessions.
Duration of sessions	Different in every task and sessions (~65.69–253.15 s).	7 hours.	Different in every task and sessions (~94–367 s).	10 min.
Outcomes	After the course, the participants exhibited a faster performance and the number of movements was significantly reduced in all of the tasks.	After the course, the participants performed all the tasks faster, increasing the speed of movements.	All the participants achieved significantly shorter task completion time on the last day; Group-S reached significantly higher task completion time with curved instruments.	The framework opens perspectives for designing ergonomic work situations and training caregivers.

Table 2. Continues

Study	Thawani et al. (2016)	Viriyasiripong et al. (2016)
Aim	To evaluate resident performance and assessed the effect of simulation training on performance in the operating room.	To analyse head motion during laparoscopic skill tasks.
Sample	First – (n = 3) and second – (n = 3) year residents.	Surgeons (n = 19).
Simulator	NeuroTouch VRH simulation.	EDGE laparoscopic simulator plus MUSE headband.
Skill training	Drill shown outside of right nasal passage. The endoscope within the right nasal corridor. Opening right sphenoid ostium. Blood accumulating on the endoscopic camera, based on excessive contact with the nasal mucosa.	Peg transfer and suturing task.
Number of sessions	2 sessions.	2 tasks, 1 session.
Duration of sessions	Not specified.	Different in every task and group (~107–279 s).
Outcomes	Simulation training was associated with an increase of performance scores in the operating room averaged over all measures ($p = 0.0045$).	Average acceleration analysis showed statistically significant differences between the groups on both vertical and horizontal axis in the laparoscopic suturing task.

Similar methods have used but different participants have observed in the Enciso et al. (2016a; 2016b; 2016c) studies. The eye-hand coordination, hand-hand coordination, and transference of objects registering time and movement metrics have trained with the virtual reality simulator. The participants passed theoretical session (one hour) and a hands-on session on simulator (7 h) and on animal model (13 h). After the training course the participants performed all the tasks faster. Animals who were in the Enciso et al. (2016a; 2016b; 2016c) studies were anesthetized and attended by veterinarians to assess their welfare.

Thawani et al. (2016) stressed on limitations which include a small number of subjects and bias adjudication − although the identifying of trained and untrained subjects was blinded. In further studies the using of proposed methods may better describe the relationship between simulated training and operative performance in endoscopic neurosurgery.

Sometimes the participants did not play the full and final version of the simulator's game, was also highlighted as the limitation of the simulators' studies (Luursema et al., 2014; Jalink et al., 2015).

Maricic et al. (2016) have used the questionnaire to evaluate the simulator ergonomics, the anatomical features and functionality of the simulation model. The study of Xiao and co-authors (2012) clearly demonstrated how the optimal ergonomic simulation setting and posture of a surgeon leads to better task performance. Some studies have included one or more questions about simulator ergonomics into the questionnaire (Botchorishvili et al., 2012; Bharathan et al., 2013; Jalink et al., 2015; Vedel et al., 2015; Lukovich et al., 2016). Two studies were talking about what was effective for practicing basic laparoscopic skills in an ergonomic manner (Xiao et al., 2013 and Xiao et al., 2014).

In Maricic et al. study (2016) showed that the new model regarding anatomical and functional characteristics as useful specific advanced training method was widely accepted among participants.

The Fig. 2 demonstrate theoretical framework for clinical task management skills (Morineau et al., 2016).

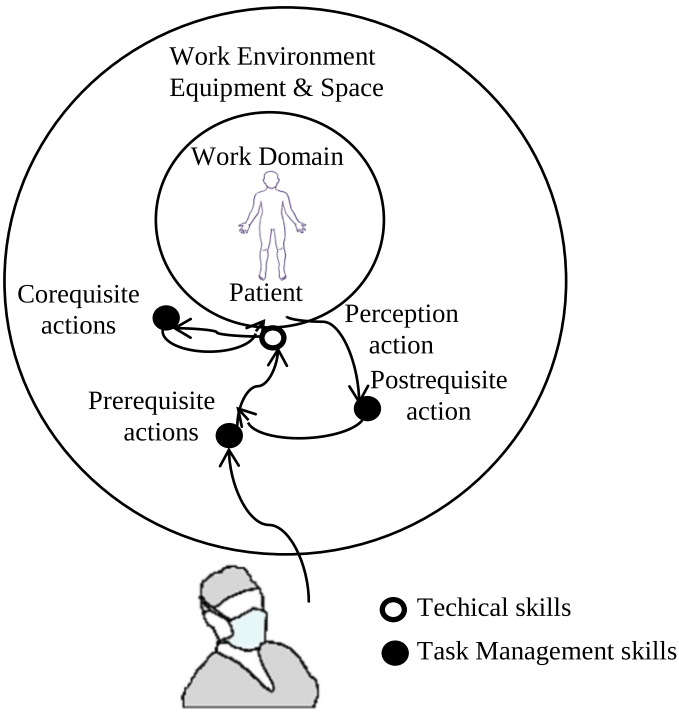

Figure 2. A framework for clinical task management skills (Morineau et al., 2016).

The Fig. 2 summarise the objective of the observed studies to develop the task management skills by proposing a framework focusing on task management deficiencies qualitatively. So far, it is not possible to use this framework as an 'on hand' tool for evaluating care performance in the course of educational process. However, it open some significant perspectives to improve understanding of performance deficiencies during care delivery inside heterogeneous medical teams.

The most of studies showed significant differences between the groups – after the simulator training the participants demonstrated faster performance (Botchorishvili et al., 2012; Luursema et al., 2012; Rinewalt et al., 2012; Xiao et al., 2012; Bharathan et al., 2013; Letouzey et al., 2014; Luursema et al., 2014; Sánchez-Margallo et al., 2014; Groenier et al., 2015; Vedel et al., 2015; Enciso et al., 2016a; Enciso et al., 2016b; Enciso et al., 2016c; Lukovich et al., 2016; Thawani et al., 2016¸ Viriyasiripong et al., 2016). That shows necessity for simulation training.

Based on yielded 26 studies, we can say that simulators are effective for training of technical skill and help to pay attention on functional status of musculoskeletal system among surgeons.

CONCLUSIONS

Our critical review focused on an effectiveness of training on technical skills with different simulators among the surgeons. The main topics were testing of new simulator with training of technical skill and only training of technical skills with existing simulator. To find more studies about the measurements of the effects of the simulator training on functional status of musculoskeletal system the other search programs could be in use. In majority studies the authors who tested the simulators have achieved positive results of surgeons' technical skills, but they used different exercises. Two hands coordination, needle suture, 2D to 3D perception, knots training, organ placing and total needling were the most often used exercises.

Based on this critical review we can conclude that simulators are important method for students and young surgeons to train technical skills effectively. In further studies the researchers should pay more attention to work place ergonomics, position and musculoskeletal system status.

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Fair Trade and social responsibility – whose duty? Estonian consumers' attitudes and beliefs

I. Riivits-Arkonsuo[1,*], M. Ojasoo[1], A. Leppiman[1] and K. Mänd[2]

[1]Tallinn University of Technology, Faculty of Economics, Institute of Business Administration, Ehitajate 5, EE19086 Tallinn, Estonia
[2]MTÜ Mondo, Telliskivi 60A, EE10412 Tallinn, Estonia
[*]Correspondence: iivi.riivits@ttu.ee

Abstract. This article investigates how the Estonian consumers endorse the idea of Fair Trade (FT) and understand the principles of social responsibility. The article is based on a study on Fair Trade and social responsibility conducted in 2014. The study examined the consumers' attitudes and beliefs associated with FT and local Estonian agricultural production. The article aims to compare if there are any difference in the beliefs and attitudes among the Estonian consumers towards supporting local farmers and producers versus supporting the FT ideas which benefit the farmers and producers from the Global South. The authors fully recognise that there is no competition among these two groups *per se*, but the perception exists in the minds of the consumers. The respondents of the nation-wide representative sample (n = 1,007) evaluated the responsibility of different economic agents such as public sector, retailers, suppliers, producers, and consumers. Most of the respondents regarded the principle of social responsibility as giving the priority to local Estonian agricultural production. The Estonian consumers tend to be sceptical about the benefits of FT or the workers and farmers from the developing countries. The awareness and knowledge about FT ideas is not high.

Key words: Fair Trade (FT), social responsibility, consumer behaviour, attitude and beliefs, the local agricultural production.

INTRODUCTION

Demand for products produced under high ethical standards and socially responsible ways is increasing all over the world (Dragusanu et al., 2014). The annual report of Fairtrade International (2015–2016) demonstrates that in 2014 global Fairtrade sales rose 16% and reached € 7,3 billion (Driving sales 2016).

The most noted definition of FT as it stands today was created by FINE:
'*Fair Trade is a trading partnership, based on dialogue, transparency and respect, which seeks greater equity in international trade. It contributes to sustainable development by offering better trading conditions to, and securing the rights of, marginalized producers and workers – especially in the South. Fair Trade organizations (backed by consumers) are engaged actively in supporting producers, awareness raising and in campaigning for changes in the rules and practice of conventional international trade.'* (FINE 2006).

Governments have a significant role to play in shaping the public policy environment in which businesses operate. Moreover, the government can play a significant role concerning setting and supporting socially responsible production, especially such production that is locally applicable, and ensuring that social standards and legislation are mutually reinforcing.

In addition to the public sector plays in its own country, we, cannot underestimate the institutional impact on empowering the workers and smallholders to be aware of social and/ or FT standards and be able to meet and benefit from them. A number of governments, including Canada, Switzerland, USA and the United Kingdom, have initiated 'green' procurement programs, focusing on a variety of goods and services. Also, many governments have used public procurement to advance targeted social goals, such as decent employment, anti-discrimination, and human rights. (Kramer et al., 2005) It is symbolic that several institutions within the EU have committed to serving only FT certified coffee and tea at their meetings (Shreck, 2005). The European Union Procurement Directives establish detailed rules which must be observed when awarding public contracts and Directive 2014/24/EU must have been transposed into national laws by April 2016. The Estonian draft is dealing with environmental and social conditions of public procurements, allowing FT products to be subject to the national legislation and practice.

Business corporations such as suppliers and retailers have an important role in supporting FT business. The importers and exporters in the food sector are integrating sustainability and transparency into their supply chain. For instance, Starbucks markets FT coffee as one of its lines being the largest purchaser of FT coffee in North America (Berndt, 2007). Fazer, one of the largest corporations in the Finnish food industry, has declared that since 2017, all its cocoa is fully Fairtrade certified. UTZ, a program and label for sustainable farming, (meaning 'Good Coffee' in the Mayan language Quiché, UTZ homepage) works based on principles which to certain extent meet the ones of the FT and aims to empower farmers making their business more viable. Estonian confectionery company Kalev was the first in the Baltic countries to join the UTZ Certified programme, and using sustainably produced cocoa. By the end of 2016, Kalev had all its chocolate made from UTZ certified cocoa.

Small or medium-size companies likewise the farmers have different approaches to Corporate Social Responsibility (CSR) than large companies. The related literature indicates that small companies are not eager for mandatory reporting of CSR activities or specific legislation. Personal values of local producers and farmers are the key factors of intrinsic motivation toward responsible business (Baden, et al., 2009).

Consumer demand is the primary driver for businesses. Pelsmacker and colleagues (2006) have concluded that the higher price is a significant hurdle that limits the eventual penetration of the FT product. At the same time, there are surveys (Hustvedt and Bernard 2010; Andorfer & Liebe, 2012; Dragusanu et al., 2014) that indicate that consumers are willing to pay more for FT and socially responsible ways of production. The consumers have the option to choose ethically-produced products (including FT) over non-ethical products. The previous studies have demonstrated that regardless of the fact that consumer's report positive attitudes toward ethical goods, their intentions and behaviours often do not follow suit (White et al., 2012).

Thus, FT and social responsibility overlap in terms of sustainable production. As the members of a consumerist society, we are responsible for using non-renewable resources in a sustainable manner. Responsibility is the bridge between our values and our actions. However, a question remains: whose responsibility is dominant and supreme in supporting FT and socially responsible production?

In the literature, the social responsibility landscape is well established (Pelsmacker et al., 2006; Baden et al., 2009; Hustvedt & Bernard, 2010; Andorfer & Liebe, 2012; Dragusanu et al., 2014). Likewise, FT-related literature brings attention to the consumer behaviour, attitudes and beliefs. Teneta-Skwiercz (2016) examines acquaintance with the FT idea in Poland, Coelho (2015) provides information about FT consumers' values and lifestyle in Portugal. Kapusuz & Kimzan (2016) demonstrate the role of the FT trust on the relationship of FT knowledge, adhesion, and willingness to pay FT premium in Turkey. Darian and others (2015) analyse consumer motivations for purchasing FT coffee. Chatzidakis and others (2014) identify the most important determinants of consumers' support for the FT movement in the United Kingdom. Pedregal & Ozcaglar-Toulouse (2011) answer on the example of France consumers to the question why does not everybody purchase FT products.

This article is focused on examining how the Estonian consumers understand the idea of Fair Trade (FT) and the principles of social responsibility. The study brings attention to the consumers' attitudes and beliefs associated with FT and compares the attitude toward supporting local Estonian agricultural production.

A better understanding of citizens' expectations of implementing FT and socially responsible production helps contribute to the cooperation between concrete stakeholders more effectively (Dragusanu et al., 2014). Driven by this, the authors of the current article take into consideration the responsibilities of different stakeholders such as public sector, retailers, suppliers, producers, and consumers.

MATERIAL AND METHODS

Sampling procedure

The study was based on a probability sample of Estonian consumers. Face-to-face interviews (n = 1,007) were carried out by the research agency Turu-uuringute AS (Estonian Surveys Ltd.) in September 2014. Respondents were selected from a random sample to guarantee the proportional representation of all Estonian counties and habitat types in the sample. The territorial model of the sample has been compiled by the population statistic database of the Estonian Statistical Office. The computer-assisted personal interviews (CAPI) were conducted in the respondents' homes in Estonian and Russian.

The survey exploited the representative probability sample concerning general demographic criteria. Thus, the results can be generalized to the Estonian population, with a margin of error for a 95% confidence interval.

Survey instrument

The construction of questionnaire adapted the logic of Ajzen's socio-cognitive model of planned behaviour (Ajzen, 1991). This model explains attitude, intention, and behaviour relations.

