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Comparison of different chlorophylls determination methods for leafy vegetables

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Abstract. Modern agricultural farming requires precise, quick and nondestructive methods for determination of basic plant physiological parameters. One of the widely used and informative parameters is chlorophyll content in plant leaves. Determination of chlorophyll content by nondestructive methods is well elaborated for main field crops, but these methods are not widely used for chlorophyll content determination in leafy vegetables. The aim of the study was to compare two nondestructive methods with a classic biochemical chlorophylls determination method. Pigment content was expressed regarding to the leaf weight and leaf area. For nondestructive chlorophyll determination were used: a low cost handheld chlorophyll meter atLEAF+ and Miniature Leaf Spectrometer CI-710 (CID- Bio-Science). Chlorophylls content was determined using one of the 21 indices incorporated in Cl-710. For comparison of methods four different plant species (lettuce, leaf mustard, radish and cabbage) were used. Plants were grown at four illumination conditions – natural light, illumination supplemented with red, blue and mixed red/blue LED light. Results showed that at the majority of the investigated wavelengths, readings of the chlorophyll meter atLEAF+ and indices used for calculation are more sensitive to chlorophyll a content calculated per unit area. The maximum sensitivity of reflectance to variation with pigment content is found at 605 nm and 696 nm and in the near infrared region (740–930 nm). Higher correlation between non-destructive methods and biochemical analyses was observed in radish and leaf mustard leaves. The highest correlation coefficient was obtained with Difference Vegetation Reflectance index (NDVI) and Simple Ratio Pigment Index (SRPI). Nondestructive chlorophyll determination with chlorophyll meter atLEAF+ and Miniature Leaf Spectrometer CI-710 can completely replace biochemical analyses.

Key words: chlorophyll, atLEAF+, CI-710, non- destructive determination.

INTRODUCTION

Nowadays modern agricultural farming requires precise, quick and nondestructive methods for determination of basic plant physiological parameters. One of the widely used and informative parameters is the chlorophyll content in plant leaves. Chorophyll content varies in plant leaves depending on plant genetics, content of mineral elements, different stress factors, etc. (Haboudane et al., 2002; Torres et al., 2015; Wang et al., 2016). Therefore leaf pigment content can provide valuable insight into the physiological performance of leaves (Sims & Gamon, 2002). Determination of chlorophyll content by nondestructive methods is well elaborated for main field crops, but these methods are not widely used for chlorophyll content determination in leafy vegetables. In the Database for remote sensing indices[1] totally 112 different indices of vegetation chlorophyll content are listed. Single wavelengths, simple ratios and more complex equations as well as derivations are used for determination of chlorophyll content in plant leaves. Eucalyptus plants showed maximum sensitivity of reflectance to variation in pigment content in the green wavelength region at 550 nm and at 708 nm in the far-red wavelengths. The reflectance in the main pigment absorption regions in the blue (400–500 nm) and in the red (660–690 nm) wavelengths proved to be insensitive to variation in pigment content (Datt, 1998). Similar results were obtained also with corn leaves were reflectance factors at 550 nm and 715 nm were inversely related to chlorophyll concentrations, but at 450 nm and 670 nm changed only slightly (Daughtry et al., 2000). Chainese researchers recommended 553 nm of detection chlorophyll content in frost damaged wheat leaves (Wang et al., 2016). Gathering more than 10 years research done in chlorophylls non destructive determination, Blackburn (2007) concluded that the major chlorophyll reflectance feature in the region 530–630 nm and in a narrower band around 700 nm, is most sensitive to pigment concentrations.

Recommended wavelengths in the NIR region for determination of chlorophyll content are 727–734 nm (Wang et al., 2016), 695–725 nm (Gitelson et al., 2003) and 710 nm and 925 nm (Maire et al., 2008).

The aim of this study was to compare two nondestructive methods with the classic biochemical chlorophylls determination method.

MATERIALS AND METHODS

Experiments were carried out in autumn 2015 in the heated polycarbonate greenhouse of the Faculty of Agriculture, Latvia University of Agriculture.

Plant material

Two varieties of lettuce plants: lettuce (*Lactuca sativa*) cv 'Lollo Bionda' and cv 'Lollo Rossa', leaf mustard (*Brassica juncea*) cv 'Scala' radish (*Raphanus sativus*) cv 'French breakfast, and cabbage seedlings (*Brassica oleracea*) cv 'Rufus', were grown in 3–5 L vegetation pots filled with commercial peat substrate *KKS-U*, pH 5.9 ± 0.3, PG Mix 15-10-20 0.6 kg m^{-3}. Lettuce cv 'Lollo Bionda', leaf mustard and cabbage has red leaves.

Additional LumiGrow The LumiBar LED strips were switched on from 6–9 AM and 16–20 PM used to obtain a 14 h photoperiod. Blue, Red and Mixed Blue/Red LED lighting was used. Control variant was without additional lighting. Plants were sown at August 29, analyses were performed at November 4, 2015. Totally 20 variants were examined. Earch variant was grown in 4 replicates.

[1] http://www.indexdatabase.de/db/a-single.php?id=17

Biochemical determination of pigments content

Content of chlorophyll a and b and sum of chlorophylls of were determined spectrophotometrically. 10 leaf discs were weighed and ground in a mortar with approximately 10 mg $CaCO_3$. Ground leaf material was extracted with three small volumes of ethanol, filled to 10 mL, centrifuged for 3 minutes and the absorbance of the supernatant solution in a 1cm cell was read at 440, 649 and 665 nm with a UV spectrophotometer UV-1800 (Shimadzu Corporation, Japan). Chlorophyll a (Chl a), chlorophyll b (Chl b) and chlorophylls sum (Chl a+b) were calculated using the equations of Lichtenthaler & Buschmann (2001). Pigment content was expressed relative to the leaf weight and leaf area. Biochemical analyses were done in two replicates.

Nondestructive determination of pigments

For nondestructive chlorophyll determination were used: a low cost handheld chlorophyll meter atLEAF+ and Miniature Leaf Spectrometer CI-710 (CID-Bio-Science), which rapidly estimates plant properties using published and accepted indices. Chlorophylls content was calculated using one of the 21 different indices incorporated in Cl-710: Structure intensive pigment index (SIPI), Chlorophyll normalised vegetation index (CNDVI), Carter indexes (CTR1, CTR2), Greening index (G), Gitelson Merzlak indexes (GM1,GM2), Lichtenthaler indexes (LIC1, LIC20, Normalized difference vegetation reflectance (NDVI), Normalized pigment chlorophyll reflectance (NPCI), Normalized pheophitinization index (NPQI), Simple ratio pigment index (SRPI), Triangular vegetation index (TVI),Transformed Carter index (TCARI), Zarco-Tejada & Miller Index (ZMI), Modified red edge simple ratio index (MRESRI), Red edge normalized difference index (RENDVI), Vogelman red edge indexes (VREI1, VREI2 VREI3), Photochemical reflectance index (PRI), Plant senescence reflectance index (PSRI), Water band index (WBI). Nondestructive measurements were done in 10 replicates.

Significance for differences between methods and variants was analysed using two-way Anova at $P \leq 0.05$. Correlation analyses were performed between biochemical data, reflectance at a single wavelength and calculated indices by using Excel Data Analyses tool pack.

RESULTS AND DISCUSSION

The spectral absorbance properties of pigments are manifest in the reflectance spectra of leaves (Blackburn, 2007). Reflectance ability of vegetable leaves depends on pigment content and anatomical properties of leaves (Fig. 1). At the visible light range (400–700 nm) absorption of chlorophylls and carotenoides is well detectable. At the wavelength range 400–500 nm and 660–690 nm reflectance of plant leaves is less than 10%. The blue region is not recommended for estimation of chlorophylls content because it overlaps with absorbance of carotenoids. In the red region absorbance tends to saturate at low chlorophyll content and therefore sensitivity of the method decreases (Wu et al., 2008). The highest reflectance of leaves in visible spectrum was detected at 550 ± 5 nm which corresponds with literature data (Daughtry et al., 2000; Haboudane et al., 2002; Blackburn, 2007). Reflectance in the near infrared region varied from 32% (lettuce) till 56% (cabbage seedlings leaves).

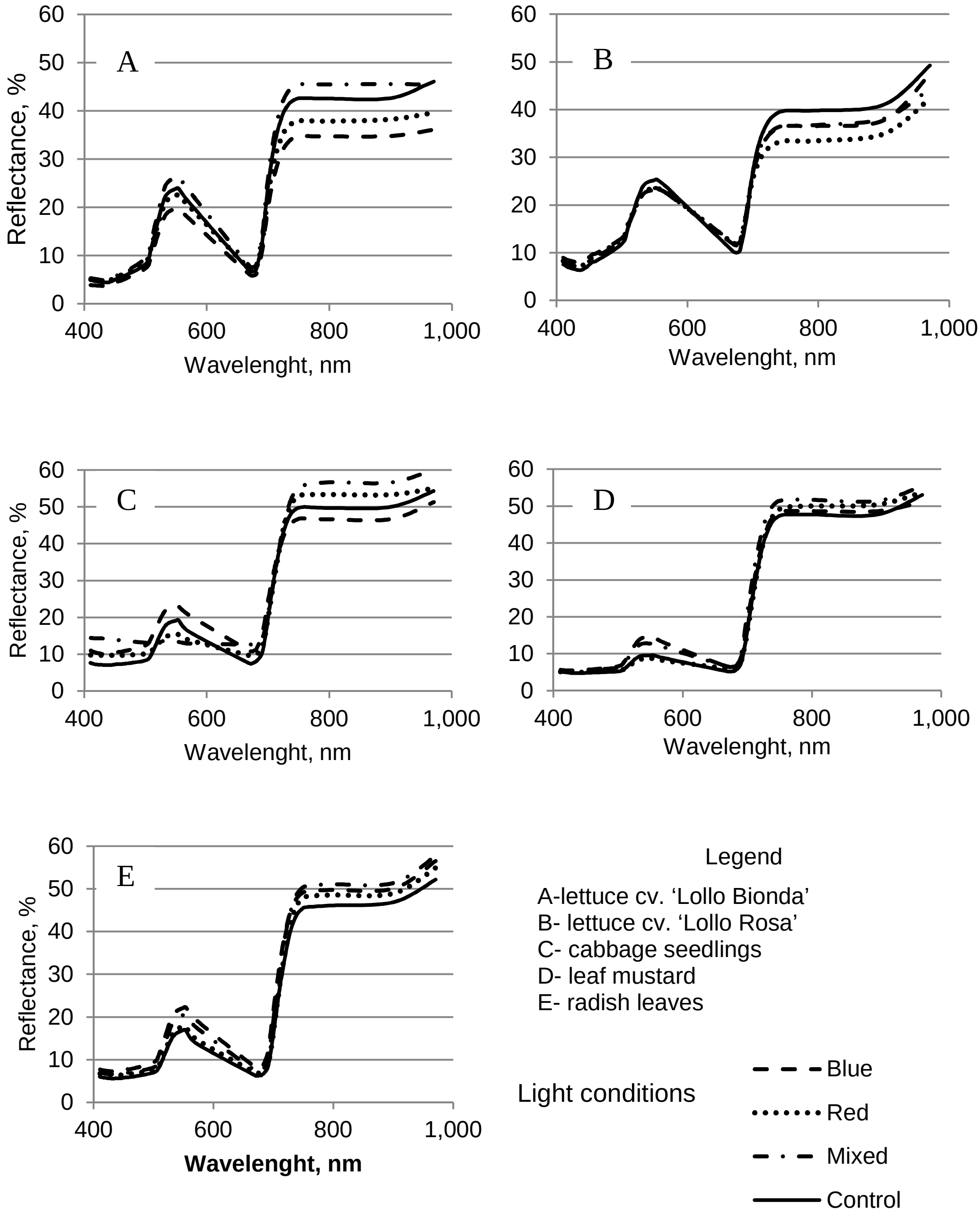

Figure 1. Reflectance spectra of leaves of; lettuce, leaf mustard, cabbage and redish grown with additional illumination with LED light of different colors.

Biochemical analyses shoved that chlorophyll content in vegetable leaves varied from 0.119 mg g^{-1} (0.221 mg dm^{-2}) fixed in lettuce 'Lollo Bionda' till 1.181 mg g^{-1} (3.146 mg dm^{-2}) determined in cabbage. Results showed that additional red lighting decreased chlorophyll content in vegetable leaves (except cabbage seedlings). There are reports about significant effects of LED illumination on plant pigment content (Olle &

Viršile, 2013) In research done with hydroponically grown lettuce significant differences in pigment content as result of LED lighting was not found (Lin et al., 2013). Similar result was obtained with cucumber transplants (Brazaitytė et al., 2009).

Table 1. Content chlorophylls in plant leaves detected biochemically

Plant	Light Variant	Pigment content, mg g^{-1}			Pigment content, mg dm^{-2}		
		Chl a	Chl b	Chl a+b	Chl a	Chl b	Chl a+b
Lettuce Lollo Bionda	Blue	0.257	0.108	0.365	0.454	0.190	0.644
	Red	0.077	0.042	0.119	0.143	0.077	0.221
	Mix	0.142	0.066	0.208	0.295	0.137	0.432
	Control	0.314	0.139	0.453	0.524	0.232	0.756
Lettuce Lollo Rosa	Blue	0.182	0.099	0.281	0.290	0.157	0.447
	Red	0.117	0.066	0.184	0.201	0.113	0.314
	Mix	0.113	0.069	0.182	0.191	0.117	0.308
	Control	0.182	0.100	0.283	0.308	0.170	0.479
Cabbage	Blue	0.666	0.330	0.996	1.558	0.771	2.329
	Red	0.806	0.375	1.181	2.147	0.999	3.146
	Mix	0.686	0.308	0.994	1.919	0.861	2.779
	Control	0.729	0.365	1.094	1.641	0.823	2.464
Leaf mustard	Blue	0.804	0.320	1.124	1.487	0.591	2.077
	Red	0.594	0.249	0.843	1.259	0.529	1.789
	Mix	0.601	0.242	0.842	1.247	0.502	1.749
	Control	0.920	0.409	1.329	1.454	0.646	2.100
Radish leaves	Blue	0.649	0.311	0.959	1.467	0.701	2.168
	Red	0.619	0.261	0.879	1.722	0.725	2.447
	Mix	0.602	0.259	0.861	1.522	0.653	2.175
	Control	0.756	0.349	1.105	1.621	0.748	2.369
	$RS_{0.05}$	0.059	0.028	0.086	0.128	0.057	0.182

Calculated coeficients of correlation between single wavelengths and biochemically determinated pigment content are showed (Fig. 2). In the visible light spectrum the maximum sensitivity of reflectance to variation in pigment content is at 605 nm and 696 nm. It fits to data described by other authors (Datt, 1998; Daughtry, et al., 2000; Blackburn, 2007). For detection of chlorophylls content reflectance at near infrared region (740–930 nm) can be used. At the visible light region better correlation was observed with chlorophyll content calculated as mg g^{-1} (w), but in NIR region if calculated as mg dm^{-2}. Similar results are obtained with low cost handheld chlorophyll meter atLEAF+ (Fig. 2).

Majority of investigated wavelengths, calculated indices and readings of chlorophyll meter atLEAF+ are more sensitive to chlorophyll a content calculated per unit area (Fig. 2, Table 2). It is not surprising, because chlorophyll a constitute a majority of the total chlorophylls. The content of chorophyll a may be up to 85.5% in total content of chlorophylls (calculated from Kitajima & Hogan, 2003).

Evaluating chlorophyll detection methods for the individual plant species, it is recognized that the use of reflectance of single wavelength is less suitable in comparison with calculated indices. At the region of visible light the best correlation between results obtained with non destructive methods and biochemical analyses was stated for radish leaves, but in NIR region for leaf mustard. Lower correlation was obtained for cabbage seedlings.

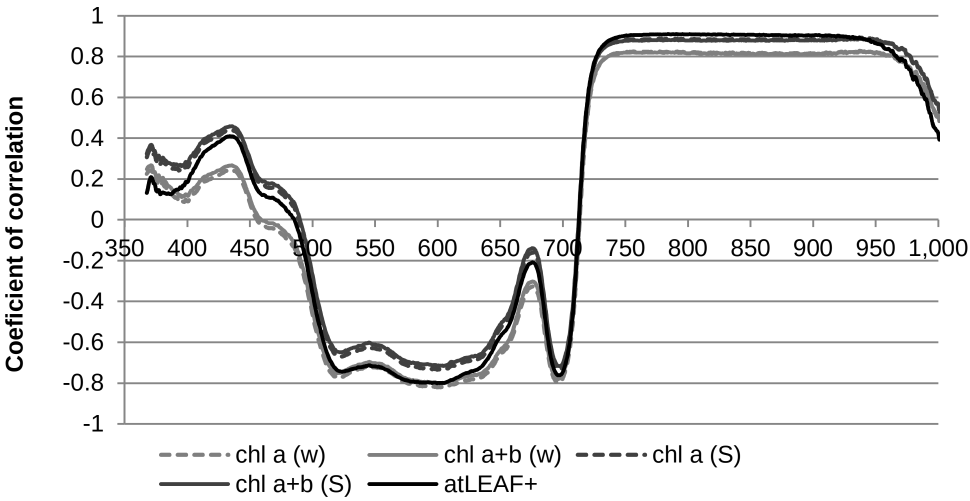

Figure 2. Coeficients of correlation between single wavelenght and biochemically detected content of chlorophyll a and sum of chlorophylls detected as mg g^{-1}(w) or mg dm^{-2} (S), and readings of chlorophyll meter atLEAF+.

Table 2. Coeficients of correlation

Index	Pigment content, mg g^{-1}			Pigment content, mg dm^{-2}		
	Chl a	Chl b	Chl a+b	Chl a	Chl b	Chl a+b
atLEAF+	0.86	0.84	0.86	0.94	0.92	0.93
SIPI	0.82	0.79	0.81	0.88	0.85	0.87
CNDVI	0.90	0.86	0.89	0.90	0.86	0.89
CTR1	-0.76	-0.79	-0.77	-0.85	-0.87	-0.86
CTR2	-0.88	-0.83	-0.87	-0.86	-0.81	-0.84
G	-0.46	-0.46	-0.46	-0.48	-0.48	-0.48
GM1	0.66	0.60	0.64	0.57	0.52	0.56
GM2	0.88	0.83	0.87	0.87	0.82	0.86
LIC1	0.66	0.58	0.64	0.56	0.49	0.54
LIC2	0.82	0.84	0.83	0.93	0.94	0.94
NDVI	-0.90	-0.91	-0.90	-0.97	-0.97	-0.97
NPCI	-0.59	-0.52	-0.57	-0.66	-0.59	-0.64
NPQI	0.66	0.58	0.64	0.56	0.49	0.54
SRPI	0.88	0.88	0.88	0.96	0.96	0.96
TVI	0.64	0.60	0.63	0.64	0.61	0.64
ZMI	0.89	0.85	0.88	0.91	0.86	0.89
MRESRI	-0.28	-0.19	-0.25	-0.12	-0.04	-0.10
RENDVI	0.90	0.86	0.89	0.90	0.86	0.89
VREI1	0.89	0.85	0.88	0.92	0.88	0.91
VREI2	-0.86	-0.82	-0.85	-0.91	-0.86	-0.90
VREI3	0.68	0.68	0.68	0.74	0.74	0.74
PRI	-0.87	-0.83	-0.86	-0.91	-0.87	-0.90

Assessing separately green leafed and red leafed vegetables it can be concluded that the non destructive determination methods is better suited for first ones. For example coeficient of correlation between measurments with chlorophyll meter atLEAF+ and biochemical methods for green leafed vegetables (lettuce cv. 'Lollo Bionda', radish leaves) is 0.990, but for red leafed ones 0.942. Similar results were obtained also with Miniature Leaf Spectrometer CI-710. All indices excluding SIPI and NDVI have higher values for green leafed vegetables. There are references in literature that the presence of other pigments did not significantly affect estimation of chlorophyll from spectral reflectance (Sims & Gamon, 2002).

Correlation coefficient between chorophyll a content and biochemical analyses for nine indices (Cl-710) was equal or higher than 0.90, for four between 0.81–0.89. If different indices are compared then the best results was detected for Normalized Difference Vegetation Reflectance index (NDVI), coefficient of correlation for chlorophyll a –0.971, for sum of chlorophylls -0.972. NDVI was calculated using equation (W680-W430) / (W680+W430), were W680 and W430 light reflectance at 680 and 430 nm respectively. The next better result was obtained using Simple Ratio Pigment Index (SRPI), were the same wave length reflectance was used for calculations. SRPI=W430/W680.

CONCLUSIONS

Majority of investigated wavelengths, calculated indices and readings of chlorophyll meter atLEAF+ are more sensitive to chlorophyll a content calculated per unit area.

The maximum sensitivity of reflectance to variation in pigment content is found at 605 nm and 696 nm and near infrared region (740–930 nm).

Higher correlation between non – destructive methods and biochemical analyses was observed in radish and leaf mustard leaves. Lower correlation was obtained for cabbage seedlings.

The non destructive determination methods are better suited for green leafed vegetables.

The highest correlation coefficient is obtained with Difference Vegetation Reflectance index (NDVI) and Simple Ratio Pigment Index (SRPI) was reflectances at wavelength 680 and 430 nm are used for calculations.

Nondestructive chlorophyll determination with chlorophyll meter atLEAF+ and Miniature Leaf Spectrometer CI-710 can completely replace biochemical analyses.

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REFERENCES

Blackburn, G.A. 2007. Hyperspectral remote sensing of plant pigments. *J. Exp. Bot.* **58**(4), 855–867.

Brazaitytė, A., Duchovskis, P., Urbonavičiūtė, A., Samuolienė, G., Jankauskienė, J., Kasiulevičiūtė-Bonakėrė, A., Bliznikas, Z., Novičkovas, A., Breivė, K. & Žukauskas, A.

2009. The effect of light-emitting diodes lighting on cucumber transplants and after-effect on yield. *Zemdirbyste–Agriculture* **96**(3), 102–118.

Datt, B. 1998. Remote Sensing of Chlorophyll *a*, Chlorophyll *b*, Chlorophyll*a+b*, and Total Carotenoid Content in Eucalyptus Leaves Remote Sensing of Environment Volume 66, Issue 2, Pages 111–121.

Daughtry, C.S.T., Walthall, C.L., Kim, M.S., Brown De Colstoun, E. & McMurtreylll, J.E. 2000. Estimating Corn Leaf Chlorophyll Concentration from Leaf and Canopy Reflectance. *Remote sensing of environment* **74**, 229–239.

Gitelson, A.A., Gritz, Y. & Merzlyak, M.N. 2003. Relationships between leaf chlorophyll content and spectral reflectance and algorithms for non-destructive chlorophyll assessment in higher plant leaves. *J. Plant Physiol.* **160**(3), 271–282.

Haboudane, D., John, R., Millera, J.R., Tremblay, N., Zarco Tejada, P.J. & Dextraze, L. 2002. Integrated narrow-band vegetation indices for prediction of crop chlorophyll content for application to precision agriculture. *Remote Sensing of Environment* **81**, 416–426.

Kitajima, K. & Hogan, K.P. 2003 Increases of chlorophyll a/b ratios during acclimation of tropical woody seedlings to nitrogen limitation and high light. *Plant Cell Environ.* **26**(6), 857–865.

Lichtenthaler, H.K. & Buschmann, C. 2001. *Current Protocols in Food Analytical Chemistry*. John Wiley and Sons, Inc., Hoboken, New Jersey. published on line. http://onlinelibrary.wiley.com/doi/10.1002/0471142913.faf0403s01/pdf

Lin, K.H., Huang, M.Y., Huang, W.D., Hsu, M.H., Yang, Z.W. & Yang, C.M. 2013. The effects of red, blue, and white light-emitting diodes on the growth, development, and edible quality of hydroponically grown lettuce (Lactuca sativa L. var. capitata). *Scientia Horticulturae* **150**, 86–91.

Maire, G., François, C., Soudani, K. & Berveiller, D. 2008 Calibration and validation of hyperspectral indices for the estimation of broadleaved forest leaf chlorophyll content, leaf mass per area, leaf area index and leaf canopy. *Remote Sensing of Environment* **112(**10), 3846–3864.

Olle, M. & Viršilė, A. 2013. The effects of light-emitting diode lighting on greenhouse plant growth and quality. *Agricultural and Food Science* **22**, 223–234.

Sims, D.A. & Gamon, J.A. 2002 Relationships between leaf pigment content and spectral reflectance across a wide range of species, leaf structures and developmental stages. *Remote Sensing of Environment* **81**(2–3), 337–354.

Torres, P.B., Chow, F. & Santos, D.Y.C. 2015. Growth and photosynthetic pigments of*Gracilariopsis tenuifrons* (Rhodophyta, Gracilariaceae) under high light in vitro culture. *Journal of Applied Phycology*, **27**(3), 1243–1251.

Wang, H. F, Huo, Z.G., Zhou, G.S., Liao, Q.H., Feng, H.K. & Wu, L. 2016. Estimating leaf SPAD values of freeze-damaged winter wheat using continuous wavelet analysis. *Plant Physiology and Biochemistry* **98**, 39–45.

Wu, C., Niu, Z., Tang, Q. & Huang, W. 2008. Estimating chlorophyll content from hyperspectral vegetation indices: Modeling and validation. *Agricultural and Forest Meteorology* **148**, 1230–124.

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The influence of basic soil tillage methods and weather conditions on the yield of spring barley in forest-steppe conditions

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Abstract. The research on the effect the main methods of soil treatment have on its hydrophysical properties was carried out as a stationary experiment at the National Scientific Centre, Institute of Agriculture NAAS. It included a grain crop rotation with the subsequent crop sequencing: winter wheat/grain maize/barley. In 2013–2015, the spring barley variety 'Solntsedar' was sown. Throughout the three years of research, the consistency of the effect of the main soil treatment methods on the overall yield stayed more or less the same. Reduction in barley grain yield against the backdrop of long-term disking at the depth of 10–12 cm is explained by the thickening of the 10–30 cm layer of soil to the critical level of 1.57 g cm^{-3}, moisture deficiency, as a result of the over-compaction of the root layer, and an increase in the amount of sterile spikelets. As the result of our research, we have come to a conclusion that for barley, soil disking at the depth of 10–12 cm is as good as ploughing if it is used as a part of differential treatment system, which includes ploughing at the depth of 28–30 cm or chisel tilling at 43–45 cm for its preceding crops. If disking was used for all crops of the grain crop rotation, a deterioration of hydrophysical properties was observed in the barley field, which can lead to a considerable reduction in the barley yield, especially in a dry cultivation year.

Key words: soil treatment, yield, barley, weather conditions, moisture accumulation, crop rotation, water consumption coefficient, vegetation period.

INTRODUCTION

Spring barley as a fodder-grain crop has the highest yield among first class grain crops. Cultivated areas of the forest steppes of Ukraine cover 15% of the crop rotation structure. In Ukraine, the average barley yield is 3.0–3.5 t ha^{-1}, while in good weather conditions and provided that high quality agricultural machines are used, it can reach 6.5–8.0 t ha^{-1} (Gorash, 2007; Gorash, 2012).

The analysis of weather conditions of the last decade, in particular of the years 2013–2015, indicates that spring grain crops, especially ones with a short vegetation period, are extremely sensitive to drought and high temperatures during the vegetation period.

Hydrothermal conditions, soil moisture in particular, are some of the main factors for yield formation, while the efficient use of available resources provides the minimum loss per yield unit. Water consumption during the vegetation period depends on weather conditions, biological peculiarities of the plant and their growth technology (Ehrenbergerová et al., 1999; Gorash, 2007; Lihochvor et al., 2010; Gorash, 2012).

Barley is a drought-tolerant crop, characterised by a highly efficient use of moisture needed to make a yield unit. Seeds require 45–50% of water of their dry mass to sprout (Kaminsky & Peter, 2003; Gorash, 2007; Lihochvor et al., 2010; Gorash, 2012). In spite of being highly moisture-efficient, the plants can still experience a deficit of water, especially at the start of the vegetation period. The reason for that is the insufficient development of root system. The critical period, in terms of water consumption, growth stages 4–6 of organogenesis (Ehrenbergerová et al., 1999; Lihochvor et al., 2010).

The total water consumption and evaporation characterizes the security of plants during separate development periods and their vegetation period as a whole. The evaporation process takes place under the influence of weather conditions: the income and loss of water in the 'soil-plant' system, the temperature of the topmost layer of soil, air and wind speed (Malienko, 2013).

Taking all of the abovementioned facts into account, the process of water accumulation in autumn and winter and the formation of a positive hydrophysical soil environment are the key measures for the formation of a high spring barley yield. This is why the search for a means of water preservation is an urgent scientific and production objective.

Purpose of the Research. To determine the influence of the basic soil tillage methods and weather conditions during summer barley vegetation period on its yield in the forest-steppe. To assess the provision of hydrophysical properties within the environment of the ploughing soil layer and its dynamics during plant vegetation.

MATERIALS AND METHODS

The experiment was started in 1969 on wet coarse silty slightly loamy forest soil with a low humus content – 1.08 or 1.29%, and a content of phosphorus: 7.1–7.9, and potassium: 7.0–8.3 mg (100 g)$^{-1}$ soil. The soil solution reaction is slightly acidic, pH_{KCl}: 5.1–5.2.

At the time of our research in the topsoil (0–45 cm) were gotten following results: humus content – 1.28–1.32%, phosphorus – 15.3–19.2 mg (100 g)$^{-1}$ and potassium – 14.9–17.7 mg (100 g)$^{-1}$. Method of Kirsanov is based on the extraction of mobile phosphorus and potassium compounds from the soil with a solution of hydrochloric acid (extraction solution), the molar concentration of 0.2 mole dm^{-1} and subsequent quantitative determination of mobile phosphorus compounds and potassium photoelectrocolorimeter – by flame photometer. The reaction of the soil was rNKCl – 5.7.

Coordinates to pilot area location: Kiev; Latitude 50°,35´; Longitude 30°,42´; Altitude 186 m. Tested soil groups by WRB classification WRB (World Reference Base): HE – 0–30 cm; I1 – 31–55 (60); I2–56 (61) – 85 (90); Ip – 91–125 (130); P – 126 (131).

The research has been carried out with grain crop rotation with the subsequent crop sequencing: winter wheat/grain maize/barley.

The barley fertilization system included the introduction of $N_{50}P_{40}K_{50}$ and the termination of all of the by-products of the preceding crop – 14.2 t ha^{-1} (maize stalks). Small potassium norm was used because during research potassium content in soil was already 14.9–17.7 mg $(100\ g)^{-1}$.

The protection system has includes the use of the following herbicides and fungicides: against weeds – Agritox 500 water soluble granules: 1.5 l ha^{-1}, Nurelle-D emulsion concentrate: 1.0 l ha^{-1}, against diseases: Vitavax 200 FF 1.5 l ha^{-1}, and against pests – Bi-58 new emulsion concentrate: 1.0–1.2 l ha^{-1} (DSTU, 2004).

The scheme of long-term stationary experiment is represented by the main cultivation system of grey forest soil (Table 1).

Table 1. The scheme of the tested soil

The main soil treatment method system	Crop rotation crop		
	winter wheat	grain maize	spring barley
Ploughing at different depths (control)	Ploughing at the depth of 16–18 cm	Ploughing at the depth of 28–30 cm	Shallow ploughing at the depth of 10–12 cm
Flat-cut tilling at different depths	flat-cut tilling at the depth of 16–18 cm	flat-cut tilling at the depth of 28–30 cm	flat-cut tilling at the depth of 10–12 cm
Differential	disking at the depth of 10–12 cm	chisel ploughing at the depth of 43–45 cm	disking at the depth of 10–12 cm
Disking at one single depth	disking at the depth of 10–12 cm	disking at the depth of 10–12 cm	disking at the depth of 10–12 cm

Soil samples used in this analysis have been selected in accordance with standard DSTU 4287: 2004, and prepared in accordance with the requirements of DSTU ISO 11464-2007. The moisture content in the soil has been determined by thermogravimetric-gravimetric method using auger sampling in soil layer 0–100 cm, measurements were taken after every 10 cm in the three periods of time – in the phase of sprouting, flowering and at the time of full maturity of grain, with the transfer to general reserves of moisture soil accordance with standard DSTU ISO 11465-2001. Yielding capacity was determined via continuous threshing. The size of the area is 200 m^2, the used plot is 120 m^2, three replications, the placement of samples in the experiment is sequential.

RESULTS AND DISCUSSION

During the spring barley vegetation period in 2015, the precipitation rainfall norm was 30% of the average perennial rainfall norm, and its distribution in time was determined by using a histogram in the package Matlab application. The year was described as abnormal. It was made unique by the simultaneous display of three types of drought: soil, atmospheric, and hydrological drought. Weather conditions within this particular year and vegetation period had a negative effect on the growth and development of barley plants. The maximum precipitation deviation from the norm – by 48.6–63.2 mm – had fallen within the period of formation of the productive elements of the ear. On average, the moisture deficiency during the vegetation period had been 224 mm (Table 2).

During their active development period, the plants were suppressed; their growth was stumped as the days of vegetation with the long-term soil drought and air heat predominated

During 20–30 April and 1–20 June there was no precipitation, and the period without rain lasted for 30 days (Table 2).

Table 2. Hydrothermal conditions of spring barley vegetation period, 2013–2015

Year	Income of heat and moisture	Month				April-July**	Hydrothermal index
		April	May	June	July		
2013	actual*	10.5	18.7	21.5	20.3	2057	0.48
		18.5	26.6	49.6	4.0	98.7	
	deviations from	+1.8	+3.6	+3.3	+1.0	+9.7	-1.07
	the norm, ±	-30.5	-25.4	-23.4	-84	-163	
2014	actual*	10.5	18.7	21.5	20.3	1974	1.45
		28.8	167	50.2	41.2	287	
	deviations from	+1.6	+1.7	0.0	+2.7	+6.0	-0.1
	the norm, ±	-20.2	+115	-22.8	-46.8	+25.2	
2015	actual*	10.4	19.1	20.8	20.1	1958	0.51
		5.6	44.8	9.8	39.2	99.4	
	deviations from	+1.7	+4.0	+2.6	+0.8	+9.1	-1.04
	the norm, ±	-43.4	-7.2	-63.2	-48.8	-162	

*In the numerator—the average monthly air temperature, °C; in the denominator—the amount of precipitation per month, mm ** in the numerator—the sum of annual daily temperatures over 10°C within the vegetation period of the plants; in the denominator—the total amount of precipitation during the same period, mm.

Throughout the years of research the precipitation fell unevenly in different seasons and months, which has had an impact on moisture accumulation in autumn and winter, as well as on the deposits of moisture in soil during the plant vegetation period. The years 2013 and 2015 were critically dry. The amount of precipitation during vegetation was 98.7 and 99.4 mm respectively, hydrothermal index was 0.48 and 0.51. 2014 was very advantageous in terms of crop formation, as 287 mm of precipitation fell and the hydrothermal index was 1.45.

In 2013–2015, the average daily air temperature increased during the whole vegetation period. In May and June, it exceeded the norm on average by +3.8 and +3.0 °C respectively. The maximum deviation from the norm was registered in May 2015, and its absolute value exceeded the average perennial norm by + 4 °C and was accompanied by the reduction in the amount of precipitation at the level of 27.0 mm in comparison to the average perennial norm.

According to the Ukraine National Science Center, Institute for Agriculture NAAS given research area corresponds to the norm of the hydrothermal index 1.55.

Elevated air temperatures and virtually no atmospheric precipitation in 2015 led to a shortened ear flowering period, premature drying and dying of lower leaves, which, in turn, affected the size of assimilation surface and the spring barley grain yield (Table 2, 4).

The research carried out by the Department of Soil Treatment and Weed Control of the 'Institute of Agriculture NAAN' on grey forest soils revealed that in optimal soil density of 1.30 g cm^{-3}, the deposits of moisture in the 0–20 cm layer make up 56 mm, at 0–30 cm – 84 mm, and with the moisture of stable withering – 13 mm (Gordienko, 1998; Yatchuk, 2008; Zvezdenyuk & Boris, 2015).

According to this data (Gordienko, 1998; Yatchuk, 2008; Zvezdenyuk & Boris, 2015; Eshchenko, 2011), the grey forest soil can contain about 70% of annual precipitation in the 0–100 cm layer, which translates into 452 mm for the research area.

Autumn-winter of 2012–2013 had the largest amount of precipitation, a total of 316 mm, which surpassed the average perennial amount by 48 mm (18%). However, during the same period in 2013–2014 and 2014–2015, the moisture deficiency was 82.0 mm (31%) and 112 mm (42%) respectively.