Asking awareness of FT label, dichotomous yes/no measures were used. To measure the extent to which the respondents agree or disagree with series of the statement and how they assess the importance of these statements four-point Likert scale was used. In this study, the survey instrument and collected data was used according to the needs of an Estonian non-profit organisation Mondo. NGO Mondo is devoted to development cooperation, global education and humanitarian aid.

An overview of the conceptual framework of current article is provided in Fig. 1. First, we examined how the respondents understand the idea of FT.

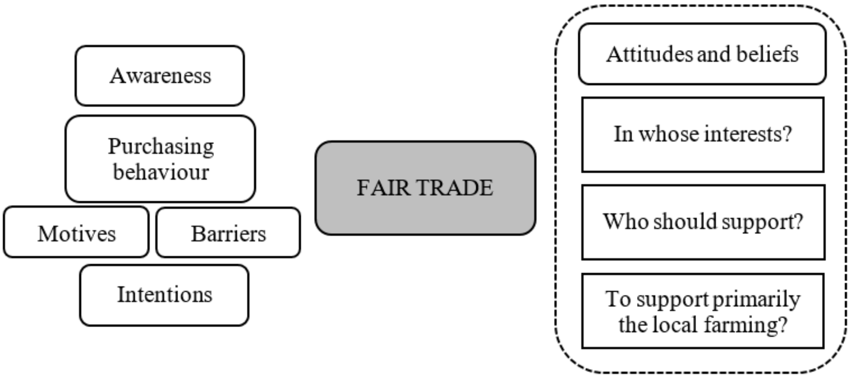

Figure 1. Conceptual framework for the study.

Next, we measured the motives and barriers for purchasing FT products followed by asking the buying intentions for the future. The questionnaire included the statements related to attitudes and beliefs to understand in whose interests FT works and who would support the FT idea in Estonia. Furthermore, we addressed the question to find out the probable gap between willingness to support FT in developing countries and local, Estonian farming.

The statistical analysis was conducted with SPSS version 22.0. Descriptive statistics such as frequency and percentage distributions likewise parameters describing the location and standard deviation were applied in the analysis.

RESULTS AND DISCUSSION

Awareness and knowledge of FT

To measure the awareness of FT label, the logo was shown to the respondents (Fig. 2) 29% answered that they have seen this logo.The awareness was much lower compared to the quality labels in Estonian food market such as the *best Estonian foodstuff* (74%) and *the sign of national flag* (77%) asked from the same sample (Riivits-Arkonsuo et al., 2016). On the other side, the Estonian Food Industry Association, in cooperation with the retail food chains, has consistently promoted both labels intending to provide clear

Figure 2. The logo shown for asking the awareness.

information to consumers of food products in the local Estonian origin. There have not been such long-term continuous campaigns to promote Fairtrade labelled products.

The survey instrument included the answer options for measurement the FT knowledge. 32% believe that FT means the payment of a fair price for the producers. 16% see the FT as the fight against poverty. 25% find that it stands for applying the ethical principles, 13% an ethical business practice. 23% associate it with trustworthiness while 8% suppose that it is just a marketing trick.

One-fourth (26%) of respondents do not have any idea concerning FT regardless of the answer options shown during the interviewing.

We can report statistically high and significant differences between respondents' background variables and variables describing the meaning of FT. The level of statistical significance was set at p-value is 0.05. Estonian respondents believe significantly more that FT means payment a fair price for the producers (37% as compared to 21% of the Russian respondents). Likewise, younger respondents (15–39) agreed with such an argument significantly more compared to older respondents. The respondents speaking Russian associated FT with good and reasonable price (24%) significantly more compared to Estonian native speaking (17%).

The extent of agreement – FT as a system operates and works in the interests of workers and farmers in developing countries

Before asking the agreement with the statement 'Do you agree that FT system operates and works in the interests of workers and farmers in developing countries', the following explanation worded by NGO Mondeo, was shown and read to the respondents: '*The FT is a system that holds the interests of smallholder farmers and plantation workers in the developing countries. The FT label that is displayed on certified products guarantees the payment of a fair price for farmers in developing countries, additional income for the communities and ensures that in production has not been used either the child labour, forced labour or damaged environment.'* A 4-point, Likert-type measurement scale was used, where 1 referred to 'fully agree', 2 'rather agree', 3 'rather disagree', and 4 'fully disagree'. 5% of respondents rated this statement '1 = fully agree', 33% 'rather agree', 25% 'rather disagree', and 16% 'fully disagree'. By excluding the non-responses, we get the mean value 2.66 (SD 0.877). That is, the respondents tend more not to believe FT to operate in the interests of workers and farmers in developing countries (41% disagree) than believe the statement (only 5% agree entirely, and 33% rather agree).

Motivation for purchasing FT products

22% of those respondents who have ever purchased FT products (n = 398,) believe that in so doing they can improve the standard of living of the people in developing countries. 15% support any socially responsible production. In the study, 10% stated that they know and trust the policy of FT. 7% recognize that purchasing such ethical products makes them feel better. On the other hand, 43% cannot name the reasons for purchasing FT products. Such a figure among those who have purchased at least once FT products indicates relatively low knowledge about the FT principles.

Barriers for purchasing FT products

61% (n = 602) of respondents do not buy the FT products. Those who reported not having purchased such products, were asked for reasons. 35% answers revealed a lack of knowledge, 9% a lack of trust. 33% stated that the products were not available in the market, or it was difficult to recognise them on the shop shelves. By the opinion of 19%, such products are not on sale in stores where the respondents are accustomed to make their everyday purchases. Offering the FT-products is not sufficient and makes those products out-of-reach especially to the people from rural areas (23%). The results demonstrate the high statistical difference between the respondents from the capital area where only by 5% FT products are not available.

The intention to purchase FT products in the future

For the asking of this question interval scale was used where 1 referred to 'definitely yes' and 4' definitely not'. Almost a half (47%) of the respondents would buy the FT products in the future, 28% would not. By excluding the non-responses, the mean value is 2.27 (SD 0.886).

Attitudes and beliefs – who should support the idea of FT?

The respondents evaluated the responsibility of the different economics agents, such as government, retailers, suppliers, producers and consumers. The Table 1 presents the results.

Table 1. Whose responsibility is to support the idea of FT, n = 1,007, Estonian population 15+

Should be supported by…	1 = Yes	2 = Rather yes	3 = Rather no	4 = No	Mean	SD
...Estonian companies that use raw materials from developing countries	33%	36%	6%	4%	1.78	0.808
...the local retail chains and supermarkets	28%	41%	9%	4%	1.85	0.781
...the local authorities and governmental institutions	22%	29%	16%	9%	2.16	0.977
…the consumers purchase behaviour	22%	34%	16%	9%	2.16	0.950

69% of respondents answer that Estonian companies that use the raw materials from developing country are responsible for supporting the FT idea. 69% think that the local retail chains and supermarkets while 51% think the local authorities and governmental institutions are responsible. 56% of respondents believe that consumers with their positive buying decisions toward FT products over the non-buying can support the FT idea.

Such results can be seen in the light of belief in the just-world theory proposing that people have a need to believe that the world is a just place where people receive the rewards and/or punishments they deserve. Just-world theory in the context of FT (White et al., 2012) means that the consumers perceive injustice toward producers who often are not treated fairly.

Our study results reveal that for 20% is very important and for 46% rather important the producers who utilize the raw material from developing countries would join the practices of Estonian confectionery producer Kalev. As mentioned above, Kalev is the first production company in the Baltic countries following the UTZ Certified programme and use sustainably produced cocoa.

Whether to support the local Estonian farmers or farmers in the developing countries?

With the statement *'it is responsible to support primarily the local producers and farmers'* agrees fully 66% and 'r*ather*' agrees 22%, as such, 88% gives the priority for the local Estonian agricultural production. Such result is expected in the Estonian context and indicates significant diversity in beliefs and attitudes towards supporting the Estonian farmers and producers versus supporting the FT ideas. In this respect, Estonia is still in the developing phase and needs a few more years of constant work, advocacy and outreach to get to the level of, e.g. Finland, in its understanding of solidarity and accountability.

The Fig. 3 depicts summary of the survey results placing the figures to the conceptual framework of the current study.

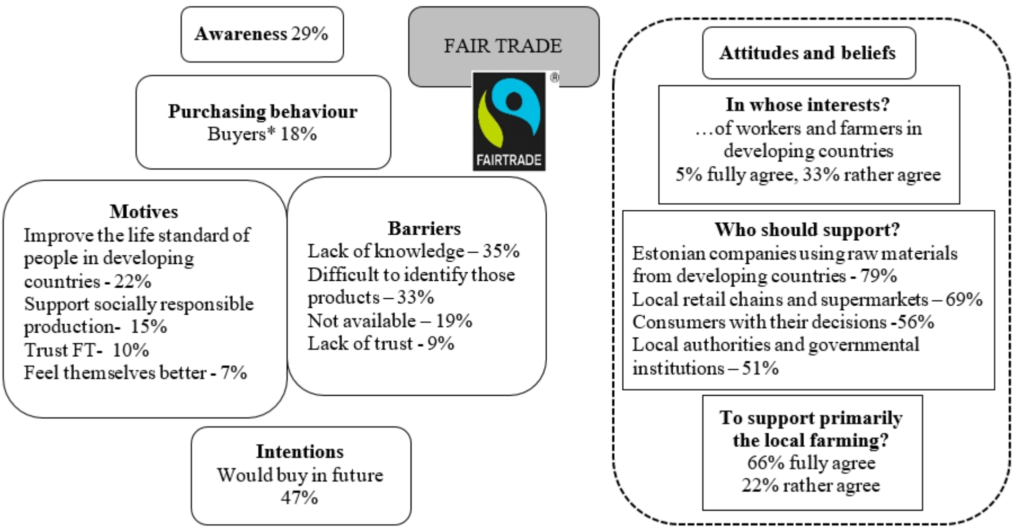

Figure 3. The survey results, Estonian nation-wide sample, age 15+ … n = 1,007.

Awareness question was asked from all 1,007 respondents, purchasing behaviour questions (* in figure) including the motives only from those who had ever purchased any FT products. Barriers questions, likewise the statements related to attitudes and beliefs were estimated by all respondents.

Based on the examples of the other countries, Estonian government should support both FT product (such as fruits, coffee, tea, sugar etc) and local production instead of taking account only the cost-benefit analysis and conditions. As suggested by Kramer et al. (2005) in the cases of procurements one of the main criteria could be social goals and sustainability of local producing.

Study of Castaldo et al. (2009) shows that socially oriented companies with strong SCR performances can achieve competitive advantage in those areas where trust is crucial in determining consumer choices, provided that the companies have the social reputation expected to accompany it.

Are the research findings consistent with previous empirical studies in literature?

What comes to comparing the values with other peer-review publications then for 41% of the student sample in Poland the idea of FT is unknown (Teneta-Skwiercz, 2016). Among Estonian students' sub-group this figure was 17%.

We can compare the motives and barriers among students in Estonia and Poland. 74% of the Polish students (n = 115) do not buy any products with FT labels (Teneta-Skwierz, 2016) in Estonia 80% (± 9.3%). Those who decide to buy these goods believe that by doing that they will help to change the situation of producers and farmers (13% in Poland and 37% in Estonia), and help to develop local societies in developing countries. The main reasons for the lack of interest in FT are unfamiliarity with FT rules (48% in Poland, 35% in Estonia) and places (shops) where these products could be bought (36% in Poland 25% in Estonia).

The Czech researchers Roubik & Mazancova (2017) report that 88% of student sample (n = 135) buy FT certified products (against Estonian students' sub-group 20%). However, they explain that such high rate might be caused by a newly installed machine with FT products at one of the buildings Czech University of Life Sciences Prague.

In Finland the awareness FT label is high (81%). Due to the nationwide sample (n = 1,022), the results of the survey conducted in 2015 by professional research agency Taloustutkimus Oy are the most comparable with results of the current study. The study results reveal that the Finnish consumers' attitudes and beliefs towards supporting FT and understanding about the social responsibility are rather advanced. (Reilu Kauppa Ry, 2015).

CONCLUSIONS

This study addresses the positioning Estonian consumers' awareness, attitudes and beliefs concerning FT idea and social responsibility. The results indicate that consumers' attitudes and beliefs towards supporting FT and understanding about the social responsibility are relatively inchoate. The majority posits the view that social responsibility means giving priority for local Estonian agricultural production. The consumers tend not to believe the FT to operate in the interests of workers and farmers in developing countries. We can attribute that attitude to ignorance as well as to the level of the comprehension of general global solidarity. The Estonian consumers who, although having come a long way from the Soviet-time approach of central economy and state responsibility followed by raw capitalism and the cultivation of liberal trade and market, are still yearning for personal wealth at the expense of those less fortunate or far away.

Many Estonians are also hesitant in believing into the individual power of changing the global situation. Rather than seeing success as a sequence of small steps that need also individual efforts, most social, economic or environmental changes are still widely being regarded as big happenings. However, the belief that Estonian local farmers and producers need more attention and support is a hopeful sign and precondition to extend the solidarity also to the farmers and producers from the developing countries. Considering that FT labelled products and concepts were first introduced to Estonia only in 2007 (Õiglasel kaubandusel …Fairtrade Estonia homepage), we can regard the results of the study promising.

Study results reveal, however, that whereas the attitude to personal choices remain to be desired, the expectations to the CSR are high – according to the study, the main responsibility for supporting FT should fall on such Estonian companies that use the raw materials from developing countries. This puts pressure of the businesses to be more socially responsible not only within Estonia but also in their dealings globally. From a managerial perspective, it is the customers' demand on one hand and the need for competitive advantage to beat the competition and attract good employees on the other hand that have been the biggest push to CSR and trade fairly. Moreover, the new generation of social entrepreneurs and more responsible, who see their companies as extensions of their own values, are putting sustainability and win-win attitude above quick gain and extraction of recourses by creating an economy that is benign by design, redesigning the process to create sustainable economic models for their businesses.

For example, there are number of Estonian companies that have Fairtrade-certified products and almost all the supermarkets, not to mention special stores, cafes and restaurants, have made such products available.