The autumn-winter moisture accumulation in the 0–100 cm soil layer during the years of research with the long-term ploughing at different depths was on average 20 mm (11%) higher in comparison to moisture deposits that accumulated with long-term disking at the depth of 10–12 cm. The moisture accumulation during the same period within the years of research has mostly been dependent on the main soil treatment system, and especially on the weather conditions of that year (Table 3).

Table 3. The influence of the main soil treatment system on the productive moisture accumulation at the start of the spring barley vegetation period, 2013–2015

The main soil treatment method system	Soil layer, cm	Moisture deposit, mm				Non-productive moisture loss during vegetation, mm
		crop maturing	barley sprouts	moisture accumulation		
		2013–2014	2014–2015	mm	%	
Ploughing at different depths at 10–30 cm (control)	0–20	27	46	19	41	183
	0–100	114	163	49	30	153
Flat-cut tilling at the depth of 10–30 cm	0–20	31	42	11	25	191
	0–100	121	161	40	25	162
Differential at 10–45 cm	0–20	33	45	12	27	190
	0–100	123	160	37	23	165
Single-depth disking at 10–12 cm	0–20	35	42	7	17	195
	0–100	129	158	29	19	173
HCP $_{0.05}$	0–20	2.87	4.11	-	-	-
	0–100	3.02	6.13	-	-	-
	0–20	3.89	2.41	-	-	-
	0–100	8.13	5.24	-	-	-

Notes: *the amount of precipitation from the time of maize harvesting to the start of barley sprouting in 2013–2015 has on average been 202 mm, which make up the non-productive loss, namely the precipitation and accumulation in autumn-winter.

Our research has shown that the non-productive moisture loss during vegetation in 2013–2015 were the highest in long-term disking at the depth of 10–12 cm. In the latter case, the loss of moisture in the 0–20 cm layer in comparison to the control plot has been 12 mm (6%), and 20 mm (10%) in the 0–100 cm layer (Table 3).

The largest moisture deposits were in the control plot, and throughout the years they exceeded the amount of moisture deposits of long-term flat-cut and single-depth disking plots by 147 and 223 m^3 ha^{-1} respectively. Moisture deposits with differential treatment were on the same level as the control plot. During the barley sprouting period, the moisture deposits throughout the research years were sufficient for efficient development of the plants in the first half of vegetation (Table 4).

In particular, this trend in moisture depositing while using different main soil treatment methods remained constant throughout the years.

In 2015, long periods without rain lasted for 48 days, i.e. about 50% of the duration of the vegetation period of spring barley. In June and I–II decade of July - with the amount of precipitation of 10 mm moisture reserves decreased to a value close to the withering point.

The maximum air temperature in the ear flowering and grain filling period was 37–39 °C. In the soil at the depth of 0–5 and 10–15 cm it was 26–28 and 23–25 °C respectively, and 35–37 °C above the surface of the crop, which had a negative impact on barley plants.

An increase in the air and soil temperature to the critical level during barley vegetation is undesirable; especially critical is the period of the leaf-tube formation/grain filling development at the 8–10th stages of organogenesis (Lihochvor et al., 2010; Gorash, 2012). The optimum temperature for plant growth and development during vegetation is +18 °C. The maximum temperature that barley can withstand for the first 25–35 hours is + 38–40 °C. A temperature increase by 1 °C leads to a decrease in yield by 4.1–5.7% (Schelling, 2003; Váňová, 2006; Lihochvor et al., 2010).

In 2015, during barley earing, there was a sharp decrease in the moisture deposits in comparison to the deposits formed in 2014. Such a sharp decrease in the amount of moisture available for the plants can firstly be explained by its intensive use and the critical stage for yield formation, and secondly by a small amount of precipitation in April and May (Table 2).

The 2015 moisture deposits in the 0–100 cm soil layer during harvest in barley field, which amounted to 450 m^3 ha^{-1}, were the lowest ever, lower than moisture deposits during harvest in 2013 and 2014 by 421 m^3 ha^{-1} and 924 m^3 ha^{-1}respectively.

In the water year 2014, the pattern of moisture distribution, both in terms of time and soil profile, was different from 2013 and 2015. On average, the amount of precipitation during vegetation exceeded its average perennial norm by 25 mm, with the hydrothermal index of 1.45, which is 0.10 lower than the norm (Table 2).

Weather conditions in 2013 and 2015 were not typical for the right-bank forest steppe, the hydrothermal index was lower than the average norm by 1.07 and 1.04 respectively, and in the main spring barley yield decreased in comparison to 2014 by 2.75 t ha^{-1} on the average (Table 4).

During the spring-summer vegetation, the amount of productive moisture in the soil decreased considerably, its lowest values were during the stage of complete ripeness of the grain (Table 4).

Table 4. The consumption of productive moisture in 0–100 cm soil layer, depending on the main soil treatment method, 2014–2015, m^3

The main soil treatment system at the depth, cm	Moisture deposits for the time period		Moisture consumption	*Water consumption	Yield		WCC*	
	Sprouts	Harvesting			t ha^{-1}	**± to control plot	m^3 t^{-1}	***± to control plot
2013								
Ploughing at different depths, 10–30 (control)	1,620	902	718	1,707	2.44	-	700	-
Different depths, flat-cut 10–30	1,330	915	415	1,404	2.02	-0.42 -17	695	-4.6 -1
Differential, 10–45	1,589	904	685	1,674	3.07	0.63 26	545	-155 -22
Single-depth disking, 10–12	1,171	762	409	1,398	1.99	-0.45 -18	702	2.6 0.4
$HCP_{0,05}$	4.79	5.01	-	-	0.12	-	-	-
2014								
Ploughing at different depths, 10–30 (control)	1,706	1,320	386	3,636	5.28	-	688	-
Different depths, flat-cut 10–30	1,516	1,357	159	3,409	5.32	0.03 1	641	-47 -7
Differential, 10–45	1,630	1,343	288	3,409	5.59	0.31 6	610	-78 -11
Single-depth disking, 10–12	1,499	1,477	22	3,538	4.82	-0.46 -9	734	46 7
$HCP_{0,05}$	6.13	6.70	-	-	0.26	-	-	-
2015								
Ploughing at different depths, 10–30 (control)	1,582	476	1,106	2,049	3.05	-	672	-
Different depths, flat-cut 10–30	1,621	443	1,178	2,121	2.47	-0.58 -19	858	186 28
Differential, 10–45	1,567	450	1,116	2,059	2.88	-0.17 -5	715	43 6
Single-depth disking, 10–12	1,571	431	1,139	2,082	2.40	-0.65 -21	869	197 29
$HCP_{0,05}$	5.24	2.17	-	-	2.40	-	-	-

Notes: *WCC: water consumption coefficient, m^3 t^{-1}; *amount of precipitation during vegetation 2013: 989 m^3; 2014: 3,250 m^3, 2015: 940 m^3. ** in the numerator, ± compared to control plot, t ha^{-1}; in the denominator ± compared to control plot, %; *** in the numerator ± compared to control plot, m^3 t^{-1}; in the denominator ± compared to control plot, %.

Our research has revealed that in 2013, the main spring barley yield was between 1.99–3.07 t ha^{-1}. With the differential soil treatment, where chisel ploughing was done at the depth of 43–45 cm during the preceding crop, and disking was done at the depth of 10–12 cm immediately before sowing barley, the grain yield was 26% (0.63 t) higher than on the control plot (Table 4). The barley yield with ploughing at different depths (control plot) at the 10–30 cm layer was 0.45 t ha^{-1}, or 18% higher than the results with single-depth disking (Table 4).

In the conditions of the 2014 vegetation period, with sufficient moisture both during sowing and plant vegetation, the barley seed yield was very high: 4.82–5.59 t ha^{-1} (Table 4).

In comparison to the previous year (2013), it was on average 2.87 t ha^{-1} (55%) higher against the backdrop of the main treatment method. The yield was 0.46 t ha^{-1} (9%) lower when long-term disking at the depth of 10–12 cm was used, compared to the control plot. In 2015, long-term single-depth disking produced the lowest yield, 0.65 t ha^{-1}, or 21% lower than the control plot (Table 4).

In our opinion, such a low yield in 2013 and 2015 was caused by the physical condition of the soil, and insufficient moisture provision to the plants—deficiency of available moisture, high temperatures of air and the layer of soil where most of the roots were located.

Weather conditions in 2013–2015 were contrasting in structure and distribution, which provided us with a possibility to fully assess their importance and impact on yield formation and achieving the genetic potential of spring barley. In autumn and winter of 2013–2014, the amount of precipitation (in the form of snow and rain) from the moment of harvesting the preceding crop (grain maize) to the start of spring barley vegetation, was 186 mm, while its amount in 2014–2015 was 16% lower. In 2013–2013 and 2014–2015 the amount of precipitation was lower than the average perennial norm by 82.0 (31%) and 112 (42%) mm respectively. During the years of research, moisture deficiency in autumn and winter has been approximately 97.0 mm (36%) (Table 2).

Vegetation periods of 2013 and 2015 were dry. They were characterized by precipitation deficiency and a heightened total sum of active air temperatures. Moisture deficiency was typical of the entire barley vegetation period, and in different months it was 43 mm or 89% (April), 63 mm or 45% (June), and 84.0 mm or 95% (July) of the monthly rate. This period coincided with the formation of barley yield (Table 2).

Vegetation period in 2014 was characterized as satisfactory. During the vegetation period, 287 mm of precipitation fell, and moisture deficiency during ear flowering (-22.8 mm) was unnoticeable due to May precipitation, since its amount was 115 mm higher than the norm (Table 2).

Throughout the three research years, the consistency of the effect of the main soil treatment methods on the yield of the main crops remained more or less the same.

Decrease in the spring barley grain yield against the backdrop of long-term disking at the 10–12 cm depth is explained by the thickening of the 10–30 cm soil layer to the critical level of 1.57 g cm^{-3}, water deficiency, as a consequence of over-compaction of the root layer, and an increase in the number of sterile spikelets.

CONCLUSIONS

1. The largest moisture accumulation in soil necessary for spring barley plant development takes place in autumn and winter using the differential soil treatment method, which in the case of grain crop rotation includes ploughing at 22–24 cm for soy, disking at 10–12 cm for wheat and barley, and chisel ploughing at 43–45 cm for maize.

Decline in the moisture schedule of grey forest soil using small-scale and non-inversing tilling is explained by an increased density in the lower part of the cultivated layer.

2. Summer precipitation, in particular in 2013 and 2015, was insufficient for achieving the full potential of the plants, while their duration and amount mostly did not live up to the requirements. The main amount of moisture, which was concentrated in the 0–20 cm layer, was expected to intensively evaporate.

3. Non-productive moisture loss in the 0–20 cm layer throughout years has been the highest when using flat-cutting at different depths and single-depth disking – 191 and 195 mm, or 95% and 96% of the moisture deposits that had accumulated in autumn and winter.

4. Disking at 10–12 cm for barley is as good as ploughing if it is used in the differential soil treatment system, which includes ploughing at 28–30 cm and chisel tilling at 43–45 cm for preceding crops. If disking was used for all crops of the grain crop rotation, a deterioration of hydrophysical properties was observed in the barley field, which lead to a considerable reduction in the barley yield, especially in a dry cultivation year.

REFERENCES

DSTU 4287:2004. *Soil quality*. *Sample collection*, K State Committee for Technical Regulation and Consumer Policy of Ukraine, 10 pp.

DSTU ISO 11464:2007. *Soil quality. Preliminary sample processing for physio-chemical analysis*. K: State Committee for Technical Regulation and Consumer Policy of Ukraine, 12 pp.

DSTU ISO 11465-2001. *Soil quality. Determining dry matter and humidity from mass. The gravimetric method*. K: State Committee for Technical Regulation and Consumer Policy of Ukraine, 10 pp.

Ehrenbergerová, J., Vaculová, K., Zimolka, J. & Mullerová, E. 1999. Yield characters and their correlations with quality indicators of hull-less spring barley grain. *Rostlinná výroba* **45**, 53–60. (in Slovak).

Eshchenko, V.A., Kaliyevsky, M.V. & Naklyoka, Yu.I. 2011. *The formation of springtime available moisture deposits and their use by grain crops depending on natural and anthropogenic factors*. Compilation of research works of Uman National University of Horticulture—Uman, **75**(1) 9–15 (in Ukrainian).

Gorash, A.S. 2012. The correlation of barley productivity elements with initial stages of development. *Agrarian Science Bulletin* **11**, 22–24.

Gorash, O.S. 2007. Features structure formation harvest of malting barley in interrelation to the quality. *Journal of Agricultural Science* **3**, 27–30.

Gordienko, V.P., Malienko, A.M. & Grabak, N.H. 1998. *Progressive soil cultivation systems*. Simferopol, 279 pp. (in Ukrainian).

Kaminsky, V.F. & Peter, M.O. 2003. To a question of solving the problem of protein. *Journal of Agricultural Science* **5**, 12–14.

Lihochvor, V.V., Petrichenko, V.F., Ivaschuk, P.V. & Korniychuk, S.O. 2010. *Crop production. Techniques of crop cultivation*. 3rd edition, Lvov: Ukrainian technologies, 1088 pp. (in Ukrainian).

Malienko, A. 2013. Concept and technology for optimization soil physical parameters of arable layer for field crops. – ICA 10th International Conference on Agrophysics, Lublin, Poland, p. 53.

Schelling, K., Born, K. & Weissteiner, C. 2003. Relationships between yield and quality parameters of malting barley and phonological and metrological data. *Journal of Agronomy and Crop Science* **189**(2), 113–122.
Zvezdenyuk, T.B. & Boris, N.E. The influence of the main methods of cultivation of grey forest soil on its agrophysical properties. *Agriculture and plant protection* **5**, 24–27 (in Ukrainian).
Váňová, M., Palík, S., Hajšlová, J. & Burešová, I. 2006. Grain quality and yield spring barley in fields trials under variable growing conditions. *Plant, Soil and Environment* **52**(5) 211–219.
Yatchuk, V.Ya. & Gavrilov, S.A. 2008. The influence of the cultivation of grey forest soil on its hydrophysical properties. *Agriculture* **80**, 28–32 (in Ukrainian).

Mechanical durability of briquettes from digestate in different storage conditions

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Abstract. A present research was conducted to determine mechanical durability of digestate briquettes and potential influence of different storage condition. Experiments were performed on briquette samples produced from digestate feedstock with moisture content of 8.2%, ash content of 10.9% and gross calorific value of 17.15 MJ kg^{-1} by hydraulic piston press with working pressure of 18 MPa with external diameter 50 mm and length 40–60 mm. Briquette samples were divided into two groups and stored inside and outside building. Both groups were subjected to five experimental testing during specific time period from May until late November 2014. Mechanical durability of each briquette was measured after every testing, subsequently overall mechanical durability of specific groups was calculated. Results showed the lowest mechanical durability after first measurement: 98.85% for Group 1 and 98.95% for Group 2. The biggest change in mechanical durability was observed between first and second testing, values of following measurements were approximately equal. The highest mechanical durability was achieved after fifth testing: 99.65% for Group 1 and 99.63% for Group 2. It implied mechanical durability equal to 99.44% for Group 1 and 99.45% for Group 2 in average. Research proved very high mechanical durability which corresponds to the highest category of this quality indicator given by standard EN ISO 17225-1. Difference between mechanical durability of groups stored in different conditions was considered as minor. Thereby briquettes made from digestate are not only secondary product of proper waste management, effectively modified fertilizer but as was found by results of this research it is also suitable fuel with outstanding mechanical properties.

Key words: biomass, densification, biofuel, abrasion resistance, renewable energy, quality control.

INTRODUCTION

Attempt to deal with solid biofuel quality is nowadays an important issue due to their consideration as a sustainable and environmental friendly renewable source of energy and substitution of fossil fuels. Moreover briquettes became a market product and its production increases these days consequently, however it must be produced in very high quality to attract the general public (Ivanova, 2012). Digestate, waste material from biogas plant stations, is commonly used as a fertilizer (Roubík et al., 2016) but after proper processing this waste material can be used as a feedstock for the briquette production. Digestate has its specific chemical and mechanical-physical properties which directly affect final quality of briquettes as well as all materials used as a feedstock for briquette production (Kratzeisen et al., 2010). Those specific properties (ash content, moisture content, calorific value, combustibility) are the reason why all kinds of briquettes must be subjected to quality tests. Mechanical durability (abrasion resistance), next important property of feedstock, is considered as one of the main indicator of the briquette quality which describes the ability of briquette to remain intact during its handling, transportation and storage (Kaliyan & Morey, 2009a; Ivanova, 2012; Muazu & Stegemann, 2015; Tumuluru et al., 2015).

Previous studies done by Kaliyan & Morey (2009a), Ivanova et al. (2014) and Repsa et al. (2014) showed that mechanical durability is the prevalent form of expression of physical quality of briquettes. Mechanical durability express the degree of briquette damage, thereby it helps to select suitable parameters for production and optimizes the densification process to produce high-quality briquettes.

It was already published in previous studies of Temmerman et al. (2006), Kaliyan & Morey (2009a), Ivanova (2012) and Tumuluru et al. (2015) that degree of mechanical durability is influenced by several factors as a characteristics of used feedstock material (moisture content, particle size, content of lignin), technical specification of production (operating temperature and pressure, type of the press) and storage conditions (relative air humidity and air temperature).

Influence of different storage conditions has been described in another published research done by Brožek (2013) which concluded that manner of briquette storing has major influence on their mechanical durability. Higher mechanical durability was observed at briquettes samples stored in heated condition apart from unheated storage conditions with weather changes.

The aim of this paper was to determine mechanical durability of digestate briquettes stored in different storage conditions by experimental way thereby to define the physical-mechanical quality of this biofuel. Furthermore the purpose was to analyze possible differences in mechanical durability between variously stored briquettes and to specify preferable storage condition.

MATERIALS AND METHODS

The production of briquette samples and subsequent quality testing was conducted in accordance with mandatory technical norms, European and International standards for solid biofuels. Namely as a basis, an International Standard EN ISO 17225–1:2015 which describes basic properties of feedstock and final products as an acceptable shape, diameter, length, moisture content, ash content, content of chemical elements and inter alia allowed values of mechanical durability was used.

Material

The briquette samples used for the experimental research were produced from the digestate material which originates from the biogas plant located in the Central Bohemian Region, Czech Republic. Feedstock used for the biogas production contains 40% of cattle manure, 30% of grass silage and 30% of maize forage. Raw unprocessed digestate material was obtained in the liquid form with 6% of dry matter. Based on such a composition, extracting of dry matter from raw digestate is highly time and energy consuming (using laboratory dryer with limited volume), therefore not feasible. According this fact, raw feedstock was firstly dehydrated mechanically and then naturally by the solar energy, without using other energy sources, on open area where the largest portion of moisture was evaporated and makes it less energy demanding process. Subsequently it was dried in the laboratory dryer LAC type S100/03 to the solid state with moisture content 8.2%.