The local retail chains and supermarkets are, according to the study, more responsible for supporting FT than local authorities and governmental institutions. It is the task of the advocacy non-profits to work with the public sector to stress its role in global fair trade to make and implement policies that provide a living wage to farmers and producers, prohibit child and slave labour and advance environmental sustainable production not only locally but globally and ban the use of unfairly produced and traded raw materials and products in the local market. In other words, the public sector can ensure that the farmers and producers in local as well as in the other countries are treated equally by the wholesalers, retailers and consumers even if the laws in the developing countries are not doing so. According to the European procurement policy, no advantage should be given to local production because as a single market, we cannot prefer Estonian good over the French ones. However, the public procurement can and should always state quality and social and environmental standards of the goods its procures above the cheap prices.

Finally, the consumers with their purchasing decisions are the main driver for FT products. Part of these people who are driven by the beliefs that FT means paying fair price to the farmers, fighting against the poverty, and improving the standards of life of the people in developing countries who are also our main food providers can be seen the current and upcoming segment to prefer fairly produced and environmentally sustainable. Due to Estonia's proximity to Finland, goods as well as attitudes transmit fast. Although there will always remain consumers who argue that the attitude of if we don't like what a company is doing, we should stop buying their products and force them to change, would not change the world, the examples of the countries with long standing history of FT and conscious consumerism show that small steps taken by thoughtful consumers – to recycle, to eat locally, to buy a blouse made of organic cotton instead of polyester – can change the world.

Although the construction of survey instrument was derived from the logic of Ajzen's socio-cognitive model of planned behaviour, the findings of this article don't explain the relationships among attitude, intention and behaviour. The limitation of this study needs to address the possible avenues for the future research.

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Livestock manure management practices in rural households in Tapanuli Utara regency of North Sumatra

H. Roubík[1], J. Mazancová[1,*], R.C. Situmeang[2], A. Brunerová[3] and T.M. Simatupang[2]

[1]Czech University of Life Sciences Prague, Faculty of Tropical AgriSciences, Department of Sustainable Technologies, Kamýcká 129, CZ 165 00 Prague, Czech Republic
[2]Del Institute of Technology, Faculty of Industrial Technology, Department of Engineering Management, Kabupaten Toba Samosir, Sumatera Utara ID 22381, Indonesia
[3]Czech University of Life Sciences Prague, Faculty of Engineering, Department of Material Science and Manufacturing Technology, Kamýcká 129, CZ 165 00 Prague, Czech Republic
[*]Corresponding author: mazan@ftz.czu.cz

Abstract. Livestock manure management is a big challenge for low income economies including the region of North Sumatra, Indonesia. Currently, low percentages of manure managed cause illegal disposals, and negative impacts on public health and environment. Therefore, the objective of this study was to assess the current trends among livestock manure management practices in rural households and to recognize potential problems with it. The questionnaire survey using randomly selected households (n = 196) was administered in the province of North Sumatra, Tapanuli Utara regency, from July to August 2014; then followed by several field visits from August to September 2016. Data obtained in the survey were analysed with descriptive statistics and cross tabulation. Majority (81%) of rural households handle manure in the process of either composting (75%) or sun-drying (6%). Remaining 6% of the respondents does not handle manure at all. Manure could represent valuable energy and plant nutrition resource, if used appropriately. However, if not handled at all or handled inappropriately, it can lead to the environmental problems. Our results revealed that current ways of stabling of livestock are inappropriate from the environmental perspective. The stabling has got only dusty earthen floor, which makes difficult for farmers wash out the excrements and pollution. Hence, there is a need to improve manure management practice to eliminate potential threats as current practices do not protect either humans, animals or environment against the risk of contamination with potential zoonotic pathogens.

Key words: manure management, waste management, Indonesia, livestock sector, rural household, Sumatra.

INTRODUCTION

Livestock plays an important role in global food production and in agricultural and rural economies in many developing countries. It also plays an important role in socio-economic development of rural households within improving wellbeing of the family household. Livestock is helping with food supply, improves family income and nutrition, improves soil productivity, agricultural diversification, and sustainable agricultural production, as well as it enhances family and community employment and in some cases also social status and ritual purposes (Bettencourt et al., 2014).

It is one of the fastest growing subsectors of agriculture worldwide. During the last decades, global production of meat, milk and eggs has rapidly expanded in response to a rapid growth in the consumption of livestock products (Thornton, 2010). A doubling of demand for animal food source is expected for developing countries by 2050 (Teenstra et al., 2014) and 70% increase for the world (Belete & Ayza, 2015).

In the early 1970's, beef was the main meat source in Indonesia, however, with the introduction of modern poultry systems, both for broiler and eggs in the 1970's, poultry meat production increased significantly. In 1995, Indonesia had 11 million heads of beef cattle and almost 12 million of goats and approximately 330,000 of dairy cattle. Over the period of 1941 to 1997 the number of pigs increased more than seven times from 1,296,000 to over 9,000,000. Beef and buffalo meat are not favoured by Indonesians because, compared to poultry both meats are expensive. The main livestock species nowadays include poultry, pigs, cattle and buffaloes. Also, it is important to notice, that 46.3% of population in 2015 were settled in rural areas (FAOSTAT, 2017) where majority of livestock production is concentrated. Currently, livestock production in rural Indonesia is mainly integrated into the way of life of rural families and communities.

The livestock sector also contributes towards conservation of environment, supplements income from crop production and other sources, and absorbs income shocks due to crop failures (Ali, 2007). Further, it can generate continuous income and employment and reduce seasonality in livelihood patterns particularly of the rural poor (Birthal & Ali, 2005). It is important to realize that rural poverty is largely concentrated among the landless (Ali, 2007) and several empirical studies indicate importance of livestock in terms of rearing positively on equity in terms of income and employment and poverty reduction in rural areas (Lefroy et al., 2000; Thornton et al., 2002; Ali, 2007; Valešová et al., 2017). Livestock breeding is also important for many of the poor in the developing countries. It does often contribute to multiple livelihood objectives and offers pathway out of poverty as it also affects and indispensable assets of the poor, their human capital and through all of it positively impacts their own nutrition and health (Randolph et al., 2007; Valešová et al., 2017). Furthermore, the livestock species play very important economic, social, and cultural functions for rural households in developing countries, as improving income and wellbeing of the family household (Bettencourt et al., 2014). Livestock is helping with food supply, improves family income and nutrition, improves soil productivity, agricultural diversification, and sustainable agricultural production, as well as it enhances family and community employment and in some cases also social status and ritual purposes (Bettencourt et al., 2014). The importance of livestock goes beyond its food production function as it provides also draught power, organic manure for fertilizing, and other products as bones, skin and blood or fibres to industrial sector and further use. When considering classification of livestock functions, according to FAO (ILRI, 1995) two classifications widely used are based on the kinds of output produced (food, cropping inputs, and raw materials) or in the uses (household consumption, supply of inputs, cash income, savings and investment, and social and ritual roles) in which these outputs are put on. Different classification divides livestock functions in economic (source of cash income, mean of savings accumulation and investment, economic status), household use (feeding, transportation, fertilizer and draught animals), socio-cultural (social status, paying bride wealth, providing animals for communal feasts or sacrifices) and leisure (horse racing, cock fighting, bullfight, hunting). Regarding cattle ownership, 97.91% smallholder farmers keep between 2–3 heads, however with high ownership disparity. In addition, total of 5.1 million farmers keep their livestock as a 'saving', not as a 'commodity' (DLBP, 2015).

When focusing on the target area, most of the population of region of North Sumatra professes the Christian religion (unlike other provinces that are predominantly Muslim), hence, there is enlarged pig production in the target area. Another important domesticated species of animal for locals are water buffaloes (which are also the symbol of the local Batak culture) and poultry. There are also significant numbers of cattle (meat and dairy breed; over 666,000 and over 1,100, respectively in 2015 in North Sumatra). However, they are not commonly kept in the rural households in the target area (as they are mainly in the large-scale farms). Numbers of livestock in 2014 and 2015 are given in Table 1.

Table 1. Total livestock in North Sumatra

Type of livestock *(local name)*	2014	2015
buffalo (*kerbau*)	116,008	117,200
cow – meat breed (*sapi*)	646,749	666,496
cow – dairy breed (*sapiperah*)	1,088	1,147
pigs (*babi*)	1,118,909	1,159,027
broiler chicken (*pedagingbroiler*)	47,179,814	47,659,709
local chicken (*ayamkampung*)	14,037,817	14,190,165

Source: Adapted from BPS (2015) with latest available data.

Manure management and housing of livestock

Considering numbers of livestock populations, it is undeniable that there is a great necessity of proper livestock manure management including proper treatment of high volumes of livestock excreta., Manure, if managed properly, can be used for multiple purposes (Roubík et al., 2016), such as fertilizer for crop production (Mieldažys et al., 2016), energy source (Roubík et al., 2017), or sometimes as basis for construction materials (Teenstra et al., 2014; Belete & Ayza, 2015; Holman et al., 2016). However, if manure is not managed at all or inappropriately (disposing to rivers and other water sources etcetera), it can lead to the environmental consequences and further problems. The negative impacts of the livestock sector include degradation of land, soil and water, reduction of the biodiversity and the air pollution (Moula et al., 2015; Sarkwa et al., 2016). Therefore, proper manure management is crucial in terms of sustainable livestock production. It is important to realize that disposal and storage of raw manure has become an environmental problem (Ghaly & Alhattab, 2013; Sarkwa et al., 2016). Manure is largely composed of animal excreta (faeces and urine) that is mixed up with other substances such as water, dirt, mammary glands and others. Recovery of pathogenic bacteria in freshly voided animal faeces shows that manure is a potential source of zoonotic pathogens contaminating the environment and represents a risk for further transmission to human (Kruska et al., 2003; Ali, 2007; Randolph et al., 2007; Lupindu et al., 2012). Several studies have also reported cases of human gastroenteritis due to bacteria entero-pathogens of animal origin following consumption of contaminated food or water or direct contact with infected animals in farms (Ali, 2007; Hoelzer et al., 2011; Lupindu et al., 2012; Cantas & Suer, 2014).

Housing of cattle is an important aspect of manure management, as it is essential for animals' optimisation of both housing and manure management. This optimisation includes factors such as feeding facilitation, hygiene, animal health and facilitation of manure collection and nutrient conservation as well as to save labour force. Poultry manure begins to decompose immediately after excretion giving off ammonia which, in high concentrations, can have adverse effects on health as well as on the productivity of birds and health of people living in the household (Ghaly & Alhattab, 2013). More frequent collection and/or cleaning of pens/stables can contribute to reducing of nitrogen losses.

In practice, manure is stored in heaps varying in their dimensions, management and occurring processes (aerobic and/or anaerobic). When water-tight floors are used, nitrogen losses decrease. On the other hand, the larger surface area of collection and storage facility of manure is, the higher risks for ammonia volatilisation occur. Among others, manure is an important contributor to anthropogenic greenhouse gas emissions, in which manure and manure management account for 10% of total livestock emissions. Agricultural practices, environment and human health are intrinsically linked (Mieldažys et al., 2016).

Liquid manure (urine and slurry) is obviously more difficult to collect and therefore is mostly flushed into the environment. However, such practices are resulting in emitting large amounts of methane (CH_4) and nitrous oxide (N_2O) into the atmosphere (Lupindu et al., 2012). Furthermore, it emits nutrients, which can contribute to public health risks such as waterborne diseases, to biodiversity losses as well as economic losses due to the increase of water treatment costs (Teenstra et al., 2014). Without proper implementation of adequate manure management practices, these negative impacts of manure are poised to increase. For example, if drying of poultry manure were practiced (to the dry matter content of 50% at least) it would substantially reduce the risk of nitrogen loss (Ghaly & Alhattab, 2013).

As can be found in FAOSTAT data (2017) livestock production accounts for 7.1 Giga tonnes of CO_2 equivalent per year, representing 14.5 percent of all anthropogenic GHG emissions involved in climate change and global warming. The majority of emitters from livestock sector are from cattle (both dairy and non-dairy) and from poultry and pig production.

This study was conducted to improve understanding of livestock manure management practices in rural households in North Sumatra, focused on Tapanuli Utara regency, in order to reveal current practices for improving livestock manure management and health within the regency.

MATERIALS AND METHODS

Description of the study area

The survey was conducted in the province of North Sumatra, Tapanuli Utara regency (Fig. 1). The population of North Sumatra consists of over 13.9 million inhabitants, which represent around 5.4% of the population of Indonesia (currently 255,461,700 inhabitants; with prediction of around 305,652,000 inhabitants in 2035 (BPS, 2015)). North Sumatra is fourth most populous province in the country. The population of Tapanuli Utara regency, according to the latest data from 2014, is over 290,000 inhabitants.

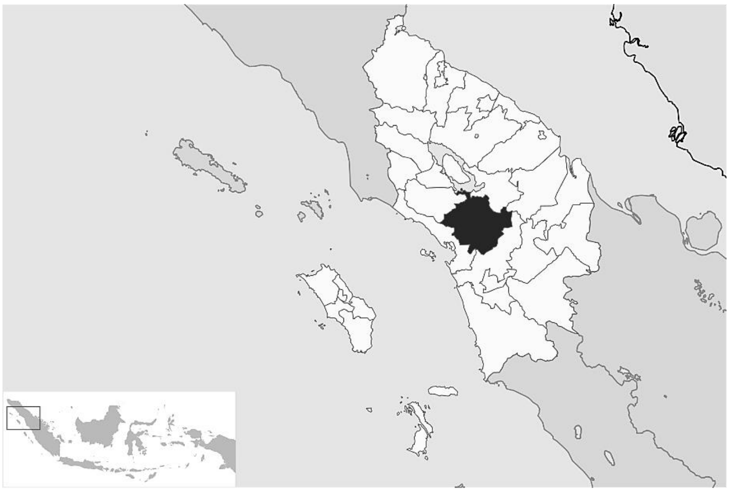

Figure 1. Target area (Tapanuli Utara regency) of North Sumatra.
Adjusted from: Wikimedia Commons.

Data collection and analysis

The survey was conducted using randomly selected households (n = 196) (on the confidence level of 95% giving margin error less than 7%) from July to August 2014 and followed by several field visits from August to September 2016. The methods of data collection consisted of 1-hour semi-structured personal interviews. Main categories of the questionnaire are given in Table 2. The results of interviews were compared with observations of the target groups. The questionnaire was designed to determine the current situation about the issue of manure management for the target area in rural households. The questionnaire included different types of questions such as open, closed, semi-open, evaluation and multiple choice questions. The questionnaire was subject to pilot testing and was subsequently adjusted and translated before final distribution. Data obtained in the survey were analysed with descriptive statistics and cross tabulation.

Secondary quantitative data regarding total livestock population and regarding total emissions from livestock sector were obtained from available statistical databases such as FAOSTAT and BPS (Badan Pusat Statistik/Central Bureau of Statistics Indonesia).

Table 2. Main categories of the questionnaire

Category	Variable
Livestock farming	Number of livestock
	Stabling of livestock
	Feeding of livestock
Manure management practices	Amount of available excrement from livestock
	Manure management practices

Estimation of methane emission from manure management

For estimation of methane emission from manure management, IPCC (2006) methods was applied using the following Eq. 1:

$$E_{CH4} = EF_{(T)} \cdot N_{(T)} \cdot 10^6 \qquad (1)$$

where E_{CH4} are methane emissions from manure management, [Gg CH_4 y^{-1}]; EF_T is emission factor for the defined livestock population, [kg CH_4 $head^{-1}$ y^{-1}]; N_T is the number of head of livestock species / category T in the country.

We used the emission factors for selected livestock according to the IPCC (2006) (Table 3).

Table 3. Emission factors for selected livestock

Livestock species	Manure management emission factor
Buffalo	2.00
Cow – meat breed	1.00
Cow – dairy breed	31.00
Pig	7.00
Broiler chicken	0.02
Local chicken	0.02

Source: IPCC (2006).

RESULTS AND DISCUSSION

General characteristics of livestock farming in the study area

Majority of interviewed farmers in the study area are facing harsh weather, the adverse weather effects and pests that affect quality and quantity of production, and consequently household incomes. According to the respondents, prolonged drought (96%), presence of pests (66%), earthquakes and floods (7% and 3% respectively) were the main problems. As stated in the SNV report (2009,) in years 1997–1999 prolonged drought caused food shortages in many provinces in Indonesia and numerous fires that devastated large areas of forests and human settlements. Earthquakes, as mentioned by farmers, appears only once a year and it is only small tremors, which does not have devastating effects.

Over the last decade, the livestock sector has grown at an annual rate of 13% (US$4.5bn) of the overall agriculture. This increase corresponds to an annual average growth of 4.6%, which is higher than the overall growth of agricultural sector (3.5%). This suggests that livestock is likely to emerge as an engine of agricultural growth in the coming decades. As shown in Figs 2 and 3, all categories except buffaloes have growing number of livestock.

This is in accordance with the continuous growing trend in meat consumption (1.1 billion tons in 2014; meaning +1.4% growth in volume since 2013 and +3.2% since 2010) (BPS, 2015). As shown in Fig. 3, by 2014, poultry production reached 47 million heads of broiler chicken, while cattle (meat breed – Fig. 2) number was approximately 0.6 million of heads. The reason for the importance of chicken meat is that it is generally fast and accessible source of proteins – the least expensive to produce and to purchase.

In Fig. 3, there is a growing trend in broiler chicken production and slowly decreasing trend of local chicken. Even though it is still demanded, especially by domestic consumers. Currently, the government policy is aimed at increasing efficiency and productivity to enable poultry producers to compete in the market through better quality products, competitive prices and good delivery systems.

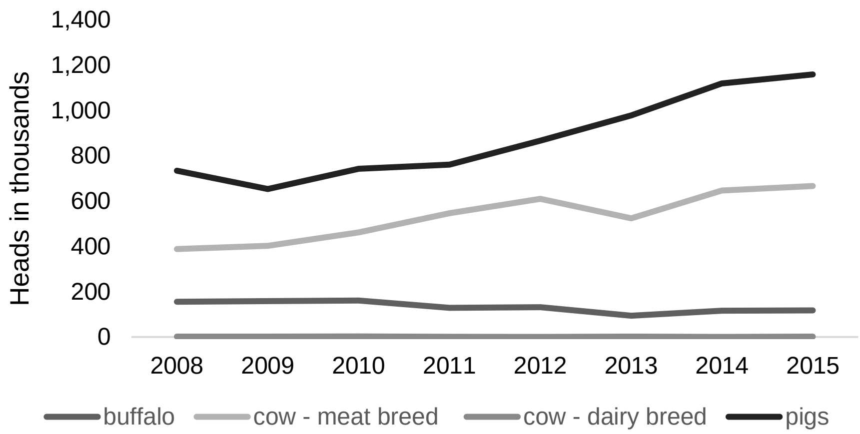

Figure 2. Development of livestock in the period 2008–2015 in North Sumatra.
Source: BPS, 2015.

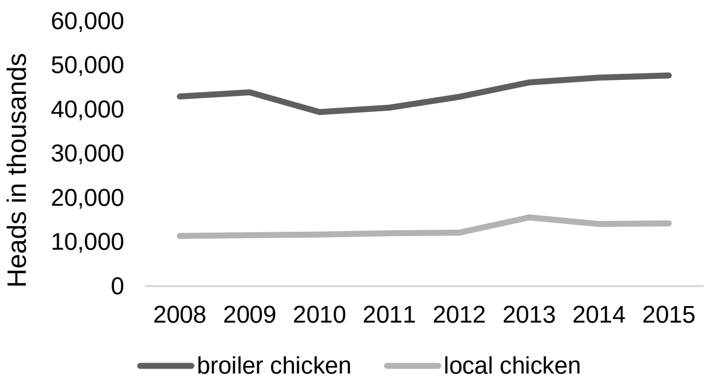

Figure 3. Development of poultry in the period 2008–2015 in North Sumatra.

The average size of farm was 1.1 (± 0.7) hectare. The farm is either located directly behind their household or in the distance reached by a motorbike in maximum 15 minutes. As shown in Table 4, the composition of livestock in small-scale farmers differs in nature.

Table 4. Livestock numbers in the interviewed households (n = 196)

	No of household	Average heads of animals	Min/Max of heads of animals
Buffalo	54	3.3	1 / 20
Pigs	73	6.4	1 / 120
Cattle	4	1.8	1 / 3
Poultry	69	56.3	2 / 40

Stabling and Feeding of livestock in the target area

Throughout much of the developing world livestock are raised in mixed farming systems, where animals have very often different functions. Livestock activities are normally integrated into the existing farming systems: animals graze on fallow land and browse on hedges, utilise crop residues as feedstuffs and produce milk and meat, manure for biogas and power for traction (Teenstra et al., 2014).

The two main methods for housing pigs in the target area are using of bamboo structures called *kandang* (majority of cases) or tethering the pigs with a rope. In both cases, it is common to keep pigs close to the household. *Kandang* is a bamboo structure often with partially open sides and usually built off the ground allowing so appropriate ventilation and waste to fall below the pen (Leslie et al., 2015). Pigs are mostly fed with local agricultural products including vegetable products (such as corn, sweet potatoes leaves, cassava and taro), fruit products (such as papaya, coconut and banana) and kitchen food waste. The quantities of feed follow seasonality – lower availability during the dry season. Such findings are in accordance with the study by Leslie et al. (2015).

Small-scale farmers keep cattle outside during the day and in open or roofed stables for night. Generally, in Sumatra it is common to collect cattle excreta when at least medium-scale production of animals (minimum 10 heads) is kept (not in the household small-scale production), then collection of excreta is executed below cattle stables.

Similarities are found in the case of buffaloes, as they are also mainly kept outside and they are taken to their housing (open or roofed) for nights. Regarding feeding practice, it can be divided into dry and wet feeding systems. Grazing is gradually changed to cut-and-carry feeding systems in the growing period of paddy and secondary crops when less grazing land is available. Low feed availability may force farmers to sell the mature animals and replace them with young ones. Smallholders tether their animals in grazing areas during the day and confine them at night. One can still see children or older people herding the animals during the day. In some areas, cattle are permitted to run free in designated areas during the cropping season and are permitted to graze crop residues during the dry season. Since recycling of crop residues is an important function of cattle, keeping them tethered eases manure collection. Allowing the cattle free range requires close supervision to maintain the security of the animals.

Poultry is most commonly kept free in the surrounding of the household or in the backyards. Therefore, its manure is usually not collected at all. However, if poultry were kept on a raised wired or slatted floor, it would allow easy collection of excreta below the floor (for example in a pit) and for further use.

As stated in Teenstra et al. (2014) between 60% and 95% of the animal's nutrient intake via feed is excreted via dung and urine containing undigested carbon and nutrients. Manure, in case of our respondents, was either disposed of as an effluent, or collected, or stored and used. In practice, management and dimensions of manure heaps vary, and processed inside heaps may be partly aerobic and/or partly anaerobic. When water-tight floors are used, nitrogen losses are also lower, but again a larger surface area for the (collection) and storage facility of manure increases the risks for ammonia volatilisation.

Therefore, it can be stated that majority of observed stabling was identified as inappropriate. Almost 2/3 of the respondents use only stabling on dusty earthen floor, which is difficult to be washed out in the way to use excrements for other purposes (such as biogas production etc.). Only less than 1/3 of the respondents keep pigs in simple stabling pens, occasionally equipped with a concrete floor.

Current livestock manure management practices in the target area

Agricultural operations generate large quantities of manure which must be eliminated in a manner that is consistent with public health guidelines (Holman et al., 2016; Wasserbauer & Herák, 2016).

Majority (81%) of rural households process manure in the way of either composting (75%) to get fertilizer or sun-drying (6%) to get fuel. Remaining 19% does not manage manure at all (meaning not collecting and leaving on the site). In the target area, amounts of excrement per each animal for buffaloes, cattle, pigs and poultry were in average 13.3 (± 8.0) kg per night, 15.2 (± 6.0) kg per night, 12.8 (± 13.5) kg per day and 4.5 (± 5.4) kg per day, respectively according to the respondents. High variances may be caused by feeding, stabling and age of animals. In case of buffaloes and cattle, the amounts of excrements were considered only for night time as they are mainly stabled only during the night time. If we focus on each of the manure management by each livestock category, the general practice in the target area is to collect only pig manure and dairy cow fully for further manure management. In case of buffaloes and cows for meat breed, it is common to wash the excreta out or collect it after night housing. In case of poultry it is common not to collect manure at all.

In the target area, traditional composting was the most common way of handling manure (when manure was managed). Such a method consists of trenches or pits about 1 m deep; the size of the trenches can vary according to the availability of land and the type of material to be composted, organic residues and night soil are put in alternate layers. After filling, the pit is covered with a layer of organic residues of approximately 15–20 cm. The materials are allowed to remain in the pit without turning and watering for three months. During this period, the material settles owing to reduction in biomass volume. Additional night soil and refuse are placed on top in alternate layers and plastered or covered with mud or earth to prevent loss of moisture and breeding of flies. After the initial aerobic composting (about eight to ten days), the material undergoes anaerobic decomposition at a very slow rate. It takes about six to eight months to obtain the finished product. Therefore, the total time used is being reported to about 1 year.

Implications from current manure management practices

In Fig. 4, methane emissions calculated from manure management in North Sumatra are clearly visible. Majority of methane emission is originating from pig production (8.11 Gg CH_4 y^{-1} in 2015) followed by that of broiler chicken (0.95 Gg CH_4 y^{-1}) and cow production for meat (0.67 Gg CH_4 y^{-1}). Methane emissions from stored solid manure can be reduced by two completely different strategies (Table 5) aiming at either promoting or preventing anaerobic conditions (Chadwick et al., 2011).

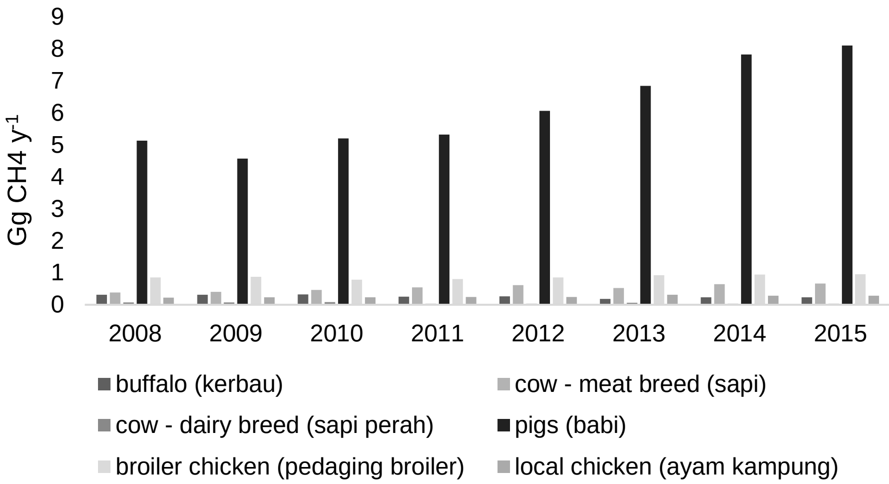

Figure 4. Methane emissions from manure management in North Sumatra, Indonesia.

Reducing the organic matter content of slurry through separation or fermentation of slurry in a biogas digester may prove to be the most efficient way of reducing CH_4 emissions during outside storage (Chadwick et al., 2011; Roubík et al., 2017).

Table 5. Potential methane reduction methods drawn from current manure management

	Reduction methods	Reference
Animal housing	Modified feeding strategy	Jordan et al., 2006; Beauchemin et al., 2008; Leytem et al., 2010; Chadwick et al., 2011
	Removal of slurry	Chadwick et al., 2011
	Cooling the slurry (in more sophisticated housing)	Chadwick et al., 2011
Manure storage	Modified feeding strategy	Beauchemin et al., 2008; Leytem et al., 2010; Chadwick et al., 2011
	Removal of slurry	Chadwick et al., 2011
		Chadwick et al., 2011
	Cooling the slurry (in more sophisticated housing)	
	Composting of manure	
		Leytem et al., 2010; Chadwick et al., 2011
	Anaerobic digestion of slurry (use of biogas plants)	Leytem et al., 2010; Chadwick et al., 2011; Roubík et al., 2016; Roubík et al., 2017

FUTURE CHALLENGES

As the production volume of the livestock sector in Indonesia is still far from meeting consumer's needs, there is expected growing trend to continue. For example, in 2008 domestic beef production was only able to satisfy 24% of the national demand and 31% in 2012. In pig sector, considering over 33 million non-Muslim Indonesians and growing number of tourists visiting the country every year, with annual average import of swine meat increased by 25% and the growing trend will continue. As livestock contributes in sustaining agricultural production and meeting needs of consumers, it can also have disastrous environmental consequences, especially if manure is not managed properly.