Sampling and distribution

Prepared material was densified by the hydraulic piston press BrikStar type 30–12 (Malšice city, Czech Republic) which operates with feedstock moisture content 8–15%, density of final products is about 900–1,100 kg m^{-3}, operating pressure 18 MPa and operating temperature 60°C. Briquettes were produced into cylindrical shape with the identical diameter of 50 mm, length varying from 40–60 mm and consequently different weight from 72.00–142.45 g (see Fig. 1).

Figure 1. Briquette samples from digestate before experimental testing.

Before experimental testing, the briquettes were randomly divided into two groups (Group 1 and Group 2) and stored in two different storage conditions from April 2014 until November 2014 (226 days in total). Mentioned storage time period was divided to five intervals ended by performing of mechanical durability tests; first test was performed at 29th day, second test at 53rd day, third test at 88th day, fourth test at 148th day and fifth test was performed after 226th day of storage. Briquettes from Group 1 were stored in the laboratory with constant relative air humidity around 40% and air temperature equal approximately to 21.5 °C. Briquettes from Group 2 were stored outside the building, covered by the plastic bag and exposed to the weather changes.

According to meteorology station of the Czech University of Life Sciences Prague the following climate data were measured during an observed time period: average air temperature equal to 14.7 °C (min. 3.5 °C and max. 27 °C) and relative air humidity in average equal to 71.4% (min. 38.5% and max. 96.1%). Process of the weather changes is noted in following graphs showed in Fig. 2.

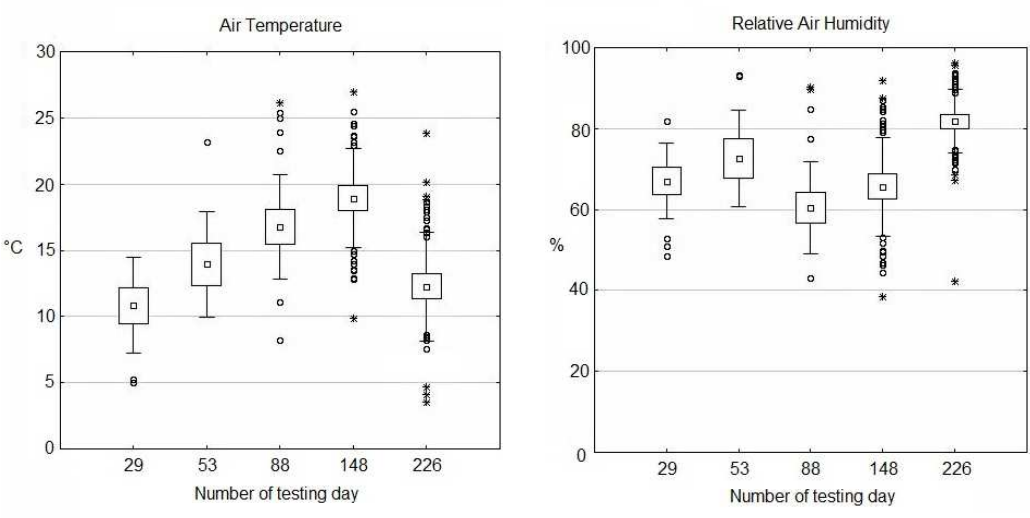

Figure 2. Weather changes in specific time intervals during observed time period.

Experimental procedure

During experimental testing in the framework of this research the moisture content, ash content and calorific value of feedstock material were determined and briquette samples were repeatedly (n = 5) subjected to mechanical durability tests. All above mentioned measurements were conducted following European Standards: EN 15234–1:2011, EN 14918:2009, EN 14775:2009, EN 14774–2:2009 and EN 15210–2:2011 which is describe below.

Mechanical durability test (DU test)

Process of durability testing were performed according to mentioned European Standards EN 15210–2:2011 which describes requirements and conditions of this test in detail. Testing was performed in special dustproof rotating drum with placement of rectangular steel partition powered by electricity. Drawing of this drum with description and dimensions is showed at Fig. 3. Minimal weight of tested group of samples is stated to 2 ± 0.1 kg[2], testing time is defined as 5 minutes which corresponds to 105 ± 0.5 rotations of drum and special sieve with holes size smaller than 45 mm was used for removing of abrasion from briquettes after testing. Briquette samples were tested five times during nine month of research duration and dates of performing the tests were following: 7th May 2014, 29th May 2014, 3th July 2014, 1st September 2014 and19th November 2014.

[2] In the case of this particular research less material than is specified in the standard has been used; other requirements of standard have been fulfilled.

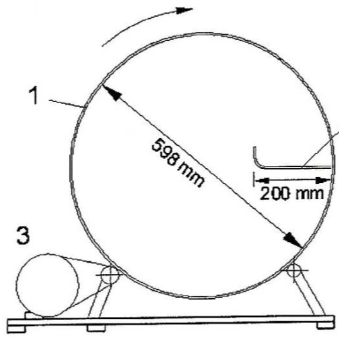

Figure 3. Drawing of rotating drum: 1–Drum, 2–Partition, 3–Engine (c).

Each briquette sample was weighed before and after testing and final mechanical durability of every briquette was calculated by using following formula:

$$DU = \frac{m_a}{m_e} \cdot 100 \qquad (1)$$

where: *D* – mechanical durability (%); m_a – weight of briquette sample after mechanical durability testing (g); m_e – weight of briquette sample before mechanical durability testing (g).

RESULTS AND DISCUSSION

Final result values showed very high level mechanical durability of briquettes made from digestate, overall average value was equal to 99.44% (minimum 96.25%, maximum 99.99%). It corresponds to the highest grade of this quality indicator (DU ≥ 95%) given by International standard for solid biofuels EN ISO 17225–1:2015. Previous research has proved suitability of digestate as a feedstock for production of densified fuel for combustion and recommended digestate as an excellent substitute for wood material (Kratzeisen et al., 2010). As it is visible from Fig. 4 the lowest mechanical durability was observed during first testing (98.90%) which corresponds to 105 rotations (29^{th} day) and the highest mechanical durability during last fifth testing (99.64%) which corresponds to 630 rotations in total (226^{th} day).

Fig. 4 also illustrates that the biggest difference between specific testing was observed between first (105 rotations) and second test (210 rotations). This phenomena was caused by abrasion of sharp edges of briquettes which comprised the main part of first abrasion. Previous research done by Temmerman et al. (2006) has showed reverse trend of mechanical durability changes. Result values of mentioned research has presented decreasing level of mechanical durability with increasing number of testing (n = 5) but time interval between testings or condition of storage of samples was not specified.

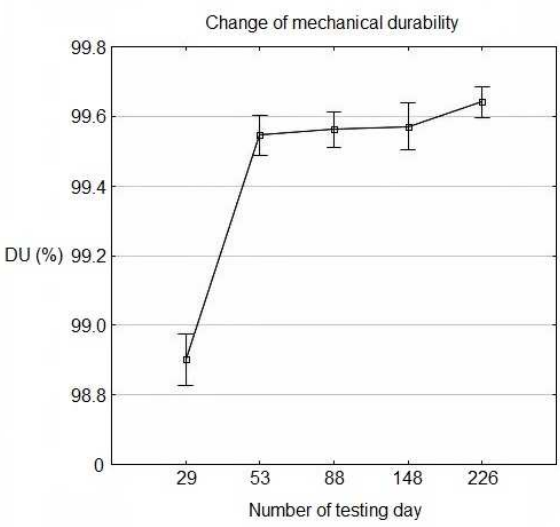

Figure 4. Average mechanical durability of all briquette samples (%) during specific testing.

For clearer evaluation of results values achieved in this research a comparison with mechanical durability of different feedstock material published by other authors was used, see in Table 1.

Table 1. Mechanical durability of briquettes from different feedstock material in %

DU (%)	Material	Author
< 90.0	giant reed	(Ivanova, 2012)
	wheat	(Tumuluru et al., 2015)
	canola	(Tumuluru et al., 2015)
	sea buckthorn	(Novotný, 2015)
	big bluestem	(Theerarattananoon et al., 2012)
≥ 90.0	wood	(Brožek et al., 2012)
	corn	(Kaliyan & Morey, 2009b)
	miscanthus x gigantheus	(Ivanova, 2012)
	rice	(Muazu & Stegemann, 2015)
	canary grass	(Repsa et al., 2014)
≥ 95.0	**digestate***	Authors data
	cotton	(Eissa et al., 2013)
	hemp	(Ivanova, 2012)
	soybean (stalk)	(Rajkumar & Venkatachalam, 2013)
	paper + board	(Brožek, 2015)

*In the case of this research less material than according to standard was used for the mechanical durability testing. Other result values were achieved by different mechanical durability testing methods (standards), thus it has informative and comparable character.

It is essential to mention that referential values of other crops (Table 1) were produced under different manufacturing conditions, however they are still comparable. Final mechanical durability can be significantly affected by the factors like compressing pressure, feedstock moisture content, temperature or particle size (Temmerman et al., 2006; Kaliyan & Morey, 2009a). According to research of Saptoadi (2008) it has been determined that mechanical durability of wood briquettes increases with decreasing size of feedstock particle size. Results values from previous researches of Temmerman et al. (2006) and Al-Widyan & Al-Jalil (2002) related to compacting presure exhibits that mechanical durability increases with increasing of compacting pressure. Those researches were done by high pressure briquetting machines which used compacting pressure 12–35 MPa however result values of Yank et al. (2016) proved high mechanical durability 91.9% of briquettes from rice husk and bran produced by manual press generating ~~a~~ compacting pressure of 4.2 MPa. This result opens chances to produce briquettes in non-electrified regions or in small production sectors and extends the scope of briquettes production on global scale.

Influence of different storage conditions

Average result values of specific testings and storage conditions, see in the Table 2 and Fig. 5 differs at minimal level. Result values exhibited higher mechanical durability for outdoor stored samples from Group 2 than for Group 1 which was stored in indoor constant conditions. Average difference between Group 1 and Group 2 was equal to 0.015 %. It can be stated that result values in average were approximately equal despite the different relative air humidity and air temperature of storage condition.

Table 2. Average mechanical durability (DU) of different stored briquette groups after specific testing (%)

Testing day	29th	53rd	88th	148th	226th	average DU
Group 1 (DU)	98.853	99.545	99.529	99.604	99.654	99.437
Group 2 (DU)	98.953	99.548	99.597	99.535	99.627	99.452

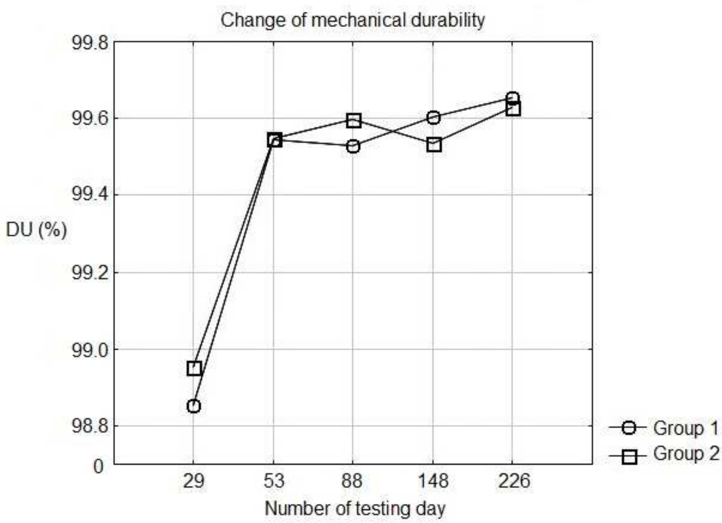

Figure 5. Mechanical durability average in different stored groups during specific testing.

According to previous research done by Kaliyan & Morey (2009a) the proper relative air humidity for storage of densified products is stated to 60–70% and air temperature should be equal to 25 °C and below Result values of this research also proved that increasing of moisture content of densified products to more than 13% can influence final product quality negatively (Kaliyan & Morey, 2009a).

Despite the fact that result values of mechanical durability observed in this paper are approximately equal higher mechanical durability was exhibited for outdoor stored Group 2. There is contradiction with previous research results of Brožek (2013). Mentioned research was also focused on influence of different storage conditions and long-term storage (9 months) of briquettes but it proved that mechanical durability of briquette samples stored in closed heated room was equal to 91.77% in average which was higher than mechanical durability of briquette samples stored in closed unheated room which was equal to 86.80% in average. Difference between results of mentioned previous research of Brožek (2013) and results of this paper can be explained by weight influence of briquette samples below.

Briquette weight influence

At the beginning of the experimental research the briquette samples were chosen and distributed randomly which caused weight inequality between groups. According to data the part of research focused on briquette weight has stated that Group 1 contained briquette samples with higher weight. This fact is visible from Fig. 6 below which displays weight distribution of briquette samples within different groups.

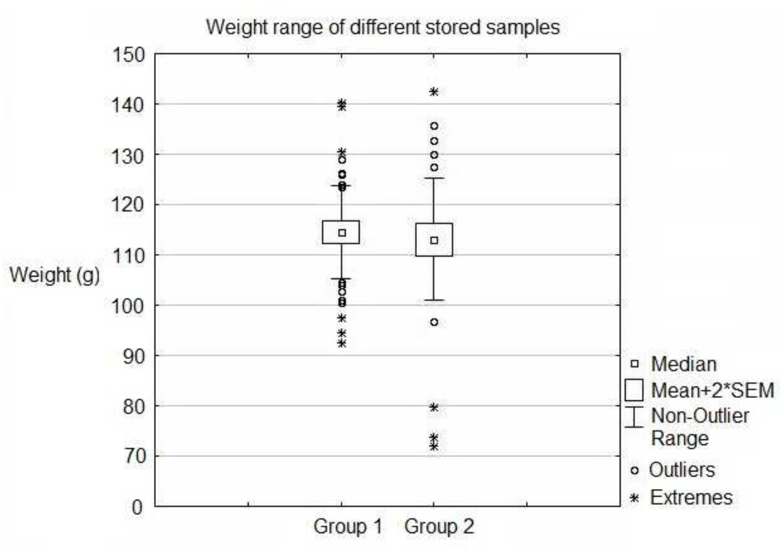

Figure 6. Weight distribution of briquette samples in observed groups (g).

For the purposes of this paper evaluation initial values of briquettes samples were distributed according to the briquette weight and mechanical durability of each different weight group was subsequently calculated. Those processed values as it is visible from Fig. 7 reflected that best degree of mechanical durability was stated for briquettes from groups with weight range 90.01–130.01 g. The lighter and also heavier briquettes showed lower degree of mechanical durability.

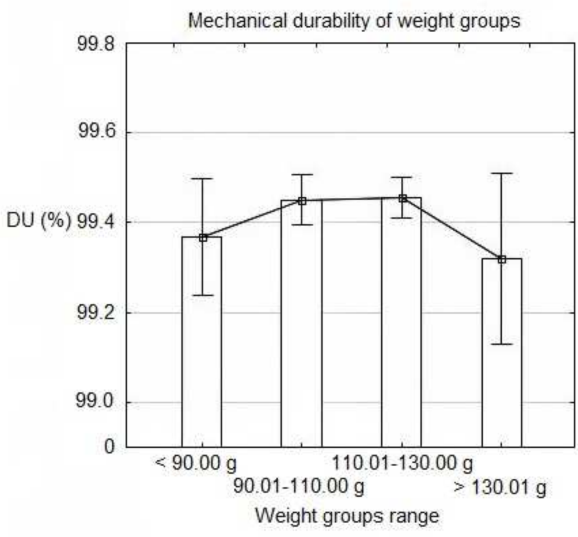

Figure 7. Comparison of mechanical durability of briquette sample groups with different weight.

CONCLUSIONS

The results of this paper implies that briquettes made from digestate exhibited very high mechanical durability (99.44% in average) in accordance to the evaluation of standard EN ISO 17225–1:2015 as well as in comparison with other tested feedstock material from previous researches. The degree of mechanical durability of digestate briquettes was not influenced by the different storage conditions in a considerable extent. Therefore briquettes from digestate are not demanding on storage condition. Higher mechanical durability was observed at briquette samples with weight range from 90–130 g (middle weight groups). Briquette samples with lower of higher weight exhibited lower mechanical durability. The research results contribute to the conclusion that briquettes made from digestate are not only secondary product of proper waste management, effectively modified fertilizer but it is also suitable fuel with outstanding mechanical properties.

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REFERENCES

Al-Widyan, M. & Al-Jalil, H. 2002. Physical durability and stability of olive cake briquettes. *Canadian Biosystems Engineering* **44**, 3.41–3.45.

Brožek, M., 2015. Evaluation of selected properties of briquettes from recovered paper and board.