Currently, manure management systems, with a special emphasis on environmental protection, are increasingly being incorporated into animal production systems (Belete & Ayza, 2015). It is important to consolidate approaches that involve biophysical, technological and human considerations across space and time to optimize livestock production systems in which manure management systems are integrated.

CONCLUSIONS

This study revealed that there is a need to improve manure management practice in order to eliminate potential threats coming from inappropriate practices. Almost 1/5 of the rural households do not manage manure at all (commonly leaving it on the site), which can lead to the environmental consequences and further problems. The current manure management practices do not protect either humans, animals or environment against the risk of contamination with potential zoonotic pathogens and therefore there is a need for the formulation of guidelines on safe manure management practices. There is need to improve the quality of human resources and maximize the use of natural and agricultural resources and supply. The construction and development of facilities and infrastructure, in addition to the development of farmer institutions are intended to ensure efficient and effective use of all development resources.

This research extends our knowledge of livestock manure management practices in rural households in Tapanuli Utara regency and therefore provides insight into current trends and proves to be particularly valuable for further consideration of implications from current practices. Future research and development in livestock manure management must focus more on strategies, techniques and systems allowing to maximize the benefits of manure while minimizing negative impacts (on the natural resources, humans, livestock and ecosystems).

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Weed community trajectories in cereal and willow cultivations after termination of a willow short rotation coppice

M. Welc*, A. Lundkvist, N-E. Nordh and T. Verwijst

Department of Crop Production Ecology, Swedish University of Agricultural Sciences, P.O. Box 7043, SE-750 07 Uppsala, Sweden
*Correspondence: Monika.Welc@slu.se

Abstract. According to guidelines for willow short rotation coppice (SRC), weeding is needed during establishment, while weed populations which develop later under a well-established willow canopy do not require control. However, farmers are concerned that weeds which develop in SRC may result in long-lasting weed infestations in succeeding crops after SRC termination. We assessed the effects of two SRC-termination methods (with shallow and deep soil cultivation) on the development of the weed flora in a cereal system (CS) and in SRC during six seasons. Richness, ground cover, life-cycle strategy and composition of the weed species, and their environmental requirements (inferred from Ellenberg index) were evaluated.
SRC-termination method had no effect on the weed community trajectories in the succeeding SRC and CS. However, cropping system and growing season had significant impacts on species richness, ground cover and composition of the weed flora.
Differences in weed communities over time and between cropping systems were related to the impact of cropping systems on factors such as light, soil moisture, nitrogen level, and soil reaction, as inferred from the Ellenberg index. After termination of the old willow cultivation, the weed flora of the SRC and CS rapidly diverged and approached the weed flora characteristic for old willow stands and non-weeded old cereal plot, respectively. We conclude that willow stands can be converted, regardless of termination method, either into willow or cereal cultivations without additional risk of weed infestations other than those specific for their respective cropping systems. Furthermore, willow cultivations in agriculture contribute to floristic diversity at the landscape scale.

Key words: crop, diversity, Ellenberg index, flora, life cycle, *Salix* spp., short rotation forestry, termination method, weed outbreak, weed species composition, weed species ground cover, weed species richness.

INTRODUCTION

Biomass from willow (*Salix* spp.) short rotation coppice (SRC) is used as a renewable energy source in several European countries (Mola-Yudego, 2010) and overseas (Volk et al., 2004). Willow SRC has an economically productive life span of 20 to 25 years and is commonly harvested in winter every 3 to 4 years. Stem dry matter biomass in a well-established commercial field can exceed 10 Mg $ha^{-1}yr^{-1}$. After this period, SRC biomass production declines and the willow SRC can be terminated (Rahman et al., 2014). Land regained after termination of willow SRC is usually incorporated back into conventional agricultural production with annual crops, but may also be replanted again with willow SRC (Norberg & Nordh, 2012).

During establishment, willows are very susceptible to weeds which develop faster and efficiently outcompete young willow plants (Abrahamson et al., 2010). A survey among Swedish farmers showed that weeds were the most important cause for premature termination of willow stands (Helby et al., 2006). Weed control during the first year is essential (Albertsson et al., 2016), and both mechanical weed control and use of herbicides are recommended in planting instructions described in 'Manual för Salixodlare' (Gustafsson et al., 2007), 'Short Rotation coppice willow – best practice guidelines' (Caslin et al., 2010), and 'Handbok för Salixodlare' (Hollsten et al., 2012). After establishment, which takes 1 to 1.5 growing seasons, willows form a dense canopy which suppresses growth of weeds in the understorey, and no further weed control is required (Verwijst et al., 2013).

When weed control in a willow SRC after canopy closure is ceased, a spontaneous development of a weed flora occurs and contributes to floristic diversity in the agricultural landscape (Gustafsson, 1986, Baum et al., 2012a). Previous land-use has been found to affect the initial development of the ground vegetation after conversion, former grasslands leading to a larger share of long-lived perennials compared to former arable land (Cunningham et al., 2006). However, Baum et al. (2013) found a poor coherence of seed bank versus actual vegetation in SRC, suggesting that recent vegetation composition is mainly due to the species pool of the adjacent vegetation and site conditions. Baum et al. (2012c) and Stjernquist (1994) found that the influence of the previous vegetation decreases with cultivation age. These findings apply to conversion of conventional agricultural cropping systems into willow SRC. However, very little is known about the flora development after reconversion of willow SRC into annual cropping systems. At present, farmers are concerned that weeds which develop in willow SRC may result in long-lasting weed infestations in succeeding crops after willow SRC termination, and this necessitates studies on reconversion of willow SRC.

In this context, the main aim of our study was to compare the development of the weed flora in crops established after termination of long-term willow SRC. As noted by Pučka et al. (2016), such an assessment of the vegetation dynamics should preferably be performed for several years in sequence. We assessed the effects of two SRC-termination methods (with deep or with shallow soil cultivation after termination of SRC, respectively) on the development of the weed flora in SRC and cereal system (CS) in during six growing seasons. Both cropping systems were established on one and the same site and thus shared the same management history and the same seed bank.

We hypothesized that: 1) deep soil cultivation during willow termination will initially and in both cropping systems reduce weed species richness and cover compared to shallow soil cultivation, because deep soil cultivation may act as a weed control method, 2) weed species richness and cover will initially be similar in both cropping systems, as they share the same management history and seed bank, 3) weed species composition in the different cropping systems will diverge over time, and 4) this divergence is due to the inherent impact of the cropping systems on their environment, as inferred from Ellenberg index.

MATERIALS AND METHODS

Site description

The experiment was performed at Ultuna near Uppsala, Sweden (59°48'N, 17°39'E, altitude 5 m) on a 2.7 ha field with a neutral (pH_{H2O} = 7.4) Vertic Cambisol (Olsson & Samils, 1984) and a willow short rotation coppice (*Salix viminalis,* clone 77683) that was grown for 25 years (1984–2009), with an initial density of 20,400 plants ha^{-1} which had decreased to 2,900 plants ha^{-1} in 2009, predominantly due to self-thinning (Willebrand & Verwijst, 1993). The 25-year-old willow short rotation coppice is named 'old willow' (OW) below.

Two areas of 100 m × 100 m each were divided into blocks of 50 m × 100 m, and these further into 25 m × 100 m subplots in a split-plot design to accommodate cropping system (willow or cereals) in each main plot and termination method (with deep or shallow soil cultivation, see below) in the split plots (Fig. 1). Within the main plots in each of the four blocks, termination method was randomly assigned to the subplots.

After inventory of the weed flora (see below) on 20–21 June 2009, a tank mixture of herbicides (glyphosate 'Roundup Bio', 360 g active ingredient (a.i.) L^{-1}, Monsanto, dose: 6 L ha^{-1} and dimethylamine salt 'MCPA 750', 750 g a.i. L^{-1}, Nufarm, dose: 0.8 L ha^{-1}) was applied on 26 June 2009 to kill willows and weeds before mechanical termination. On 27 and 29 July 2009, willows were mechanically terminated using two methods: deep termination (TD) method using a multi mulcher (Seppi M. Multiforst), which removed above- and belowground part of stumps with soil cultivation to a depth of about 13 cm, or shallow termination (TS) method using a flail mower (Berti 250ECF/DT), which removed aboveground parts of stumps without soil cultivation (Norberg & Nordh, 2012). Within a few weeks after termination, weeds started to germinate in all plots where both TD and TS were applied.

Plots dedicated to CS on which TS was applied underwent disc harrowing on 3 September 2009. Winter wheat (*Triticum aestivum* L.) was sown on plots dedicated to cereals and on a nearby reference plot (see below) on 17 September 2009. Plots dedicated to SRC were planted with *Salix schwerinii* × *Salix viminalis*, clone 'Tora' (Svalöf-Weibull AB) on 18 May 2010 using a Woodpecker (Norberg & Nordh, 2012). During the growing seasons 2011, 2012 and 2014, spring barley (*Hordeum distichon* L.) was cultivated while spring wheat (*Triticum aestivum* L.) was sown in 2013 and 2015. Winter wheat and spring barley were sown with a density of 350–400 seeds m^{-2} and spring wheat with 500 seeds m^{-2}. Plots dedicated to cereals were disc harrowed in 2009 and 2010, and in subsequent years ploughed to a depth of 20–25 cm, either during autumn or spring, and prior to sowing the seed bed was prepared by harrowing. From 2012 on, mineral fertilization was applied annually with NPK 21-4-7 (YARA) at an N-supply of 80 kg ha^{-1}, about two weeks after sowing.

In spring 2009, a reference plot for cereal cultivation was established, at about 600 m distance from the experimental field. The reference plot had a size of 2,450 m^2 and had been cultivated with annual crops (mainly cereals) during the five preceding years, without any mean of the weed control. During summer 2009, the site was in fallow by performing rotary cultivation five times during the growing season. The reference plot is named 'old cereal' (OC) below.

Monthly mean temperature of growing season (May to September) was 14.3 °C(2009), 18.8 °C(2010), 13.8 °C(2012), 15.2 °C(2013), 14.6 °C(2014), and 13.8 °C(2015). Average monthly rainfall during the growing season (May to September) was 69.6 mm (2009), 58.6 mm (2010), 83.5 mm (2012), 37.6 mm (2013), 60.3 mm (2014), and 63.0 mm (2015) (Anonymous, 2016).

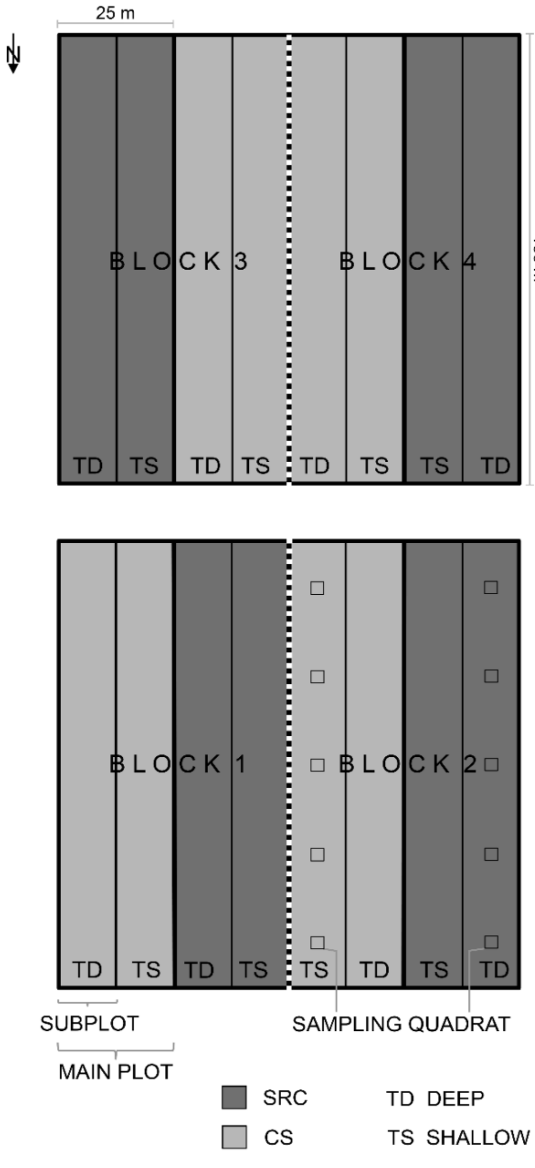

Figure 1. Design of the field experiment at Ultuna, Sweden. Bold lines indicate main treatments [crop: willow (SRC), dark grey; cereal (CS), light grey]; thin lines indicate split plots (subplots) [termination method: with deep soil cultivation (TD) or with shallow soil cultivation (TS)]. Dotted lines separate the blocks. The sampling quadrants (2 m × 2 m) indicate where the weed flora was recorded, however, for clarity of the figure, sampling quadrants are drown only on two subplots.

Inventory of the weed flora

All plant species different from the cultivated crops were considered as weeds. The weed flora was recorded within five 4 m^2 sampling quadrants located 10, 30, 50, 70 and 90 m from the subplot's headland, distributed along a transect centrally located in each subplot (Fig. 1). The first inventory of the flora was performed in June 2009 on the entire area of OW cultivation (16 subplots predesigned to be planted anew with SRC or converted to CS) and in July 2009 on the OC plot, also using five sampling quadrants of 4 m^2. Thereafter, the inventories were performed on 26 July 2010, 28 June 2012, 14–15 July 2013, 28 and 30 July 2014, and 27 July 2015 in SRC and CS (no inventory was performed in 2011). These dates coincided with the phenological stage of spike ripening (Bleiholder et al., 1997) of *Dactylis glomerata* L. in SRC and were used to minimize differences between growing seasons with regard to the phenological development of the flora. The weed flora inventory included taxonomic identification of the weeds to the species/genus (Lid & Lid, 2005), classification to the life forms (Raunkiær, 1934), habitat type, growth forms (Chapin et al., 1996) and life-cycle strategy and Grime's strategy (Grime et al., 2007). The nominal transformation (van der Maarel, 2007) of Braun-Blanquet scale (Braun-Blanquet, 1932; Braun-Blanquet, 1964) was used to assess the ground cover of the species in sampling quadrants.