Research in Agricultural Engineering **61**(2), 66–71.
Brožek, M. 2013. Study of briquette properties at their long-time storage. *Journal of Forest Science* **59**(3), 101–106.
Brožek, M., Nováková, A. & Kolářová, M. 2012. Quality evaluation of briquettes made from wood waste. *Research in Agricultural Engineering* **58**(1), 30–35.
Eissa, A.H.A. Gamea, G.R., El Saeidy, E.A. & El Sisi, S.F. 2013. Quality characteristics for agriculture residues to produce briquette. In *Trends in agriculture engineering*. Praha: Czech University of Life Sciences, Prague, pp. 156–162.
EN 14774-2. Solid biofuels – Determination of moisture content – Oven dry method – Part 2: Total moisture – Simplified method. 2010, pp. 1–12.
EN 14775. Solid biofuels – Determination of ash content. 2010, pp. 1–12.
EN 14918. Solid biofuels. Determination of calorific value. 2010, pp. 1–52.
EN 15210-2. Solid biofuels – Determination of mechanical durability of pellets and briquettes – Part 2: Briquettes. 2011, pp. 1–12.
EN 15234-1, Solid biofuels – Fuel quality assurance – Part 1: General requirements 2011, pp. 1–24.
EN ISO 17225-1. Solid biofuels – Fuel specifications and classes – Part 1: General requirements. 2015, pp. 1–64.
Ivanova, T. Kolaříková, M., Havrland, B. & Hutla, P. 2014. Mechanical and chemical properties of briquettes made of waste hemp (Cannabis sativa var. Finola) biomass. *Agritech Science* **8**(2), 1–4.
Kaliyan, N. & Morey, R.V. 2009a. Factors affecting strength and durability of densified biomass products. *Biomass and Bioenergy* **33**(3), 337–359.
Kaliyan, N. & Morey, R.V. 2009b. Densification characteristics of corn stover and switchgrass. *Transactions of the ASABE* **52**(3), 907–920.
Kratzeisen, M. Starcevic, N., Martinov, M., Maurer, C. & Müller, J. 2010. Applicability of biogas digestate as solid fuel. *Fuel* **89**(9), 2544–2548.
Muazu, R.I. & Stegemann, J.A. 2015. Effects of operating variables on durability of fuel briquettes from rice husks and corn cobs. *Fuel Processing Technology* **133**, 137–145.
Novotný, O. 2015. *Sea buckthorn wood processing for solid biofuels*. Czech University of Life Sciences Prague. 81 pp.
Rajkumar, D. & Venkatachalam, P. 2013. Physical properties of agro residual briquettes produced from Cotton , Soybean and Pigeon pea stalks. *International Journal on Power Engineering and Energy* **4**(4), 414–417.
Repsa, E., Kronbergs, E. & Pudans, E. 2014. Durability of compacted energy crop biomass. *Engineering for Rural Development* **13**, 436–439.
Roubík, H., Mazancová, J., Banout, J. & Verner, V. 2016. Addressing problems at small-scale biogas plants: a case study from central Vietnam. *Journal of Cleaner Production* **112**(4), 2784–2792.
Saptoadi, H. 2008. The Best Biobriquette Dimension and its Particle Size. *Asian Journal on Energy & Environment* **9**(3), 161–175.
Temmerman, M., Rabier, F., Jensen, P., Hartmann, H. & Bohm, T. 2006. Comparative study of durability test methods for pellets and briquettes. *Biomass and Bioenergy* **30**(11), 964–972.
Theerarattananoon, K., Xu, F., Wilson, J., Staggenborg, S., Mckinney, L., Vadlani, P., Pei, Z. & Wang, D. 2012. Effects of the pelleting conditions on chemical composition and sugar yield of corn stover, big bluestem, wheat straw, and sorghum stalk pellets. *Bioprocess and biosystems engineering* **35**(4), 615–23.
Tumuluru, J.S., Tabil, L.G., Song, Y., Iroba, K.L. & Meda, V. 2015. Impact of process conditions on the density and durability of wheat, oat, canola, and barley straw briquettes. *BioEnergy Research* **8**(1), 388–401.
Yank, A., Ngadi, M. & Kok, R. 2016. Physical properties of rice husk and bran briquettes under low pressure densi fi cation for rural applications. *Biomass and Bioenergy* **84**, 22–30.

Agronomy Research **14**(2), 337–344, 2016

Influence of blade shape on mulcher blade air resistance

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Abstract. Mulching is an energy-intensive agricultural operation. The efforts to reduce the energy intensity makes the designers explore new solutions which would reduce the energy intensity. One of the possibilities to reduce the energy intensity of mulching is to use a work tool of different shape. The paper introduces comparison of several shapes of blades intended for the mulcher with vertical axis of rotation, where especially the rake and cloth angle is changed. The measurement was performed by means of a laboratory model of a one mulcher rotor and in the field conditions where the mulcher Bednar MZ 6000 with a range of 6 m and three rotors had been used. The measurement was performed particularly from the point of view of the energy loss caused by drag of knives. The measurement done by means of the model of the mulcher has confirmed the hypothesis that larger cloth causes increased resistance of the mulcher and higher rake angle results in decreased mulcher resistance. However, larger cloth may contribute to better work quality in the field conditions.

Key words: Mulcher blades, mulching, energy loss, rake angle, cloth angle, air resistance.

INTRODUCTION

Mulching is a technological process during which crushed plant residues are left on the surface. It is primarily used for cutting and crushing green plant residues, old grass on permanent grasslands and for treating fallow lands. Mulching can also be used for crushing crop residues on the arable land (Andrejs, 2006; Mayer & Vlášková, 2007; Syrový et al., 2013).

Mulcher with vertical axis of rotation (Fig. 1) is a rotation mower. Many authors tried to measure its energy intensity but their results differ significantly (Table 1).

The energy intensity of mulching or shredding of plant material is dependent on the type of processed crop, parameters of the cut (mass performance, cutting speed etc.) and shape and condition of the cutting tool (Syrový et al., 2008; Hosseini & Shamsi, 2012; Kronbergs et al., 2013; Pecenka & Hoffmann, 2015). Shape of the cutting tool, especially the rake angle and the angle of the tool cloth (Fig. 2), may significantly affect the energy intensity of work. Concerning mulchers with vertical axis of rotation, the rake angle is mostly 0° which is a perpendicular cut. 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, 1991; Kakahy et al., 2012; Kakahy et al., 2013) depending on other parameters of the cut such as cutting speed. Chattopadhyay and Pandey (2001) observed the lowest required energy at the rake angle of 40°.

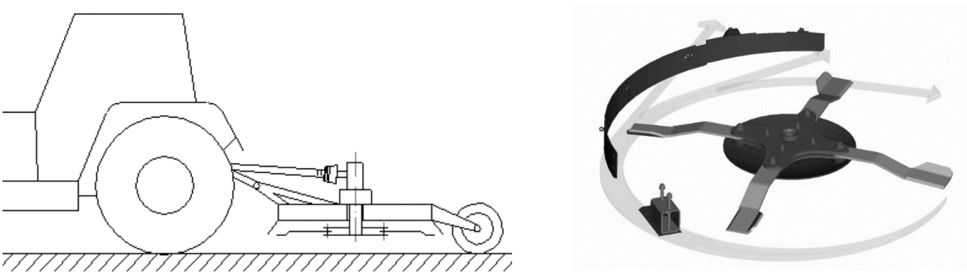

Figure 1. Principial figure of mulcher with vertical axis of rotation (Bednar FMT, 2013; Andrejs, 2004).

Table 1. Results of energy intensity 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 $t\ h^{-1}$
ASABE D497.7 (2011)	5	Mower
	8	Mower with conditioner
Syrový et al. (2008)	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 $km\ h^{-1}$
Tuck et al. (1991)	8–10	Mower with sharp blade
	10–12	Mower with worn blade
McRandal & McNulty (1978b)	5	Mower
	3.5–6.5	Mower with conditioner

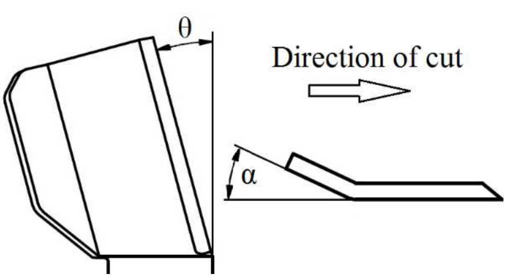

Figure 2. Angles on the cutting tool (θ – rake angle, α – cloth angle).

Another parameter affecting energy intensity of the mulcher with vertical axis of rotation is the energy loss. 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, 1991).

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).

The aim of the paper is to verify the impact of changing the cloth angle and the rake angle on the energy loss during mulching because energy losses are important part of the total energy intensity of the mulcher with vertical axis of rotation.

MATERIALS AND METHODS

Shapes of working tools were modified as follows: modification of the rake angle, modification of the cloth angle and extension of the blade. As for the original working tool the rake angle is 0° (perpendicular cut), the cloth angle is 45° and the blade length is 205 mm. As for the designed working tools (Fig. 3) the rake angle is 0°, 15° and 25°, the cloth angle 35° and 25° and the blade length 312 mm for tools with the rake angle 0°, 319.5 mm for tools with the rake angle 15° and 333.9 mm for tools with rake angle 25°. The tools are marked as follows: rake angle X cloth angle (e.g. 0X35 means the rake angle is 0° and the cloth angle is 35°).

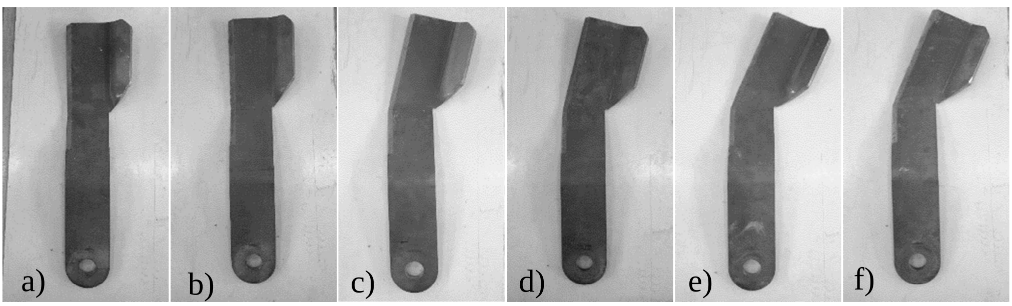

Figure 3. Proposed working tools (a – 0X35, b – 0X25, c – 15X35, d – 15X25, e – 25X35, f – 25X25).

In order to determine the impact of designed working tools on energy losses a measurement was carried out using a laboratory model of a one mulcher rotor (Fig. 4) in laboratory conditions. The model is driven by an asynchronous electric motor with the power of 22 kW and a frequency inverter Siemens with maximum power 30 kW. The torque, input power and rotor speed were measured by means of the torque sensor MANNNER Mfi 2500Nm_2000U/min (accuracy 0.25%). The data were saved to a hard drive of the measuring computer HP mini 5103 by means of the A/D converter LabJack

U6 with resolution 18bit and the module for pulse sensors Papouch Quido 10/1. The frequency of capturing the data was 5 Hz.

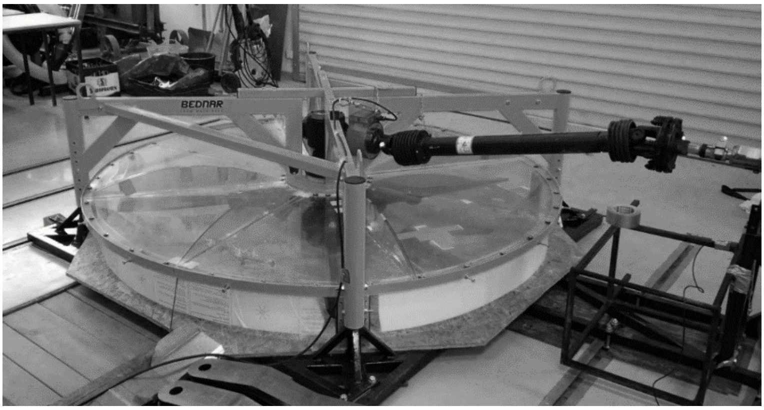

Figure 4. Laboratory model of one mulcher rotor.

Moreover, a measurement was carried out in field conditions with real mulcher where the torque and the input power, transmitted through the PTO shaft of the tractor to the mulcher machine running idle in a working height (approximately 50 mm) above the grassy stubble field, were measured. The Mulcher MZ 6000 with a vertical axis of rotation made by the company Bednar FMT s.r.o. was used during the field measurement as well as the tractor FENDT 818 (Fig. 5). The above mentioned mulcher has a working range 6 m, three rotors and working rotor speed 1,000 rpm. The above mentioned torque sensor Manner was used for measuring the torque and the input power. The frequency of capturing the data was 5 Hz. The moisture of the grass mater was high with an average value 67% and a standard deviation 7.3%.

Figure 5. Working set – tractor Fendt 818 and Mulcher MZ 6000.

RESULTS AND DISCUSSION

The torque increased with the second power of the rotational speed which is caused by the air resistance. During the measurement most of the measured variants did not reach 1,000 rpm due to safety since the acceleration of the model frame vibrations reached up to 12 g at the peak values. The values for 1,000 rpm were calculated by means of the 2nd degree polynomial with the coefficient of determination higher than $R^2 = 0.999$. Fig. 6 depicts progress of the input power depending on the rotor speed of the model for the individual shapes of working tools. It is evident that the input power increases with the third power of the speed. When comparing the individual variants it is evident that low cloth angle means low losses due to air resistance. This is caused by the fact that smaller cloth means smaller front area which has major influence on air resistance. In the case of increasing rake angle the front area reduces as well as the air resistance coefficient C_X, but decline of the input power is not so distinctive (significant).

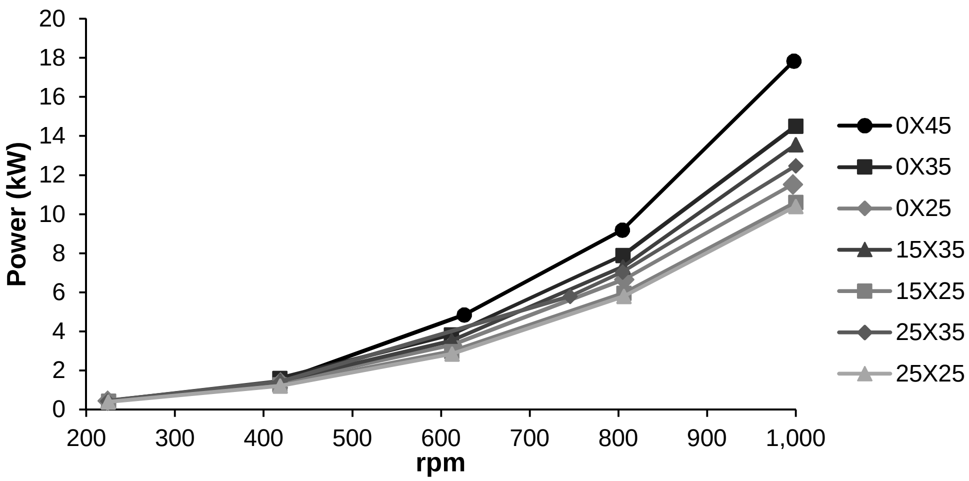

Figure 6. Dependence of power on rotation speed of rotor for all shapes of working tools.

Fig. 7 presents the comparison of tools with a zero rake angle measured in the field conditions with the mulcher MZ6000 at 50 mm high above the grass stubble. It is evident that a low cloth angle means low energy losses during any rotor speed. The reason is the same as for the laboratory model, i.e. small front area of the tool thus lower air resistance. Fig. 8 presents the comparison of the influence of increasing rake angle for tools with the cloth angle 25°. There are deviations from the results of measurement on the laboratory model which are probably caused by random errors made during the measurement in field conditions. It is obvious that the rake angle does not have such a significant effect on the dissipation of power in the given conditions, as the cloth angle.

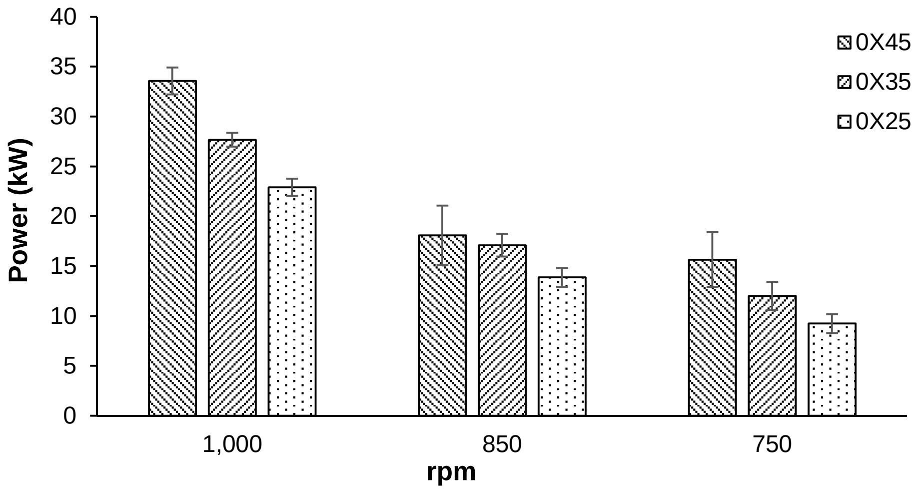

Figure 7. Comparison of mulcher input power for tools with different cloth angle.

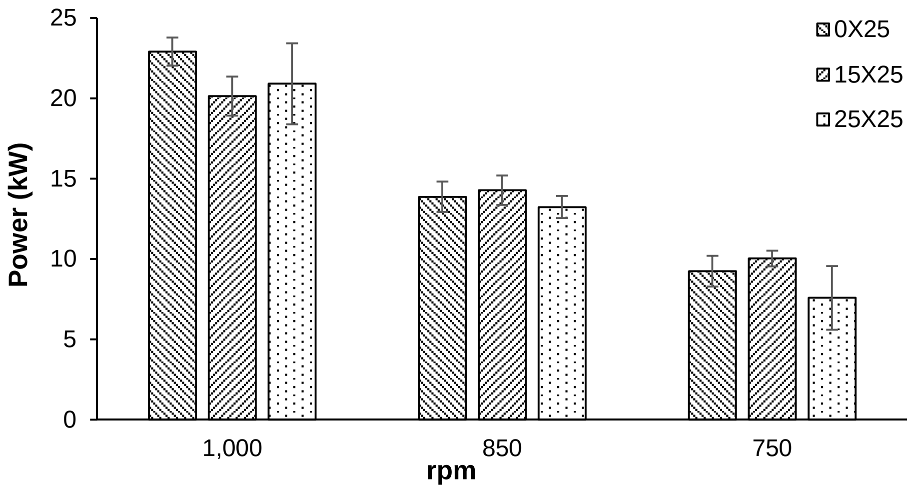

Figure 8. Comparison of mulcher input power for tools with different rake angle.

CONCLUSIONS

The measurement performed by means of the laboratory model proves that reducing the cloth angle means lower losses due to air resistance because lower cloth angle causes reducing the front area of the tool. Increasing tool rake angle also causes reduction of aerodynamic losses since the front area is reduced and the air resistance coefficient is affected. Optimizing the shape of the blade from the point of view of aerodynamics helps to save the energy which is also confirmed by Zu et al. (2011). It was also found out that the rotors in the mulcher influence each other since the input power of the laboratory model of the mulcher rotor was significantly higher than 1/3 of the input power of the whole mulcher when running idle.

Losses measured in the field conditions helped to verify the hypothesis derived from the laboratory model. The dissipation of power is affected mainly by the speed and the cloth angle, the rake angle does not have such a significant effect on reducing the energy losses during idle running. However, it can be assumed that the rake angle has a particular influence on the cutting energy. Use of low cloth angles may cause decrease of work quality because lower cloth angles reduce ventilation effect which provides repeated contact of the blade with the material and thus helps to perfect crushing of the above ground parts of plants.

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REFERENCES

ASABE D497.7. Agricultural Machinery Management Data. 2011.