Analyses of weed species richness and diversity

The PROC MIXED procedure in SAS 9.4 (SAS Institute Inc., Cary, NC, USA) was used to investigate differences in weed species richness and weed ground cover between and within growing seasons and in different life-cycle strategy categories (i.e. 'annual', 'biennial', and 'perennial'). Weed species richness was also analyzed per group 'only SRC', 'only CS' and 'SRC + CS'. Cropping system and termination method and their interaction were used as explanatory variables. Block was modeled as a random variable. Termination method was statistically insignificant in the mixed-design ANOVA of weed species richness ($P = 0.92$) and weed ground cover ($P = 0.77$) and was therefore excluded as explanatory variable in the overall analyses of weed species richness in the groups 'only SRC', 'only CS' and 'SRC + CS' and in occurrence percentage and cover percentage of weed species richness in life-cycle strategy categories.

Lack of replicates and uneven number of measurements in OW ($n = 80$) and OC ($n = 5$) necessitated the use of one-way ANOVA and Tukey honestly significant difference test at 95% confidence level to assess differences between cropping systems.

Weed species composition

Gradients in weed species composition based on cover-abundance in SRC and CS (growing seasons 2010 and 2012–2015) were assessed by Non-metric Multi-Dimensional Scaling (NMDS) performed using the software package Canoco 5, Windows release (5.02) (ter Braak & Šmilauer, 1997–2012). The Bray-Curtis distance measure and NMDS solution was based on 3 axes without optimization and perturbations, and formula for stress type 2 (i.e. the sum of squared differences between individual distance values and their mean) were applied. Treatments of ties in distances were set as primary, i.e. different occurrences of the same distance value might be matched with different fitted values. The stress values (Clarke, 1993) and number of iterations for separate years ranged from 0.07 (2010) to 0.0005 (2015), and 43 (2010) to 353 (2015), respectively.

Indicator species analysis revealing association of weed species to cropping system was performed for separate growing seasons on cover-abundance datasets using RStudio v. 0.98.501©2009–2013, package 'labdsv' v. 1.6–1 (Roberts, 2010). Based on these data, indicator values, being multiplication of species specificity (the proportion of sites of type *j* with species *i*) and fidelity (the proportion of the number of individuals of species *i* that are in a *j* type of site) (Dufrêne & Legendre, 1997), were produced for all weed species, but only those which are statistically significant were tabulated.

Environmental conditions (inferred from Ellenberg index)

Based on cover-abundance data for each weed species composition within a sampling quadrant the Ellenberg index, calculated as weighted mean of Ellenberg values for light, soil moisture, soil nitrogen level and soil reaction, was produced as a proxy for environmental conditions (Ellenberg, 1992; Diekmann, 1995; Diekmann & Lawesson, 1999; Grandin, 2004). Differences in environmental conditions inferred from the Ellenberg index as dependent on crop, growing season and their interaction were analyzed with PROC MIXED procedure in SAS 9.4 (SAS Institute Inc., Cary, NC, USA).

RESULTS AND DISCUSSION

Weed species characterization: richness and ground cover

Number of weed species and their life forms

For all growing seasons and crops, including OW and OC, a total number of 86 weed species was identified (Table 1). After conversion, 77 species were recorded during growing season 2010 and 2012–2015 in SRC while the corresponding number for CS was 30 species. Hemicryptophytes constituted 51% and 20% of the weed species detected in OW and OC, respectively. The average proportion of hemicryptophytes (all growing seasons) was 63% and 28% in SRC and CS, respectively. In 2010 a proportion of 52% and 55% in SRC and CS, respectively were hemicryptophytes. They increased from 63% to 66% in SRC but decreased in CS from 31% to 0% over a period 2012–2015. Therophytes constituted 10% and 60% of the weed species detected in OW and OC, respectively. On average for all growing seasons, 8% and 31% of the weed species detected in SRC and CS, respectively were therophytes. They decreased from 15% to 5% in SRC and increased from 7% to 67% in CS during growing season 2010 and 2012–2015 (Table 1). This change over time in proportion of therophytes is associated to the disturbance frequency inherent to the cropping system. The high frequency of soil cultivation in the CS primarily allows for weed species which can complete their life cycle within one growing season. Likewise, the abundant occurrence of hemicryptophytes in SRC is indicating a lower frequency of soil disturbance.

Table 1. Botanical characterization of the weed species identified in different cropping systems during growing seasons 2009–2010 and 2012–2015. Growth habit is not specified for *Epilobium* sp. L. and *Galium* sp. L. (apart from *E. angustifolium*, *E. montanum*, *G. aparine*, and *G. odoratum*) due to a great diversity in growth habit of these genera. The main habitat type preferred by each weed species in Scandinavia is given. Abbreviated names of plant species are used in Fig. 5

No.	Name of plant species	Abbreviation	Occurrence per growing season						Raunkiær's life form [1]	Life-cycle strategy categories[2]	Grime's strategy[3]
			2009	2010	2012	2013	2014	2015			
1	*Acer platanoides* L.	A pla	OW	-	-	SRC	-	-	M	P	S
2	*Achillea millefolium* L.	Ach mil	-	-	-	-	-	SRC	H	P	C-S-R
3	*Alopecurus pratensis* L.	Alop prat	-	-	-	SRC	SRC	-	H	P	C-S-R / C
4	*Anthemis arvensis* L.	Ant arv	-	-	-	-	-	SRC	G	A	R
5	*Anthriscus sylvestris* Hoffm.	Ant sylv	OW	SRC, CS	SRC, CS	-	-	SRC	H	A	C / C-R
6	*Arctium tomentosum* Mill.	Arct tom	-	-	SRC	-	-	-	H	B	ns
7	*Arrhenatherum elatius* (L.) P. Beauv. ex J. & C. Presl	Arrh elat	OW	-	-	-	-	-	H	P	C
8	*Artemisia absinthium* L.	Art abs	-	-	SRC	SRC	SRC	-	C	P	C / C-S-R
9	*Bromus secalinus* L.	Brom sec	-	-	-	CS	-	-	T	A	ns
10	*Bunias orientalis* L.	Bun orient	OW	SRC, CS	SRC	SRC, CS	SRC	SRC	H	B	ns
11	*Capsella bursa-pastoris* (L.) Medik.	Cap bur	-	-	CS	-	-	-	T	A	R
12	*Carum carvi* L.	Car car	-	-	-	SRC	SRC	SRC	H	B	ns
13	*Cerastium arvense* L.	Cer arv	OW	-	-	-	-	-	C	B	S-R / C-S-R
14	*Chelidonium majus* L.	Chel maj	-	-	SRC	SRC	SRC	-	H	P	C-R / C-S-R
15	*Chenopodium album* L.	Chen alb	OC	SRC	CS	SRC, CS	CS	CS	T	A	C-R
16	*Cirsium arvense* (L.) Scop.	Cir arv	OW, OC	SRC, CS	SRC, CS	SRC, CS	SRC, CS	SRC, CS	G	P	C
17	*Cirsium vulgare* (Savi) Ten.	Cir vulg	-	-	-	SRC, CS	-	-	H	P	C-R
18	*Convulvulus arvensis* L.	Conv arv	-	SRC, CS	SRC, CS	SRC, CS	SRC, CS	SRC	G	P	C-R
19	*Cornus sanguinea* L.	Cor san	-	-	-	-	-	SRC	M	P	S-C
20	*Crataegus monogyna* Jacq.	Cra mon	OW	-	-	-	-	SRC	M	P	S-C
21	*Dactylis glomerata* L.	Dac glom	OW	CS	SRC	SRC	SRC	SRC	H	P	C-S-R / C
22	*Deschampsia cespitosa* (L.) P. Beauv.	Des ces	OW	-	-	-	SRC	SRC	H	P	C-S-R / S-C
23	*Elymus repens* (L.) Gould	El rep	OW, OC	SRC, CS	SRC, CS	SRC, CS	SRC, CS	SRC, CS	G	P	C / C-R
24	*Epilobium angustifolium* (L.)	Epil ang	-	SRC	-	-	SRC	-	H	P	C
25	*Epilobium montanum* L.	Epil mon	-	-	-	SRC	-	-	H	P	R / C-S-R
26	*Epilobium* sp. L.	Epil sp.	-	-	SRC	SRC	SRC	SRC	ns	ns	ns
27	*Erodium cicutarium* (L.) L`Her.	Ero cic	-	-	-	SRC	SRC	-	H	B	S-R

Table 1 (continued)

28	*Festuca pratensis* Huds.	Fes prat	OW	SRC	SRC	SRC	SRC	SRC	H	P	C-S-R
29	*Festuca rubra* L.	Fes rub	OW	SRC	SRC	SRC	SRC	SRC	H	P	C-S-R / C / S-C / S
30	*Filipendula ulmaria* (L.) Maxim.	Filip ulm	-	-	-	SRC	SRC	-	H	P	C / S-C
31	*Fragaria vesca* L.	Fra ves	OW	-	SRC	SRC, CS	SRC	SRC	H	P	S / C-S-R
32	*Fumaria officinalis* L.	Fum off	OW, OC	SRC	CS	CS	-	CS	T	A	R
33	*Galeopsis tetrahit* L.	Gale tet	-	SRC, CS	SRC, CS	-	-	SRC, CS	T	A	C-R
34	*Galium aparine* L.	Gal apar	OW	SRC, CS	SRC, CS	SRC, CS	SRC, CS	SRC, CS	T	A	C-R
35	*Galium odoratum* (L.) Scop.	Gal odor	-	-	-	SRC	SRC	SRC	G	P	S-C / C-S-R
36	*Galium* sp. L.	Gal sp.	OW	SRC, CS	SRC	-	-	-	ns	ns	ns
37	*Geranium robertianum* L.	Ger rob	OW	SRC, CS	SRC	SRC	SRC	SRC	H	B	R / C-S-R
38	*Geum urbanum* L.	G urb	OW	SRC, CS	SRC, CS	SRC, CS	SRC	SRC	H	P	C-R / C-S-R
39	*Glechoma hederacea* L.	Glech hed	-	CS	-	-	-	-	G	P	C-R / C-S-R
40	*Hypericum perforatum* L.	Hyp perf	-	-	-	SRC	SRC	SRC	H	P	C-R / C-S-R
41	*Juncus effusus* L.	Junc eff	-	-	-	SRC	SRC	-	H	P	C / S-C
42	*Lactuca serriola* L.	Lac serr	-	-	CS	-	SRC, CS	-	T	B	ns
43	*Lamium album* L.	Lam alb	-	SRC	-	-	-	-	H	P	C-R
44	*Lamium purpureum* L.	Lam purp	-	-	-	CS	SRC	-	H	P	R
45	*Lathyrus pratensis* L.	Lath prat	OW	SRC	SRC	-	-	SRC	H	P	C-S-R
46	*Leucanthemum vulgare* Lam.	Leu vul	-	-	SRC	-	-	-	H	P	C-S-R / C-R
47	*Lonicera tatarica* L.	Lon tat	OW	-	-	-	-	-	N	P	ns
48	*Lonicera xylosteum* L.	Lon xyl	OW	SRC	SRC	-	-	-	N	P	ns
49	*Matricaria inodorata* L.	Mat inod	OC	-	-	-	-	-	T	A	R
50	*Medicago lupulina* L.	Med lup	OW	-	SRC	SRC	SRC	SRC	H	A	R / C-S-R
51	*Melilotus albus* Medik.	Mel alb	-	-	-	SRC	-	SRC	H	B	C-R
52	*Myosotis arvensis* (L.) Hill	Myos arv	OW	-	SRC	SRC	SRC	SRC	H	P	R
53	*Phleum pratense* L.	Ph prat	OW	-	-	-	-	-	H	P	C-S-R
54	*Poa pratensis* L.	P prat	-	-	SRC	SRC, CS	SRC	SRC	H	P	C-S-R
55	*Poa trivialis* L.	P triv	OW	-	SRC	-	-	SRC	H	P	R / C-S-R
56	*Potentilla arenaria* Borkh.	Pot are	-	-	-	SRC	SRC	-	H	P	ns
57	*Prunus padus* L.	Pru pad	OW	SRC	-	SRC	-	SRC	M	P	S-C
58	*Ranunculus repens* L.	Ran rep	OW	SRC, CS	SRC, CS	SRC	SRC	SRC	H	P	C-R
59	*Roegneria canina* (L.) Nevski	Roe can	-	-	-	-	SRC	-	H	P	ns

Table 1 (continued)

60	*Rhamnus cathartica* L.	Rha cath	-	-	-	SRC	SRC	-	N	P	S-C
61	*Rosa* sp.	Rosa sp.	OW	-	-	SRC	SRC	SRC	N	P	ns
62	*Rubus idaeus* L.	Rub idae	OW	-	-	SRC	SRC	SRC	N	P	S-C
63	*Rubus saxatilis* L.	Rub sax	-	-	-	SRC	-	-	N	P	S / C-S-R
64	*Rumex crispus* L.	Rum cris	OW	SRC, CS	SRC, CS	SRC	SRC	SRC	H	P	C-R / C-S-R
65	*Sambucus racemosa* L.	Samb rec	OW	-	SRC	SRC	SRC	SRC	N	P	ns
66	*Senecio vulgaris* L.	Sen vul	-	-	-	-	SRC	-	H	P	R
67	*Sinapis arvensis* L.	Sin arv	OW, OC	SRC	CS	SRC, CS	CS	-	T	A	R / C-R
68	*Solanum dulcamara* L.	Sol dunc	-	-	-	SRC	SRC	-	C	P	C-S-R / C
69	*Sonchus arvensis* L.	Son arv	OC	-	-	-	-	-	H	P	C-R
70	*Sonchus asper* (L.) Hill	Son asp	OW	SRC	-	-	-	-	T	A	R / C-R
71	*Sorbus aucuparia* L.	Sorb auc	OW	-	-	-	-	-	M	P	S-C
72	*Stellaria media* (L.) Vill	Stell med	OC	CS	SRC	SRC	-	-	T	B	R
73	*Symphoricarpos albus* (L.) S. F. Blake	Sym alb	OW	-	-	-	-	SRC	N	P	C / S-C
74	*Taraxacum officinale* F. H. Wigg.	Tar off	OW, OC	SRC, CS	SRC, CS	SRC, CS	SRC, CS	SRC	H	P	R / C-S-R
75	*Thlaspi arvense* L.	Thl arv	OW, OC	SRC, CS	CS	CS	CS	-	T	A	R
76	*Tragopogon pratensis* L.	Trag prat	-	-	SRC	-	-	-	T	B	C-R / C-S-R
77	*Trifolium pratense* L.	Trif prat	-	CS	-	SRC	SRC	-	H	P	C-S-R
78	*Trifolium repens* L.	Trif rep	OW	SRC	SRC	-	-	SRC	H	P	C-S-R / C-R
79	*Tussilago farfara* L.	Tuss far	-	-	SRC	CS	-	-	G	P	C / C-R
80	*Ulmus glabra* Huds.	Ul glab	OW	SRC	SRC	-	-	-	M	P	C / S-C
81	*Urtica dioica* L.	Urt dioi	OW	SRC, CS	SRC	SRC, CS	SRC	SRC	H	P	C
82	*Urtica urens* L.	Urt uren	-	SRC	-	-	-	-	T	A	R / C-R
83	*Veronica arvensis* L.	Ver arv	OW, OC	-	SRC	-	SRC	-	T	A	S-R
84	*Veronica chamaedrys* L.	Ver cham	-	-	-	SRC	SRC	SRC	H	P	C-S-R / S
85	*Vicia cracca* L.	Vicc crac	-	SRC	SRC	SRC	SRC	-	H	P	C / C-S-R
86	*Viola reichenbachiana Jord*	Vio reich	-	-	-	-	SRC	SRC	H	P	S

Occurrence per growing season: Weed species present in old willow (OW, 2009); willow short rotation coppice (SRC, 2010, 2012–2015); old cereals (OC, 2009); cereal system (CS, 2010, 2012–2015), or absent in any cropping system (-); **Raunkiær's life form**: Chamaephyte (C); Geophyte (G); Hemicryptophyte (H); Megaphanerophyte (M); Nanophanerophyte (N); Terophyte (T); (ns) not specified in the literature used due to a great diversity in growth habit of these genera; **Life-cycle strategy categories**: Annual (A); Biennial (B); Perennial (P); (ns) not specified in the literature used; **Grime's strategy**: Competitor (C), Ruderal (R), Stress tolerator (S); (ns) not specified in the literature used. [1] Raunkiær, 1934; [2] Lid & Lid, 2005; [3]Grime et al., 2007.