Andrejs, V. 2006. Possibilities to reduce energy intensity of mulching in dependence on quality of work. Diploma thesis, Czech University of Life Sciences Prague, Prague, 57 pp. (in Czech).

BEDNAR FMT s.r.o. 2013. *http://bednar-machinery.com/cz/produkty/detail/437/mulcher-mz#ke-stazeni*. Accesed 1.3.2016. (in Czech)

Čedík, J., Pexa, M., Pražan, R., Kubín, K. & Vondřička, J. 2015. Mulcher energy intensity measurement in dependence on performance. *Agronomy Research* **13**(1), 46–52.

Hosseini, S.S. & Shamsi, M. 2012. Performance optimization of a rotary mower using Taguchi method. *Agronomy Research* **10**(1), 49–54.

Chattopadhyay, P. & Pandey, K. 2001. Impact Cutting behavior of sorghum stalks using a flailcutter - a mathematical model and its experimental verification. *Journal of Agricultural Engineering Research* **78**(4), 369–376.

Kakahy, A.N.N., Ahmad, D., Akhir, M.D., Sulaiman, S. & Ishak, A. 2012. Effects of Knife Angles and Cutting Speeds on Pulverization of Sweet Potato Vines. In: *Proceedings of USM-AUT International Conference 2012 Sustainable Economic Development: Policies and Strategies* **167**, 45–50.

Kakahy, A.N.N., Ahmad, D. Akhir, M.D., Sulaiman, S. & Ishak, A. 2013. Pulverization of sweet potato vine at different mower speeds. In: *IOP Conference Series: Materials Science and Engineering* **50**, 6 p.

Kronbergs, A., Kronbergs, E., & Repsa, E. 2013. Evaluation of reed canary grass shredding and compacting properties. *Agronomy research* **11**(1), 61–66

Mayer, V. & Vlášková, M. 2007. Mulching on soils put to rest. *Agritech Science* **1**(2), 1–5, http://www.agritech.cz/clanky/2007-2-1.pdf, Accessed 20.1.2015. (in Czech).

McRandal, D.M. & McNulty, P.B. 1978a. Impact cutting behaviour of forage crops I. Mathematical models and laboratory tests. *Journal of Agricultural Engineering Research* **23**(3), 313–328.

McRandal, D.M. & McNulty, P.B. 1978b. Impact cutting behaviour of forage crops II. Field tests. *Journal of Agricultural Engineering Research* **23**(3), 329–338.

O'Dogherty, M. J. & Gale, G. E. 1991. Laboratory Studies of the Effect of Blade Parameters and Stem Configuration on the Dynamics of Cutting Grass. *Journal of Agricultural Engineering Research* **49**(2), 99–111.

O'Dogherty, M.J. & Gale, G.E. 1986. Laboratory studies of the cutting of grass stems. *Journal of Agricultural Engineering Research* **35**(2), 115–129.
Pecenka, R. & Hoffmann, T. 2015. Harvest technology for short rotation coppices and costs of harvest, transport and storage. *Agronomy Research* **13**(2), 361–371.
Persson, S. 1987. *Mechanics of cutting plant material*. American Society of Agricultural Engineers, St. Joseph, 288 pp.
Srivastava, A.K., Goering, C.E. & Rohrbach, R.P. 2006. *Engineering principles of agricultural machines.* American Society of Agricultural Engineers, St Joseph, 588 pp.
Syrový, O., Bauer, F., Gerndtová, I., Holubová, V., Hůla, J., Kovaříček, P., Krouhlík, M., Kumhála, F., Kvíz, Z., Mašek, J., Pastorek, Z., Podpěra, V., Rybka, A., Sedlák, P., Skalický, J. & Šmerda, T. 2008. *Energy savings in crop production technologies.* Research Institute of Agricultural Engineering, p.r.i., Prague, 101 pp. (in Czech).
Syrový, O., Světlík, M., Pražan, R., Pastorek, Z., Kubín, K. & Gerndtová, I. 2013. *Mobile energy devices and the approximate values of unit fuel and energy consumption* (*Mobilní energetické prostředky a orientační hodnoty jednotkových spotřeb paliv a energií).* Research Institute of Agricultural Engineering, p.r.i., Prague, 56 pp. (in Czech).
Tuck, C.R., O'Dogherty, M.J., Baker, D.E. & Gale, G.E. 1991. Field Experiments to Study the Performance of Toothed Disk Mowing Mechanisms. *Journal of Agricultural Engineering Research* **50**, 93–106.
Zu, L., Zhang, L. & Wang, H.K. 2011. Optimization design of the lawn mowing vehicle's blade based on aerodynamics. *Advanced Materials Research* **199–200**, 173–181.

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The impact of information technologies upon the social interaction culture among employees in Latvian enterprises

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Abstract. The purpose of this paper is to explore the impact of information technologies upon the social interaction culture among employees in Latvian enterprises. To transform the available data and information into a valuable form for decision–making and subsequent actions, organisations have to provide an efficient communication circulation system, which is directly affected by each company's social interaction culture. Based on previous study results in Latvia the problem of the research is to reveal and assess how to increase mutual confidence among colleagues and encourage to share of information. Tasks of the study were to research the basis of the review of scientific sources and to study the organisational and individual factors affecting employees' perceptions regarding the role of information technologies in the information sharing process in Latvian organisations. The research showed that in organisations with positive social interaction culture, employees and supervisors socialize, interact and share information much more frequently in a verbal form, which promotes a sense of adherence to the organisation; information technologies, for their part, are used for creation of database and distribution of formal instructions.

Key words: social interaction culture, information sharing.

INTRODUCTION

At the end of last century, a new system of social interaction grew up, which integrated various types and means of communication and which is characterised by a new culture of social interaction. In this connection, Rudnick (1996) writes:

'In a world where the corporate information network is the dominant employee communications conduit for news, information and feedback, it seems logical for the employee communicator to have a role in the creation and management of the network. And the employee communicator is perhaps the best manager within the organization to develop strategies for use of that network as a communications resource, to champion use of the network for two–way communications, for feedback and dialogue.'

Today, one–way or even two–way communication has been replaced by meaningful multi–directional communication. This new system of social interaction introduced significant changes into contemporary culture, turning it into informative.

A characteristic feature of XXI century is serious informatisation process of all spheres of the modern society. It is expected that the development of information technology will become increasingly important. According to the forecasts given by the management consulting firm 'Boston Consulting Group', the impact of technologies and Internet upon national economies will increase until 2016 by 11% reaching 4.2 trillion US dollars in economically most advanced countries and in the European Union. Due to this fact, more and more serious focusing on new information technologies and their expansion in the social environment is observed. Scientists have found that members of virtual communities tend to share the sense of values, belonging and preferences among each other (e.g., Postmes et al., 2001; Bagozzi & Dholakia, 2002; Dholakia et al., 2004).

Modern society is congested with increasing information flows that must be captured and processed. Therefore, the process of social interaction cannot do without information technologies any more. Massive 'flooding' of the modern social world with intensive information traffic has changed the habits of social interaction and information exchange, including acquisition, processing, analysis, storage, preservation and distribution of information. Several studies have shown that information and communication technologies affect the behaviour of information seekers (e.g., Heath, 2007; Olander, 2008; Morris et al., 2010; Niu et al., 2010). The study by Morris et al. (2010) found that using social networking sites to seek information enabled researchers to find information and receive personalised answers, increasing their confidence in the validity of the information.

For the company to be able to successfully communicate in the new age of Internet and technologies, communication with key audiences should be developed skilfully, systematically, purposefully and according to the situation. To transform the available data and information into a valuable form for decision–making and subsequent actions, organisations have to provide an efficient communication circulation system, which is directly affected by each company's social interaction culture. In this regard, social interaction culture at Latvian enterprises will become the research subject of the Paper.

The social interaction culture that facilitates dissemination and exchange of information is identified as a positive aspect in innovative organisations; however, the organisational and individual factors affecting the social interaction culture among employees, are often hard to explain and influence. According to the company research performed by the telecommunication operator and Internet service provider in Latvia 'Lattelecom', development of information technologies is not the only criterion affecting development and competitiveness of enterprises. Loyalty and stability of the workforce are also mentioned by enterprises as important factors for persistence of competitiveness (Rutule, 2010).

One of the most significant aspects ensuring investigation of innovations including competition, is organisation's receptiveness of changes and enabling the flow of information, so that the required information was any time available to each employee. In addition, recent rapid advancements in information technology have opened a new age in which the successes of organizations are vitally dependent on the adaptation and application of new and existing knowledge assets on key business processes (Ndlela & du Toit, 2001). It is very important for business managers to be able to convert the wealth of available data and information into a valuable form for decision–making and subsequent actions; collected data must be converted into intelligence (Fleisher & Bensoussan, 2007).

Virtual communication has many benefits. Mostly, they are the information exchange rate and interactivity – the possibility to participate. Social interaction can be different: collective, verbal, non–verbal, direct, indirect, external and internal. Forms of social interaction are chosen depending on the needs of contacting parties.

The process of communication is explained as transfer of signals to the other, which is capable of receiving these signals. There are different levels, and mostly non–verbal communication takes place. And yet it comes into senses, winds into movements, gestures and facial expressions, until it finds expression in words in addition accompanied by the appropriate intonation. All this is very much missed by communication on the Internet, where merely certain letter and word combinations are displayed on the monitor. Information technologies directly affect social communication, because a very important component of communication is virtually missing – the effect and reflection of emotional presence. When creating a certain impulse, senses are created at the same time.

Organisations increasingly develop new communication channels and platforms, while some of the previously used communication tools are becoming less valid and are used more rarely. The possibilities are varied, because modern social interaction platform provide continuous interaction taking place immediately. Each employee who has access to the Internet, can quickly and easily contact both within the organisation and outside the enterprise and with people all over the world. It has certainly brought something new to the mutual communication (Fig. 1).

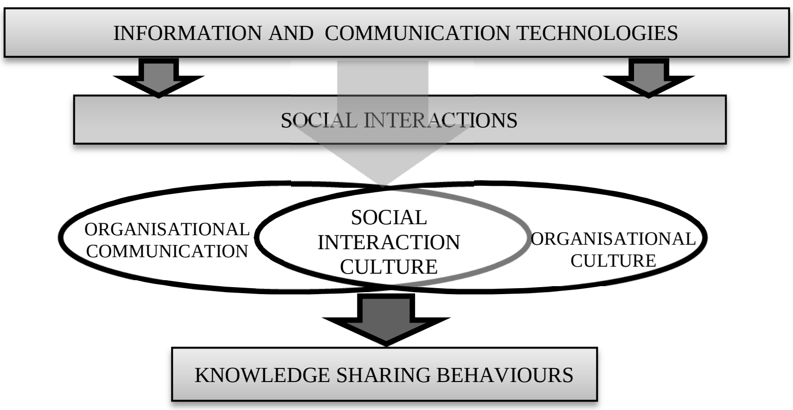

Figure 1. Influence of information and communication technologies upon the social interaction culture.

Information and communication technologies undoubtedly determine the social interaction culture in the organisation through direct impact upon social interaction. Social interaction culture is formed in close connection with organisational culture and organisational communication behaviours that continuously subject to the influence of information and communication technologies. Postmes et al. (2001) for example, argued that in groups that used computer–mediated communication, the existence of group norms is significant and influential. Use of information technologies in communication directly affect social interaction culture by determining what interacting will be like by degree of formality (businesslike or informal), what form the communication direction will take (anonymous, individual or mass), what the structure of contacting will be (vertical or horizontal), and what the decisive information style will be like.

The network of social interaction is increasingly expanding. This is clearly illustrated by statistics and studies, highlighting the modern communication trends. For example, the study performed in 2010 within the framework of media agency's ‘Universal McCann’ research ‘Wave 5’ on communication via social networks revealed that in Latvia, personal communication among active Internet users more often takes place via social networks rather than in person. In Latvia, direct contacts are as second, followed by phone calls, e–mail and SMS. However, the research team media agency 'Inspired' pointed out that Latvian Internet users are not that active with regard to content creation and sharing (Rutule, 2010).

Evaluation of the background studies in Latvia on provision of organizational culture in Latvia indicated the trends that employees lack incentive to share information. When establishing procedures of the information turnover process, the goal of communication should be estimated – to involve, to find out the opinion, to gain responsiveness or to enlighten on the information required for the organisation. Data from preliminary research in Latvia showed that companies spend 35% of time for data collection stage and only 12% – for communication (Cekuls, 2014).

Although the enterprises that seek to maximise knowledge sharing among their employees, often invest in a variety of new technologies, the reasons of inefficient knowledge sharing may not be simple availability or unavailability of technologies. Social interaction materializes in an interactive, communicative and perceptive way, so it is important for the enterprise to identify what social interaction culture will stimulate achievement of goals of the particular organisation.

The range of information technology tools is huge, and it increases day by day, but is worth to look at this phenomenon from another side as well. The current research evaluates whether the informative knowledge sharing technologies available for organisations, affect social interaction and whether they facilitate absolutely efficient knowledge sharing at the organisation. Given that social interaction is aimed at building partnerships, getting information and at settling interpersonal relationships, people mutually interact through many nuances of social interaction including facial expression, eye contact, gestures, tone of voice and temperament. People continuously examine these social nuances in order to make sure whether a mutual understanding is reached.

Social interaction will certainly be dependent on the purposes of using the social networks. Therefore, the use of social networks and their return will differ. This should be considered when planning the company's communication activities, because the existing information technologies at the enterprise do not mean a real improvement of an existing communication.

In today's competitive environment, more and more sophisticated communication strategies are used to be able to ensure the circulation of information and an efficient process of knowledge–sharing. Furthermore, it is important to identify side–factors that may affect social interaction in organisations. Creating the social environment with the new information and communication technologies, organisations tend to lose touch with the nuances of social interaction, cultural values, as well as the characteristics of traditional society.

MATERIALS AND METHODS

To find out individuals' opinions and attitudes, the focus group is selected as the most appropriate data collection method for high–quality research. The focus group interview took place in Riga on 8 December 2015. Members from various industries and with different employment period were included in discussion group. In aggregate, opinions of the employees from 24 different enterprises were summarized regarding the aspects affecting the social interaction culture in enterprises.

Results of the focus group discussions, possibilities of their interpretation and use should be repeatedly considered and weighted. The aim of group discussion was to obtain the range of opinions of members on the impact of information technologies upon the culture of social interaction in organisation. Group discussions provide the view of members upon aspects including stereotypes and the general disposition.

In order to obtain opinions of different range, members from various industries and with different employment period were included in discussion groups. The focus groups were formed in view of the age and gender structure, the industry represented by the company and the time worked for the company. Information on the focus group members has been summarised in Table 1.

Table 1. Informative description of the focus group participants

Member Nr.	Age	M/F	Position	Work Experience	Industry
Interview nr.1	57	M	Employee	39	Transportation
Interview nr.2	48	M	Supervisor	23	Transportation
Interview nr.3	37	F	Employee	16	Food Services
Interview nr.4	38	M	Employee	19	Retail Trade
Interview nr.5	44	F	Supervisor	20	Education
Interview nr.6	58	F	Employee	37	Retail Trade
Interview nr.7	29	F	Supervisor	4	Finance and Insurance
Interview nr.8	31	M	Employee	10	Communication and IT
Interview nr.9	27	F	Employee	5	Finance and Insurance
Interview nr.10	45	M	Employee	25	Logistics
Interview nr.11	29	M	Supervisor	5	Communication and IT
Interview nr.12	26	M	Employee	8	Retail Trade
Interview nr.13	33	M	Supervisor	9	Communication and IT
Interview nr.14	41	F	Supervisor	17	Health Care
Interview nr.15	39	F	Supervisor	14	Food Services
Interview nr.16	44	M	Employee	24	Communication and IT
Interview nr.17	42	F	Supervisor	18	Education
Interview nr.18	41	M	Employee	20	Communication and IT
Interview nr.19	36	M	Supervisor	12	Communication and IT
Interview nr.20	33	M	Employee	15	Logistics
Interview nr.21	46	M	Employee	23	Wholesale
Interview nr.22	59	M	Supervisor	35	Logistics
Interview nr.23	48	F	Supervisor	24	Finance and Insurance
Interview nr.24	34	F	Supervisor	10	Retail Trade

Participants represent a variety of industry sectors: transportation, food services, finance, retail trade, etc. Most of the participants represent the communication and IT industry.

At the beginning of the discussion, the moderator presented the objective of the discussion and rules of procedure. The discussion participants were asked to present themselves, to provide a brief description of the industry of their company, etc.

The place of companies' business is mainly Riga, but several members from other regions of Latvia were included in the research.

In aggregate, opinions of the employees from 24 different companies were summarised regarding the aspects affecting culture of social interaction in the age of information technologies and with the purpose to elicit the impact of information technologies and communications upon the organisational communication in the organisation.

RESULTS AND DISCUSSION

Today, the environment – economics, social conditions, technologies – are rapidly changing, and an organization has to be able to survive and develop; therefore the organization shall follow the information the competitive environment and be able to introduce alterations. The participants emphasized that changes denote a constant adjustment of one's activities and search for new opportunities. The organization will never be successful where its management fails to notice changes or is unable to foresee them in future. Today, changes have affected many areas, especially the social interaction culture.

Results of the research show specifics of the social introduction culture in Latvian enterprises. The main problem pertains to aspects affected by information and communication technologies: communication satisfaction, organisational and interpersonal trust, motivation etc.

Before the discussion, participants were asked to write down 3–5 associations, which, in their view, are related to social interaction in the aspect of mutual communication in the age of information and communication technologies.

The most pressing challenges for the discussion participants are associated:

1) with the role of information technologies in providing the circulation of information. e.g.,
   Interviewee nr.2:'In fact, any future work will be done with the help of information technologies.'
   Interviewee nr.6:'Dependence on information technology manifesting as excessive use of them, interferes with the ability to form normal relationships with peers.'
   Interviewee nr.7:'Social networks will push out and replace real relationships and leave a negative impact on the culture of social interaction.'
2) with efficiency of information flow. e.g.,
   Interviewee nr.14:' Development of our civilisation and even its existence has become dependent on information technologies, and we can no longer exist without information technologies at the current level of our development and welfare.'
   Interviewee 17:'When using information and communication technologies, we are often confronted with the Communication breakdown, which is often a very disturbing factor, better communicate face to face.'