Grime's strategy

Following the triangular plane of which the corners represent a defined strategy (Grime et al., 2007), weed species which are able to tolerate stress, i.e. stress tolerators (S), stress tolerant ruderals (S–R) and stress tolerant competitors (S–C), were observed in both OW and OC in growing season 2009, and then during growing seasons 2010 and 2012–2015 predominantly in SRC (3–21%). Ruderals (R) > competitive ruderals (C–R) > intermediate between competitor (C), stress tolerators (S) and ruderals (C–S–R) constituted the majority (each around 20%) of weed species in OW. In OC, in contrast the order was R > C > C–R (each around 30%). Weeds in SRC and CS belonged predominantly to the C–R (22–60%), C (15–40%) or C–S–R (5–29%) category during all growing seasons (Table 1). The relative high share of ruderals is likely related to both disturbance frequency and nutrient levels inherent to the cropping systems. Gustafsson (1988) also found that ruderal species became increasingly common during succession in willow SRC. As described earlier by Baum et al. (2012b), mostly common species, typical for disturbed and anthropogenic environments, were found both in cereal and willow SRC.

Weed species richness and weed ground cover

Cropping systems OW and OC differed in the weed species richness and ground cover ($P = 0.0061$, $F = 9.51$ and $P = 0.0000$, $F = 108.94$, respectively).

The average weed species richness and average weed ground cover was affected by crop ($P < 0.0001$), growing season ($P < 0.0001$) and crop × growing season ($P < 0.0001$) (Fig. 2), but not by termination method. In our first hypothesis we postulated that deep soil cultivation during termination of OW, initially and in both crops would reduce weed species richness and ground cover compared to shallow soil cultivation, due to that deep soil cultivation during OW would act as a weed control method. However, no effect of this one-time action was found, likely because the disturbance regime associated with SRC establishment and the disc harrowing in 2009 and 2010 in CS overruled a possible effect of termination method.

With regard to weed species richness, statistically significant differences were observed for the groups 'only SRC', 'only CS' and 'SRC + CS' within but not between growing seasons (Fig. 3). Weed species found in both SRC + CS were rare, decreased from 4.63 (2010) to 3.13 (2015). These were mostly weeds of wide distribution and common in many cropping systems (e.g. *Cirsium arvense*, *Elymus repens*, *Taraxacum officinalis*, Håkansson (2003)). SRC-specific species already dominated during the establishment year and over time continued to enlarge their share in SRC. Weed species richness in the CS however, already deviated from the richness in the SRC during the first growing season after termination, and was lower. Thereby we did not find support for our second hypothesis that seed bank and site history would result in similar weed species richness and ground cover of SRC and CS. This indicates that the seed bank typical for SRC could not be expressed in the CS, probably due to the high frequency of soil disturbance, or that historical effects on the seed bank generally are of short-term (Bohan et al., 2011). Weed flora richness and diversity was higher in SRC compared to CS. This is in accordance with previous work of Baum et al. (2012a) and Weih et al. (2003) who found that species richness was higher in fields grown with woody perennials such as willow and poplar than in cereal cultivations.

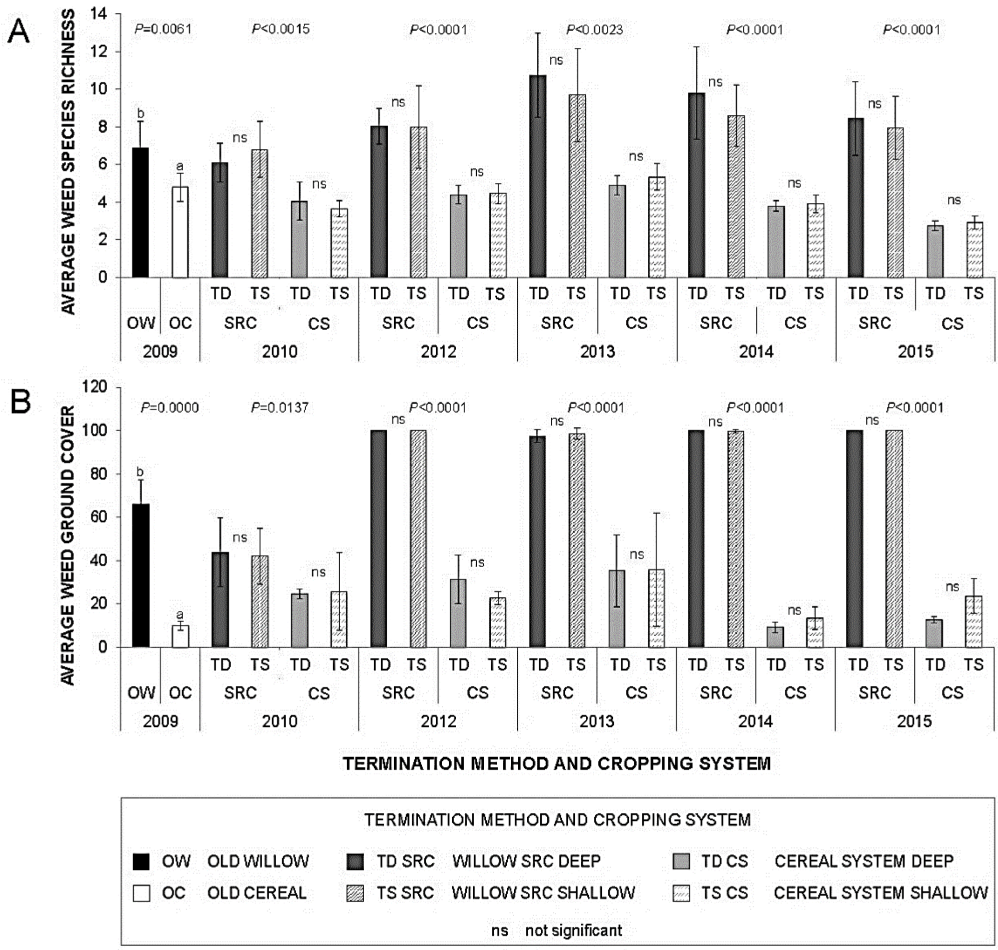

Figure 2. The average weed species richness (A) and average weed species ground cover (B) during growing seasons 2009–2010 and 2012–2015 presented for different crops: old willow (OW, black bar), old cereal (OC, white bar), willow SRC established after application of termination method with: deep soil cultivation (TD SRC, dark grey bars) andshallow soil cultivation (TS SRC, dashed bars), and cereal CS established after application of termination method with: deep soil cultivation (TD CS, light grey bars), and shallow soil cultivation (TS CS, stripped bars). Values are means (OW: n = 80, OC: n = 5, TD SRC, TS SRC, TD CS and TS CS: n = 20) of species richness and ground cover within blocks (± standard deviation). P-values indicate statistically significant differences between willow and cereal crop within growing season. An abbreviation 'ns' indicates that there were no significant differences between TD and TS within growing season.

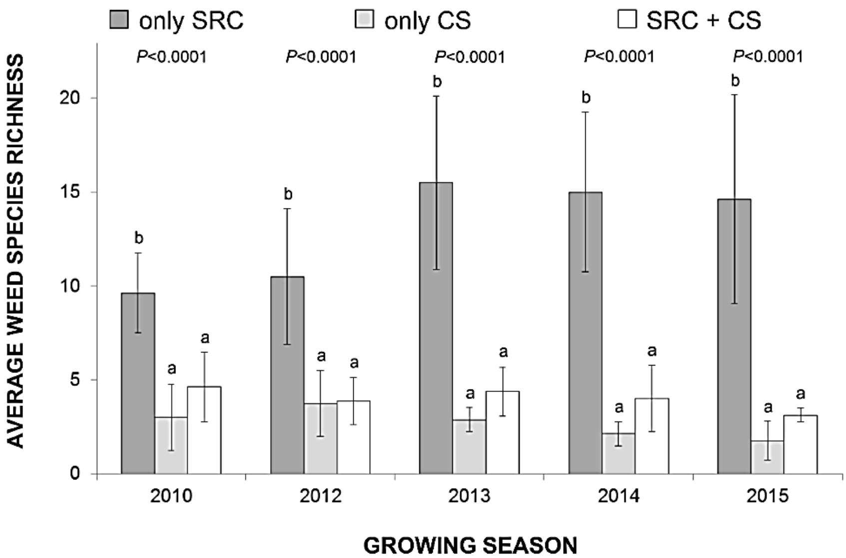

Figure 3. The average richness of weed species within groups 'only SRC' (dark grey bars), 'only CS' (light grey bars) and 'SRC + CS' (white bars) during growing seasons 2010 and 2012–2015. Values are means ($n = 4$) of weed species richness for block and within a crop (± standard deviation). Different letters and *P*–values indicate statistically significant differences between different groups of weed species within growing season. There were no significant differences within separate groups between growing seasons.

Life-cycle strategy categories

Average occurrence percentage of weed species in different life-cycle strategy categories in OW and OC, SRC and CS during all growing seasons (except 2015 for SRC) was perennials > annuals > biennials (Fig. 4, A). Average occurrence percentage of biennials fluctuated more in SRC than in CS until they were absent in SRC in 2015. An increase in the average occurrence percentage of annuals was recorded between 2013 and 2014 in SRC. This was attributed to an increase in the occurrence percentage of *Galium aparine*, *Medicago lupulina* and *Veronica arvensis* in the weed flora. The reason of this increase could not be specifically explained.

In OW and OC the average ground cover percentage of weed species in different life cycle categories was perennials > annuals > biennials. This structure remained the same during 2010 and 2012–2015 in CS but varied in SRC (Fig. 4, B) where the most pronounced change was observed for biennials. As the growing season proceeded, they were eliminated from the weed assemblages in SRC from perennials > biennials > annuals (2012), perennials > biennials = annuals (2013), perennials > annuals > biennials (2014), perennials > annuals (2015). Predominance of annuals in CS and perennials in SRC is determined mostly by the frequency of disturbances associated with management practices in specific cropping system (Håkansson, 2003). Furthermore, conversions from annual to perennial crops are known to lead to a shift from annual to perennial weed species (Andersson & Milberg, 1998) while annual weed species become dominant on arable land (Majekova et al., 2010), attributed to an increase in disturbance frequency inherent to the cropping system. Similarly, we demonstrated that a conversion from a woody perennial to an annual crop led to a shift from perennial to annual weeds.

Woody perennials disappeared rapidly after conversion to CS, while they gradually got foothold in SRC. This category also included some garden escapes like *Symphoricarpos albus* (L.) S. F. Blake and *Lonicera tatarica* L. and other native species such as *Cornus sanguinea* L., *Crataegus monogyna* Jacq., *Lonicera xylosteum* L., *Prunus padus* L., *Rhamnus cathartica* L., *Sambucus racemosa* L. and *Sorbus aucuparia* L., which all are disseminated by birds.

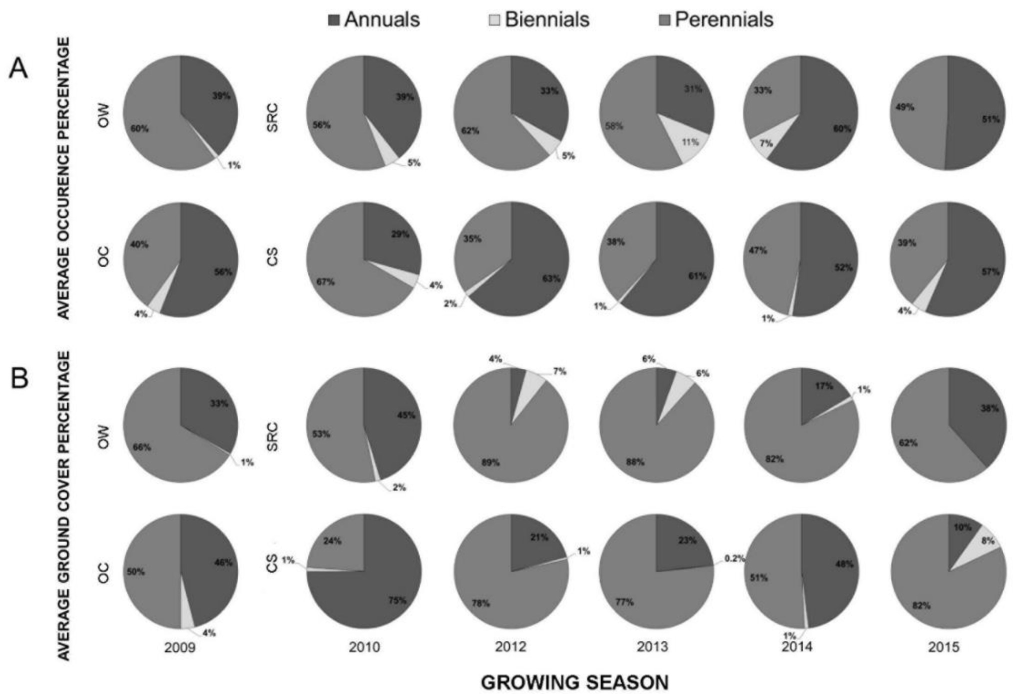

Figure 4. The average occurrence percentage in quadrants (A) and average ground cover percentage (B) of weed species per life-cycle category (% annuals, dark grey; % biennials, light grey; % perennials, grey) during growing seasons 2009–2010 and 2012–2015 presented for different crops: old willow (OW), old cereal (OC), willow short rotation coppice (SRC) and cereal system (CS).