3) with organisational communication system. e.g.,
Interviewee nr.2: 'Online social networks allow Internet users to form groups, where they can exchange written, audio and visual information.'
Interviewee nr.21: 'In the past, there was an expression: If a company does not have a website, there is no company.' Now, this expression has been paraphrased: 'If the company is not in Facebook, Twitter, Linkedin, there is no company'.
Interviewee nr.13: 'A company has no system for communicating important information.'
Interviewee nr.4: 'We gather a lot of information, but it is not clear who needs it.'

4) with effectiveness of communication in organization. e.g.,
Interviewee nr.16:'Almost every company has social networking accounts, which is an important channel for sales and customer information.'

5) with the information exchange. e.g.,
Interviewee nr.17: 'It will be practically impossible for an economically active person not to use IT in personal sphere and for work, because people expect they will be able to communicate without limitations via mobile phone, e– mail, social networks etc. Due to expansion of social networking in the business environment, the boundaries between personal and working environment will disappear the future.'
Interviewee nr.3: 'We lose the opportunity to go into the substance of the information and focus on the most important issues.'
Interviewee nr.7: 'We stick to a strict hierarchy: I deal with the information available to me.'

6) with the knowledge sharing behaviours. e.g.,
Interviewee nr.24: 'The existing global situation requires involvement of all employees in knowledge sharing.'
Interviewee nr.23:'Whatever we do, we cannot put hundred percent our feelings in a printed version, so other person does not feel them to the core and does not know how true our written words are.'

7) with mutual communication satisfaction. e.g.,
Interviewee nr.19: 'An employee will not always hand over the whole information to a manager.'

8) with trust and confidence. e.g.,
Interviewee nr.2: 'I have a feeling that nobody cares for my information, because everything has already been decided; no transparency; no certainty for preservation of copyright.'

Managers, for their part, more often than specialists have seen the problems associated with efficiency of information flow due to information and communication technologies.

Summarizing the results of preliminary discussion, it should be concluded that the views were characterised by contradictory statements about the role of information technology and their impact on social interaction culture. Responses showed that although information technologies accelerate the flow of information, they still affect the communication quality from the perspective of human factor. (Fig. 2).

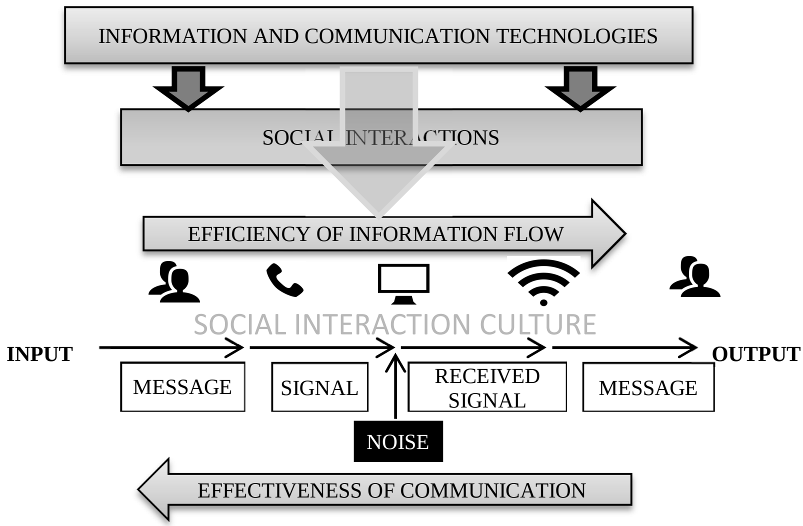

Figure 2. Influence of information and communication technologies upon the communication quality.

The individual in the process of social interaction acts as a decoder that decodes a message. However, the use of information communication technology ensuring the decoding or perception are more likely to be affected, but the message is decoded incorrectly. There may be different reasons, because perception has various components: knowledge, experience, ability to evaluate the situation, ability to select information and ability to understand the medium non–verbally. Among the obstructive factors in the aspect of communication, the participants mentioned, e.g., 'Communication breakdown', which occurs when using information technologies as a communication tool; likewise, the participants pointed out that such cases often lead to confusion, because the information breakdown problems are not predictable both in terms of time and of content. Participants expressed the opinion that effectiveness of communication broadly depends on the percept about other person created 'face to face'. This may mean that the report may be received wrongly or partially. E.g.,

Interviewee nr.23:'In virtual communication, you cannot see the speaker's face or hear his voice, which is certainly an important part of the conversation....and new small and also larger mistakes or lack of understanding came out.'

Although all participants confirmed that information technologies provide a communication speed and could be considered as a positive factor for ensuring (efficiency of information flow), however, the volume of received information is increasing in disproportion with the ability to look through the received data. The participants expressed the view that under the impact of information technologies, the role of such social interaction culture values as organisational trust, interpersonal trust and confidence decreases, because the amount of information is constantly growing and putting pressure on the data reliability assessment and building trustful relationships.

The author summarised the issues of concern and nominated the most topical themes in focus group, which show how information technologies influence the social interaction culture. From the problems listed by respondents at the focus group discussion, the following discussion topics were selected:

1. information technologies and efficiency of information flow;
2. information technologies and effectiveness of communication;
3. social interaction culture values (communication satisfaction, knowledge sharing behaviours, trust and honesty, loyalty etc.)

Participants acknowledged that the information technology communications means can provide gathering, storage and distribution of any information, efficiently speeding up circulation and storage of information. During the discussion it was suggested that the modern information technology systems can be a unique and invaluable assistant, which opens up unprecedented opportunities for organizations, e.g., improvement of training process. Today, information technologies can provide great support for business by facilitating access to information, improving the performance of various processes and ensuring close cooperation of all employees in reaching the enterprise's objectives. The discussion participants believe that advised use of information technology solutions will increase operational efficiency, improve product and service quality and contribute to the development of the enterprise. However, the participants expressed the view that in order to provide the best solutions for implementation of information technology system, the enterprise needs an overview of the organisation's future direction.

Interviewee nr.23:'...the enterprise could have guidelines defining what and which type of communication is expected by organisation management during the transition to use of information and communication technologies as a means of communication between employees, what ethical requirements should be followed etc. Although they are quite self–evident things, it is not bad to define them.

Interviewee nr.17:'...to identify the actual situation, it is necessary to gather information on potential risks and evaluate their prevention methods… and then, based on the results of the examination, to eliminate shortages and build IT infrastructure, according to the enterprise culture.'

Participants of the discussion agreed that implementation of information technologies can significantly reduce the administrative burden and costs for enterprises. It is therefore important to improve the business environment and to use the opportunities offered by technologies, such as introduction of electronic document circulation, etc .

Interviewee nr.1: 'Paperless' or electronic document sharing enables organisations and enterprises to achieve economy of human resources, financial, time and other resources'.

Interviewee nr.17: 'For example, the electronic document sharing provides transparency of document circulation, reduces corruption risks in institutions.'

During the discussion, the opinion was expressed that new technologies create new opportunities and at the same time unprecedented problems, because nowadays, one person during the day obtains more information than several generations during many centuries. Often, people cannot cope with the amount of information. This causes stress, wrong decisions, discomfort and leaves impact upon such social interaction culture values as motivation, loyalty and interpersonal trust. Results of focus group discussion revealed a number of factors affecting the social interaction culture (Table 2).

Table 2. Influence of the factors of information technologies upon the social interaction culture

Influence of information technologies	Influence upon the social interaction culture
Interference of communication breakdown	Selective barriers can be created – the recipient of a message captures only the information they want to perceive
The volume of received information is increasing in disproportion with the ability to look through the received data.	The constantly growing amount of information is putting pressure on assessment of data reliability and on building trustful relationships. The participants expressed the view that under the impact of information technologies, the role of such social interaction culture values as organisational trust, interpersonal trust and confidence decreases, because the amount of information is constantly growing.
The information technology communications means can provide gathering, storage and distribution of any information, efficiently speeding up circulation and storage of information.	Under the impact of information technologies, exchange of information and knowledge sharing behaviours decrease.
Modern information technology systems can be a unique and invaluable assistant, which opens up unprecedented opportunities for organizations, e.g., improvement of training process.	Can facilitate learning of social interaction culture
Today, information technologies can provide great support for business by facilitating access to information, improving the performance of various processes and ensuring close cooperation of all employees in reaching the enterprise's objectives. A person during one day obtains more information than several generations during many centuries.	Under the impact of information technologies, the exchange of information and knowledge sharing behaviours can decrease if such social interaction culture values as organisational trust, interpersonal trust and confidence are missing in the organisation. Often, people cannot cope with the amount of information. This causes stress, wrong decisions, discomfort and leaves impact upon such social interaction culture values as motivation, loyalty and interpersonal trust.
Use of information technology solutions will increase operational efficiency, improve product and service quality and contribute to the development of the enterprise.	Under the impact of information technologies, exchange of information and knowledge sharing behaviours may decrease.
Implementation of information technologies can significantly reduce the administrative burden and costs for enterprises.	The enterprise needs an overview of the organisation's future direction, which includes also the social interaction culture.

During the discussion, the opinion was expressed that values of social interaction culture are created by people, therefore the human factor plays an important role in building the social interaction culture in the organisation. Social interaction is undoubtedly characterised by the emotional component. Several participants believe that information technologies are also able to provide presence of this component, e.g.,

Interviewee nr.4: ’From the web *camera of computer or cell phone, based on our face mimics, it is possible to determine our emotional attitude to what we see on a computer or cell phone.’*

However, loss of privacy together with entry of information and communication technologies in the social environment was referred to as one of the main counterarguments. e.g.

Interviewee nr.21: ‘One can manipulate with us and influence what information we receive. Already now, in fact, we receive all information through Internet databases and social networks, so the one who rules over these channels, will determine what kind of information we receive.'

The issue on social interaction culture values was topical during the discussion, particularly in the cases of implementing new technologies. During the discussion, respondents were asked qualifying questions regarding the impact of social interaction cultural values of the organisation – whether trust affects information turnover; what is the role of trust and honesty between employees. Participants of the discussion think that defining of a value system is the first step in creation of social interaction culture.

Interviewee nr.12: ‘…organisational values form the basis of its culture, so it is important that employee's individual values were similar with organisational values’.

It gives a clear idea of how an employee should act in some or other situation. It is important for the organisation to define its system of values, working out, for example, by–laws or simply record the values in a free narrative.

Interviewee nr.5: ‘...if permanent social interaction culture values is defined in the company, it enables every employee feel him/herself as a part of a single mechanism, and joint efforts help to achieve the goal – culture supports the business processes in the organisation’.

During the discussion, group members expressed ideas and beliefs based on their personal experience that inefficient communication in many organisations is the main reason of problems. Communication should not be unilateral – there must be feedback. Participants also emphasized that information turnover should be timely, which a substantial prerequisite for knowledge is sharing to have an added value in the organisation. Always make sure whether the other party has understood the information. Good communication is a way to reach trust; excessive control, however, can reduce trust.

Participants emphasized that nowadays, information technologies are widely applied, but the human factor should not be forgotten. If communication is not efficiently managed, an information gap occurs filled by inaccurate information or rumour, which does not create a motivating environment and do not facilitate achievement of goals.

Interviewee nr.27:‘Communication using information technologies or virtual communication can certainly be important in building relationships. However, its pros are at the same time its cons. For example, consideration of answers – positive, because you have no chance to say a spontaneous, incorrect or unverified *information, but at the same time, we read and correct an important answer for tens of times – to make it sound better. And such document does not contain our true attitude any more, but 'polished up' sentences'.*

If information units are connected with each other, analysed or otherwise processed, knowledge originates. But knowledge can be only acquired through information, its distribution and use.

Participants emphasized that knowledge in the organisational context is information integrated in a common system, easily available and used for ensuring operation of the organisation. Previously expressed knowledge can be supplemented by new information due to knowledge sharing among people during conversations, and it can again become source knowledge stored in memory. Knowledge is seen as the basis for each separate employee's decision making and action. Depending on this basis, the employee will be able to select the action most suitable to the situation. In its turn, knowledge originates from the data transformed through context into information, and from information transformed through experience into knowledge. As a result of employees' interaction, transformation of knowledge from an individual's knowledge into common organisational knowledge is ensured. Transformation takes place in the process of activity as people share their knowledge.

Employee's knowledge is one of reserves of intellectual capital and organisation's intangible resources that allow successful functioning of the organisation. Evaluating the role of knowledge as a resource favouring competitiveness, the issue regarding the role of knowledge sharing in the process of competitive intelligence becomes topical.

Interviewee nr.15: 'Knowledge sharing ensures the company staff becoming more valuable, because employee's knowledge constantly increases, the employee learns.'

Interviewee nr.22: 'Knowledge sharing stimulates employees' expertise.'

Social interaction culture changes in the process of organisational learning. Knowledge sharing ensures that each employee both teaches and learns. Trust arises gradually and within a longer period of time, and only when employees and manager have verified it by their actions.

Interviewee nr.12: 'A good company's communication system providing information turnover encourages mutual trust. Trust is associated with company's results and efficient process.'

Interviewee nr.1: 'Trust among employees ensures knowledge sharing.'

Creation of the atmosphere of mutual trust within the collective body is one of the competencies having a long–term crucial effect for efficient operation of organisational processes. Information and communication technologies can affect formation of feedback. Creation of a percept about the message recipient is encumbered, and so is the ability to act or to participate in the process. The new social interaction culture is characterised by standard communication values.

CONCLUSIONS

The last ten years are characterised by rapid development of information and communication paradigm that affects social interaction culture. Results of research show that enterprises attempting to increase information sharing among employees, often introduce new technologies in order to improve information turnover. However, the results of focus group discussion showed that not only availability of technologies in the organisation is important for employees, but also various other factors that determine the social interaction culture in the organisation: interpersonal trust, organisational trust, and loyalty, support, fairness etc.

Information and communication technologies increase the distances within the social communication space. The social communication area is much wider than the personal communication area. The new culture of social interaction should involve those communication values, which characterise the social interaction competencies of the human factor: (1) the ability to build tolerant and loyal relationships; (2) the ability to predict the results of the communication; (3) the skill to maintain the unity of internal and external culture; (4) the ability to create feedback (5) being able to use the communication competencies in accordance with the communication style, etc. In the age of information technologies, a standardized communication style is often dominating with missing creativity and personal component.

Summarising the results, the research showed that in organisations with positive social interaction culture, employees and supervisors socialize, interact and share information much more frequently in a verbal form, which promotes a sense of adherence to the organisation; information technologies, for their part, are used for creation of database and distribution of formal instructions.

Neither conclusions regarding the reasons, nor generalisations can be made on the basis of these opinions or views, because the number of participants is small; the range of the expressed opinions, however, is wide enough to gain a picture on the various aspects of the investigated phenomenon. Therefore, such examination of opinions is important and necessary due to the gnostic reason.

REFERENCES

Bagozzi, R. & Dholakia, U. 2002. Intentional social action in virtual communities. *Journal of Interactive Marketing* **16**(2), 2–21.

Cekuls, A. 2014. Competitive Intelligence. *Globeedit*. Germany, 268 pp. (in Latvian).

Dholakia, U., Bagozzi, R. & Pearo, L. 2004. A social influence model of consumer participation in network and small group–based virtual communities. *International Journal of Research in Marketing* (**21**), 241–63.

Fleisher, C. & Bensoussan, B. 2007. Business and Competitive Analysis: Effective Application of New and Classic Methods, 491 p.

Heath, F. 2007. The impact of evolving information–seeking behaviours upon research libraries: a case study. *Journal of Library Administration* **46**(2), 3–16.

Morris, M., Teevan, J. & Panovich, K. 2010. A comparison of information seeking using search engines and social networks. *Proceeding of ICWSM*, Washington, DC, pp. 23–26.

Ndlela, L. & du Toit, A. 2000. Corporate culture as a foundation for successful knowledge management. *South African Journal of Information Management* **1**(4), March.

Niu, X., Hemminger, B., Lown, C., Adams, S., Brown, C., Level, A., McLure, M., Powers, A., Tennant, M. & Cataldo, T. 2010. National study of information seeking behavior of academic researchers in the United States. *Journal of the American Society for Information Science and Technology* **61**(5), 869–890.

Olander, B. 2008. Scholarly communication in transition: computer scientists' information behaviour over twenty years. *Information Research* 13(4), 35–35.

Postmes, T., Tanis, M. & de Wit, B. 2001. Communication and commitment in organisations: a social identity approach. *Group Processes and Intergroup Relations* **4**(3), 207–26.

Rudnick, M. 1996. Employee communications: how technology impacts on practice. *Managing Service Quality* **6**(2) 45–48.

Rutule, E. Communication via social networks. *http://www.webradar.lv/2010/11 /petijums–ari–latvija–interneta–lietotaji–biezak–komunice–socialajos–tiklos–nevis–klatiene/*Accessed 12.1.2016.

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Determination of spatial distribution of ammonia levels in broiler houses

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Abstract. Ammonia concentration plays a significant role in broiler performance. High concentration of ammonia impairs the immune system and increases cases of respiratory disease in birds. Ammonia concentration can be reduced using various chemical additives such as zeolite. In the present study, spatial variability of ammonia concentration was investigated and analysed in two broiler houses. In House 1 (H1) sawdust only was used as litter material whilst sawdust used together with zeolite was used in House 2 (H2). Ammonia concentration measurements were taken from 21 points in each of the broiler houses. The readings were recorded at on a weekly basis using birds' height as height measurement bases. In order to create spatial distribution maps, Inverse Distance Weighted (IDW) and Radial Basis Functions (RBF) methods were used and analysed. The performances of these techniques were assessed by using validation test methods (root mean square error (RMSE) and mean absolute error (MAE)) with the best performing method (lowest RMSE and MAE) being selected for creating ammonia spatial distribution maps. The results indicated that spatial ammonia distribution is more uniform in H2 compared to H1. It was also observed that ammonia levels were lower in H2 than H1. The presence of zeolite as a litter addition can be attributed to study findings positively affected the broiler performance. It was considered that using zeolite with sawdust as litter material significantly reduced ammonia concentration. In H1, higher ammonia concentrations of greater than 25 ppm were recorded near ventilation fans and at the centre of the house. Because of this it is recommended to install additional fans at middle of the house for remove harmful ammonia.

Key words: Ammonia concentration, Interpolation, Litter, Zeolite.