Weed species dynamics

Weed species abundance and composition

As deduced from the direction and length of the weed species vectors, the abundance of weed species changed over time and the composition of the weed flora became progressively more crop-specific as the growing seasons proceeded (Fig. 5). From growing seasons 2010 and 2012–2015, the weed flora composition diverged along the first NMDS axis, which represents cropping system. Along the second NMDS-axis, the weed flora composition showed a separation of subplots on basis of their spatial distribution and termination method.

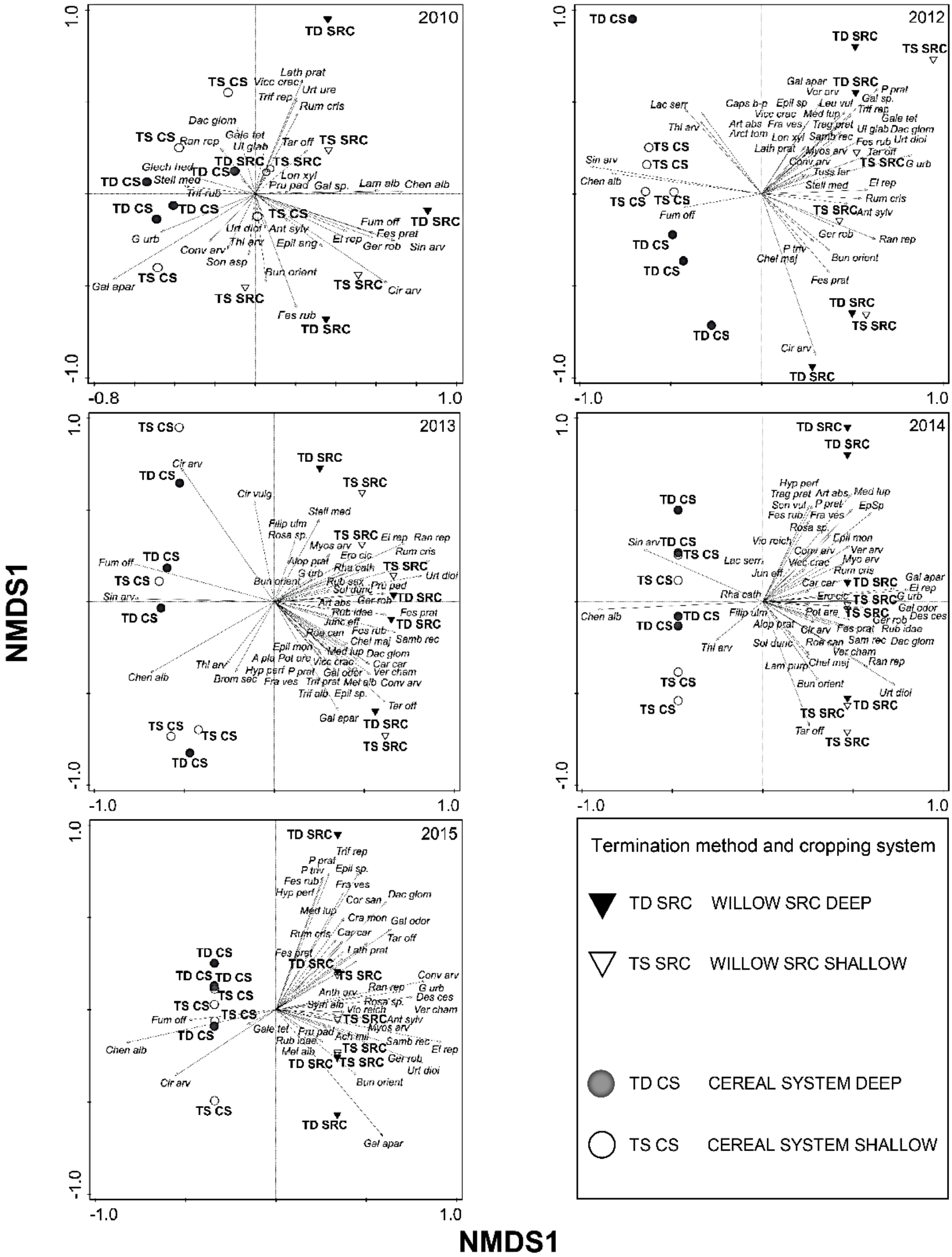

Figure 5. Gradients in the weed species composition in willow short rotation coppice (SRC) and cereal system (CS) during growing seasons 2010 and 2012–2015 assessed by Non-metric Multi-Dimensional Scaling (NMDS). NMDS axis 1: cropping system, NMDS axis 2: weed flora composition. Each point represents one subplot of willow established after application of: deep termination method (TD SRC, black triangles), and shallow termination method (TS SRC, white triangles), and cereal system established after application of: deep termination method (TD CS, light grey circles), and shallow termination method (TS CS, white circles). Identities of the weed species are encoded according to Table 1.

In SRC the abundance of *Urtica dioica* L., *Geum urbanum* and *Galium aparine* L. increased while the abundance of *Cirsium arvense* (L.) Scop. decreased during growing season 2012–2015. In CS, *Sinapis arvensis* and *Chenopodium album* were abundant weed species, whereas the abundance of *Thlaspi arvense* L. decreased during growing season 2012–2015. The weed flora in CS during 2010 contained *Geum urbanum*, *Dactylis glomerata* and *Ranunculus repens* L., which were abundant in the OW. However, the abundance of these species declined rapidly when the cultivation of CS was continued (Fig. 5). This once again stresses the importance of the cropping system specific disturbance frequency, which favours therophytes and prohibits forest species to get a foothold in cereal systems.

Divergence of the weed flora

The divergence of the weed flora during 2010 and 2012–2015, a change in specificity of a certain weed species to a certain cropping system was observed (Table 2). The indicator species analysis showed that the weed species *Sinapis arvensis*, *Chenopodium album* and *Fumaria officinalis*, were indicative weed species for SRC in growing season 2010 while only one weed species, *Elymus repens* (L.) Gould, was indicative for CS. This is likely due to the fact that willow is not a competitive crop in an early stage, thereby giving these summer annuals the opportunity for a rapid development during initial willow establishment.

Table 2. *P*-values of indicator values of weed species specific for a given category (SRC, dark grey; CS, light grey; both SRC + CS, white) during growing seasons 2010 and 2012–2015. Only statistically significant values at 95% confidence level within growing season are presented

	Growing season				
	2010	2012	2013	2014	2015
Weed species					
Sinapis arvensis	0.001	0.001	0.003	0.029	
Chenopodium album	0.001	0.002	0.002		0.001
Elymus repens	0.006	0.003	0.001	0.001	0.001
Fumaria officinalis	0.001	0.038	0.004		
Geranium robertianum		0.023	0.003	0.002	0.001
Geum urbanum		0.001	0.001	0.001	0.001
Dactylis glomerata			0.019	0.004	0.005
Ranunculus repens		0.001	0.003		0.001
Rumex crispus		0.006	0.003		
Poa pratensis		0.030		0.029	
Deschampsia cespitosa				0.001	0.002
Galium odoratum				0.019	0.007
Galium aparine				0.001	0.022

In 2012 *Geranium robertianum* and *Poa pratensis* L. were indicative for SRC, and *Sinapis arvensis* and *Chenopodium album* – for CS. A few weed species (i.e. *Elymus repens*, *Fumaria officinalis*, *Geum urbanum*, *Ranunculus repens* and *Rumex crispus* L.) were found in both cropping systems. Indicative weed species for SRC in 2013 were *Geranium robertianum*, *Geum urbanum*, *Dactylis glomerata*, *Ranunculus repens*, and *Rumex crispus*. In the same growing season only *Fumaria officinalis* was indicative species for CS. Three weed species (i.e. *Sinapis arvensis*, *Chenopodium album* and *Elymus repens*) occurred in both cropping systems. Weed species *Geranium robertianum*, *Geum urbanum*, *Dactylis glomerata*, *Poa pratensis*, *Deschampsia cespitosa* and *Galium odoratum* (L.) Scop. were indicative for SRC in 2014. S*inapis arvensis* was the only indicative weed species for CS in 2014, whereas *Elymus repens* and *Galium aparine* occurred in both cropping systems. In 2015 *Geranium robertianum*, *Geum urbanum*, *Dactylis glomerata*, *Ranunculus repens*, *Deschampsia cespitosa* and *Galium odoratum* were indicative weeds for SRC. CS had only one indicative weed species, *Chenopodium album* and *Elymus repens* and *Galium aparine* was present in both cropping systems.

Similarly to the average occurrence percentage of weed species in different life-cycle strategies, also the differences in weed species indicative for SRC and CS are likely to be determined by the frequency of disturbances associated with management practices in specific cropping system. Disturbance-sensitive weeds such as e.g., *Geum urbanum* L., *Geranium robertianum* L., *Dactylis glomerata* L., and *Deschampsia cespitosa* (L.) P. Beauv. were indicative for willow SRC in our study and also commonly found in other willow SRC (Gustafsson, 1988; Augustson, 2004) in which management was ceased. In contrast, indicators of CS which is frequently disturbed were *Chenopodium album* L., *Fumaria officinalis* L. and *Sinapis arvensis* L. which are competitors and ruderals completing their life-cycle within one growing season (Håkansson, 2003).

CS harbored annual weed species such as e.g. *Chenopodium album*, *Fumaria officinalis* and *Sinapis arvensis* during growing seasons 2012–2015, but these were also indicative for SRC in the growing season 2010. This is likely due to the fact that the old willow stand had developed many gaps in the canopy (Verwijst, 1996), thereby providing niches in which light-demanding species could maintain a seed bank. While some traces of site history were present in the form of some species (e.g. *Anthriscus sylvestris, Bunias orientalis, Fragaria vesca, Geum urbanum, Urtica dioica*) during the first year in CS, the divergence in weed species composition between cropping systems was immediate, which supports our third hypothesis.

NMDS analyses employed cover-abundance data (based on nominal transformation of the Braun–Blanquet methodology) which provide the information about the ground cover percentage of a given weed species in a given cropping system. The analyses revealed thus the changes in gradients of ground cover of weeds in SRC and CS over time (Fig. 5). In contrast, indicator values in indicator species analysis (Table 2) are multiplication of weed species' specificity (i.e. abundance relative to other weed species in the same weed assemblage) and their fidelity (i.e. the proportion of the ground percentage of a given species in a given crop) in a given crop. Thus, the difference between these two approaches is that NMDS revealed exclusively how much ground cover percentage is occupied by a given weed species and in a given crop, whereas indicator values showed how large is the ground cover of a given weed species (in relation to other weed species in the same assemblage) and how strongly it affiliates to a given cropping system.

Environmental conditions (inferred from Ellenberg index)

The Ellenberg index (light, soil moisture, soil N level and soil reaction) was affected by cropping system (P < 0.0015), growing season (P < 0.0059, except soil reaction) and cropping system × growing season (P < 0.0001). Light regime was significantly affected by cropping system in growing season 2012 and 2014 (P < 0.0079; Table 3). Apart from growing season 2010, soil moisture was significantly affected by the cropping system (P < 0.0071). The impact of the cropping system on the soil N level was significant for growing season 2012, 2014 and 2015 (P < 0.0001). Soil reaction was significantly affected by the cropping system for growing seasons 2012–2015 (P = 0.0017). This supports our fourth hypothesis that divergence of the weed species composition in SRC and CS is due to the inherent impact of the cropping systems on their environment, as inferred from the significance for the Ellenberg indices during most of the growing seasons. Soil moisture may be retained under willow, due to its litter layer and shading canopy. Also, the top soil (1–10 cm) is known to become more acid under willow SRC (Jug et al., 1999), which partly explains the divergence of the weed flora in our cropping systems (Fig. 5) towards a more acidophilus weed assemblage under the willow crop.

Table 3. P-values of Ellenberg index for light, soil moisture, N concentration and soil reaction during growing seasons 2010 and 2012–2015. Values statistically significant at 95% confidence level within growing seasons are presented

	Growing season				
	2010	2012	2013	2014	2015
Ellenberg index					
Light		0.0079		< 0.0001	
Soil moisture		< 0.0001	0.0071	< 0.0001	< 0.0001
Soil N level		< 0.0001		< 0.0001	< 0.0001
Soil reaction		0.0011	0.0002	< 0.0001	0.0017

CONCLUSIONS

We conclude that: 1) method of termination of willow SRC had no effect on weed species richness and ground cover, 2) the cropping system, but neither the initial seed bank nor site management history, had prevalent impact on the expression of seed bank in SRC and CS, 3) divergence in weed species composition between SRC and CS was immediate as was observed already in the first growing season after termination of old willow cultivation, and 4) the divergence in weed species composition in SRC and CS was affected by the cropping system and its inherent environmental conditions as inferred from the Ellenberg index.

Willow stands can be converted, regardless of termination method, either into cereal cultivations or willow SRC without additional risk of weed infestations other than those specific for their respective cropping systems. Winter cereals already may be sown in the growing season of willow termination. As both the SRC and CS systems harboured cropping system specific species, willow cultivations in an agriculture landscape contribute to floristic biodiversity, although their flora mainly consist of specific ruderal species which are characteristic for an anthropogenic environment.

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Shiyatov, S.G. 1986. *Dendrochronology of the upper timberline in the Urals*. Nauka, Moscow, 350 pp. (in Russian).

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