INTRODUCTION

High ammonia concentrations in broiler houses have negative effects on bird performance, feed efficiency and welfare. In order to maximize flock performance and health, the ammonia concentration must remain at the level of 25 to 50 ppm (Miles et al., 2004). Ammonia concentrations inside broiler houses are usually higher than recommended levels. Ammonia concentrations are influenced by many factors such as temperature, humidity, litter properties and management. Several studies demonstrated the importance of using various chemical additives to reduce ammonia emission (Shreve et al., 1995; Burgess et al., 1998; Do et al., 2005; Li et al., 2008; Kaoud, 2013). Zeolite is one of these properties and has been used widely in broiler houses due to its high ammonia and humidity absorption capability. Loch et al. (2011) and Eleroglu & Yalçın (2005) stated that zeolite can be safely used as litter material. These above stated research findings positively contribute on importance of reducing ammonia levels in litters, however they did not highlight on the use of geostatistical analyses for litter-ammonia levels determination. Geostatistical analysis has been applied in many different disciplines (Jing & Cai, 2010; Wallgren, 2013; Arslan, 2014a; Arslan, 2014b; Guler, 2014; Stevens, 2014), however few studies concentrated on the spatial variability of ammonia concentrations in broiler houses. Miragliotta et al. (2006) applied spatial analysis of thermal, aerial and acoustic environmental conditions in a tunnel broiler house and determined probable in-house stress zones. Miles et al. (2011) spatially evaluated the physical and chemical properties of a litter material in a broiler house under different rearing seasons. In geostatistical analyses, temporal and spatial variation of desired parameters can be visually mapped for better interpretation.

In geostatistics, different interpolation methods can be performed for estimating any data set. However, the key issue is to select the most appropriate interpolation method (Burrough & McDonnell, 1998). The most widely used deterministic methods are Inverse Distance Weight (IDW) and Radial Bases Function (RBF), which create surfaces based on measured points. This study investigates spatial distribution of ammonia levels in broiler houses having different litter material using the above mentioned common interpolation methods (IDW and RBF). The objectives of this work were,

– to select the most appropriate interpolation method using IDW and RBF to visualize spatial variability of ammonia in two broiler houses;
– to compare the effects of different litter materials consisted of sawdust and sawdust/zeolite mixture on environmental parameters and chickens described above,
– and to determine the areas in broiler houses where the worst environmental conditions (more than 50 ppm ammonia concentration) are observed.

MATERIALS AND METHODS

The study was conducted in two commercial broiler houses (H1: Sawdust, H2: Sawdust+Zeolite), in Bafra (Samsun). Bafra is located in the province of Samsun in northern Turkey (41° 31' latitude and 35° 53' longitude). Prevailing wind direction is South-East (SE). The broiler houses, oriented North-East, have the same dimensions (12 m wide, 124 m long and 2.4 m high) and capacities of 24,250 birds at the beginning of the study. Sawdust and sawdust/zeolite mixture were used as alternative litter materials. In both houses feeding, watering, lighting and ventilation are controlled automatically. The buildings are composed of insulated roof and side walls. The buildings have 12 air inlets, which are 0.6 m high and 3 m wide and are placed on the northeast and southwest sides of the buildings as shown on Fig. 1. The building has four exhaust fans with a total ventilation efficiency of 35,000 $m^3 s^{-1}$. The birds were housed for 48 days before slaughtering.

The ammonia concentrations were measured at birds' height (0.2–0.3 m) on a weekly basis using a digital gas detector. Measurement were taken from 21 points at 3 locations across the width (3 m apart) and 7 locations along the length of the building (15 m apart) (Fig. 1). ArcGIS software was used to create ammonia contour maps.

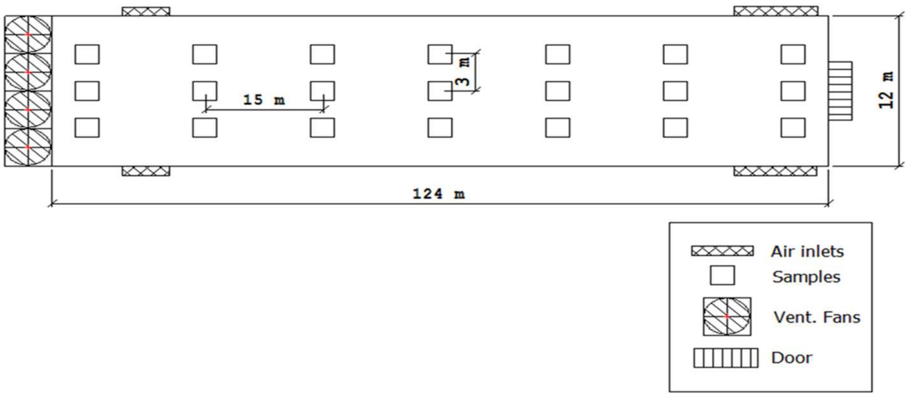

Figure 1. Grid samples in broiler houses.

Interpolation Methods

In the current study, different interpolation methods were applied for predicting the spatial distribution of ammonia. The IDW method estimates cell values using a linearly weighted combination of a set of sample points. The weight is a function of inverse distance (Childs, 2004). Estimates are determined using the formula:

$$Z = \frac{\sum_{i=1}^{n}(Z_i/d_i^m)}{\sum_{i=1}^{n}(1/d_i^m)} \tag{1}$$

where Z is the estimation value, Zi is the measured value at point i, di, is the distance between estimation value (Z) and data value (Zi), m is the weighting power that ranges from 1 to 5. In the current study, estimates of IDW by using common weighting powers (1, 2 and 3) were compared.

The RBF is a deterministic interpolation method used to represent two-dimensional curves on three-dimensional surfaces. It can be linked to using a mathematical function to fit a rubber -sheeted surface through known points. The RBF method has five different basis functions: completely regularized spline (CRS), spline with tension (ST), multiquadric function (MQ), inverse multiquadric function (IMQ) and thin plate spline (TPS) (Xie et al., 2011). The most widely used two radial basis functions (CRS and ST) were selected in the present study to determine spatial distribution of ammonia.

Cross-validation

This research used cross-validation to assess the accuracy of the interpolation. Cross validation is based on calculating the value of the variable at locations where the actual (measured) value is known, but has been temporarily omitted from input data, and then measuring the cross-validation error by comparing the estimated value with the actual (measured) value (Davis, 1987).

The precisions of different techniques were assessed by root mean square error (RMSE). The RMSE measures how much error there is between two datasets. The RMSE usually compares an estimated value and a measured value. Lower values of RMSE indicate better accurate prediction. The RMSE is defined mathematically as:

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(Z - Z_i)^2} \qquad (2)$$

where, Z is the estimation value at point i, Zi is the measured value at point i, n is the number of samples.

The mean absolute error (MAE) is another useful measure widely used in model evaluations. The MAE measures the average magnitude of the errors in a set of forecasts, without considering their direction. Lower values of MAE indicate better accurate prediction. The MAE is determined by using this formula:

$$\mathrm{MAE} = \frac{1}{n}\sum_{i=1}^{n}|Z_i - Z| \qquad (3)$$

in which, Z is the estimation value at point i, Zi is the measured value at point i, n is the number of samples.

This study assessed different interpolation methods, namely IDW (p = 1, 2 and 3) and RBF (CRS and ST). The RMSE and MAE were used to compare the precisions of different interpolation methods and best method was selected for the creation of spatial ammonia level distribution map in broiler houses.

RESULTS AND DISCUSSION

Descriptive statistics including minimum values, maximum values, average values, standard deviations and coefficient of variation are summarized in Table 1. The average ammonia concentrations generally increased with age of birds, as described in literature (Miles et al., 2008; Miles et al., 2011). At week 3, the litter amendment (zeolite) in H2 seemed to be responsible for lesser average ammonia concentration estimate, 18.74 ppm vs. 67.54 ppm in H1.

Table 1. Ammonia concentrations (ppm) in two broiler houses

Birds Age (weeks)	House 1					House 2				
	Min.	Max.	Avg.	SD.	CV(%)	Min.	Max.	Avg.	SD.	CV(%)
	Ammonia (ppm)									
1	5.00	25.00	13.87	4.46	32.15	5.00	16.00	9.66	2.40	24.84
2	12.00	54.00	26.11	10.14	38.84	4.00	34.00	19.35	9.73	50.28
3	27.00	121.00	67.54	26.13	38.69	0.00	39.00	18.74	11.71	62.49
4	27.00	63.00	44.09	9.31	21.11	8.00	51.00	31.13	11.13	35.75

The broiler performances at two houses are summarized in Table 2. The live weight of broilers was higher at H2 than those of the H1 (1,861 g vs. 1,647 g). Feed intake of broilers in the H2 was higher 701 gr. than those of the H1. This is reflected in a higher feed conversion in H2 (2.08 vs 1.93). The death rate in the building with sawdust zeolite mixture litter was lower than in the broiler house only with sawdust litter (7.42 % vs.

9.15 %) this can be attributed to the presence of zeolite. This hypothesis was confirmed by several authors (Karamanlis et al., 2008; Nikolakakis et al., 2013).

Table 2. Broiler performances in two broiler houses

Broiler House	Capacity (birds)	Number of dead birds	Feed Intake (g)	Live weight (g)	Feed conversion	Mortality (%)
H 1	24,250	2,220	3,175	1,647	1.93	9.15
H 2	24,250	1,800	3,876	1,861	2.08	7.42

Comparison of Interpolation Methods

Comparison of the used interpolation methods for ammonia concentrations are provided in Table 3. There are five different combinations for two different interpolation methods in the table. Three common weighting powers (1, 2 and 3) of IDW method and two most widely used radial basis functions (CRS and ST) of RBF method were tested and the most appropriate method was selected.

The best values are indicated in bold as shown in Table 3. Of the five methods examined, IDW (1) showed the best precision in week 1 in H1 and in week 3 in H2; IDW (2) performed the best in week 4 in H1 and H2. At week 2–3 in H1 and week 1–2 in H2, the best results were obtained from RBF (ST) with the lowest MAE and RMSE values. Fig. 3 shows the ammonia concentration levels maps that were created from the selected best interpolation methods.

Table 3. The MAE and RMSE statistics of IDW and RBF in two broiler houses

	Weeks	IDW (1)		IDW (2)		IDW (3)		RBF-CRS		RBF-ST	
		MAE	RMSE	MAE	RMSE	MAE	RMSE	MAE	RMSE	MAE	RMSE
House 1	1	**4.23**	**5.26**	4.23	5.63	4.48	6.10	4.25	5.42	4.27	5.40
	2	5.28	6.58	5.40	6.81	5.52	6.92	5.30	6.55	**5.27**	**6.57**
	3	13.79	16.38	13.48	17.12	14.23	18.06	13.95	16.93	**13.61**	**16.02**
	4	6.90	8.59	**6.34**	**8.00**	6.59	8.16	6.37	8.05	6.61	8.38
House 2	1	4.34	5.39	4.23	5.63	4.25	5.78	4.78	6.28	**4.27**	**5.39**
	2	5.31	6.44	4.85	6.65	5.17	7.09	5.10	6.52	**5.00**	**6.64**
	3	**13.80**	**16.39**	13.44	17.09	14.24	18.06	14.02	17.00	14.14	16.86
	4	6.90	8.59	**6.36**	**8.01**	6.58	8.15	6.39	8.04	6.37	8.06

Mapping Spatial Distribution of Ammonia Concentration

As the research was carried out during the winter season, only two fans were operated and a few inlets were opened with the objective of avoiding the cold weather from affecting the housed broilers. It was noted that during week 3 and 4 shown in Fig. 3 ammonia concentration levels in H1 were much higher compare to those in H2, this is likely attributed to the absence of zeolite in the former and poor ventilation as bird age increased. In H1, mean ammonia concentration ranged from 13.87 to 67.54 ppm, but in H2, the range was 9.66 to 31.13 ppm ammonia (Table 1).

In H1, throughout the rearing period ammonia concentration below the ideal limit (25 ppm) was observed only in week 1. In the second week, ammonia concentrations measured at fan areas exceeded 25 ppm and continued to increase up to week 3, due to poor ventilation. As observed by Wheeler et al. (2006), ammonia concentration was higher during winter season when low ventilation rates provided less fresh air dilution of ammonia. Towards the end of the rearing period, higher ammonia levels (above 50 ppm) were observed in the centre part of the H1 (Fig. 3). This was thought to be a result of uneven distribution of air flow in the building. As seen in Fig. 2 of air flow pattern, because of the cold fresh air entering first through the inlets, ammonia levels in this first section of buildings were lower. Ammonia concentrations tend to be higher at centre of the broiler house, because of inefficient air exchange in this section. Similar results were obtained by Miles et al. (2006) using kriging method. They found out that higher ammonia levels were in the centre of the house, near the end wall and cooling pads and attributed this to stagnant airflow in these areas.

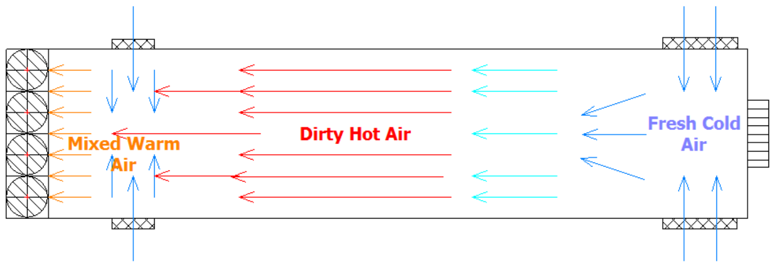

Figure 2. Air flow pattern in the broiler houses.

In H2, litter treatment (zeolite) seemed to be responsible for a lower ammonia concentration. Similar results were found by Lefcourt et al. (2001). They stated that zeolite treatment can reduce ammonia volatilization. At the beginning of the flocks' rearing period, ammonia levels were at their lowest (below 12.5 ppm). During weeks 2 and 3, ammonia was about 10 ppm within the first 30 metre length of building and increased (25–37.5 ppm) towards the fans region. At the end of the flocks' rearing in week 4, ammonia levels were even higher (37.5–50 ppm) from the centre region and towards the end of the broiler house (Fig. 3).

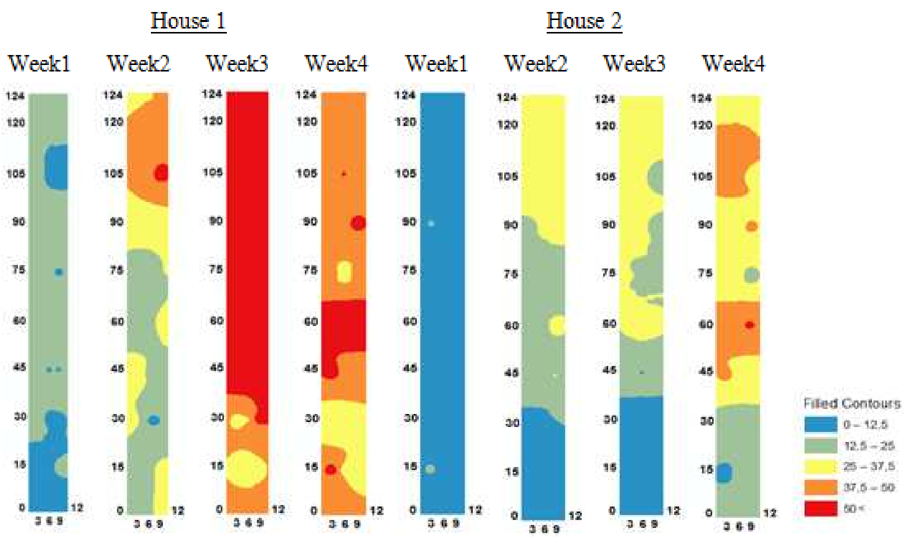

Figure 3. Ammonia concentrations contour maps in two commercial broiler houses.

CONCLUSIONS

In this study, litter addition (zeolite) was used to reduce ammonia concentration in the broiler house. Spatial changes of ammonia concentrations in two broiler houses having different litter materials (H1: sawdust, H2: sawdust+zeolite) were determined using interpolation methods. Ammonia concentration level maps were created using the best interpolation methods which were determined using R^2 and RMSE statistics.

Result of this experiment concludes that using zeolite together with sawdust as litter material significantly reduces ammonia concentration levels and improves production performances of broilers. It was also determined that variable ammonia concentration levels were present along the length of the house, with highest levels occurring at the centre of houses and near the end of the house. Because of this, it is recommended that additional fans should be installed in these two regions for remove of harmful ammonia. These findings may be helpful in designing broiler house to control ammonia concentration and emission (e.g. litter amendment, adequate ventilation).

REFERENCES

Arslan, H. 2014a. Spatial and temporal distribution of areas with drainage problems as estimated by different interpolation techniques. *Water and Environment Journal* **28**, 203–211.

Arslan, H. 2014b. Estimation of spatial distrubition of groundwater level and risky areas of seawater intrusion on the coastal region in Çarşamba Plain, Turkey, using different interpolation methods. *Environmental Monitoring and Assessment* **186**(8), 5123–5134.

Burgess, R.P., Carey, J.B. & Shafer, D.J. 1998. The impact of pH on nitrogen retention in laboratory analysis of broiler litter. *Poultry Science* **77**, 1620–1622.

Burrough, P.A. & McDonnell, R.A. 1998. *Principles of geographical information systems*. Oxford University Press, Oxford.

Childs, C. 2004. Interpolation surfaces in ArcGIS spatial analyst. *ArcUser* July-September, 32–35.

Davis, B.M. 1987. Uses and Abuses of cross-validation in geostatics. *Mathematical Geology* **19**(3), 241–248.

Do, J.C., Choi, I.H. & Nahm, K.H. 2005. Effects of chemically amended litter on broiler performances, atmospheric ammonia concentration, a nd phosphorus solubility in litter. *Poultry Science* **84**, 679–686.

Eleroglu, H. & Yalçın, H. 2005. Use of natural zeolite-supplemented litter increased broiler production. *South African Journal of Animal Science* **35**(2), 90–97.

Guler, M. 2014. A comparison of different ınterpolation methods using the geographical ınformation system for the production of reference evapotranspiration maps in turkey. *Journal of the Meteorological Society of Japan* **92**(3), 227–240.

Jing, N. & Cai, W. 2010. Analysis on the spatial distribution of logistic ındustry in the developed east coast area in china. *The Annals of Regional Science* **45**, 331–350.

Kaoud, H.A. 2013. Removal of ammonia gas emission from broiler litter. *Global Journal of Scientific Researches* **1**(2), 42–47.

Karamanlis, X., Fortomaris, P., Arsenos, G., Dosis, I., Papaioannou, D., Batzios, C. & Kamarianos, A. 2008. The effect of a natural zeolite (clinoptilolite) on the performance of broiler chickens and the quality of their litter. *Asian-Australasian Journal of Animal Sciences* **21**(11), 1642–1650.

Lefcourt, A.M. & Meisinger, J.J. 2001. Effect of adding alum or zeolite to dairy slurry on ammonia volatilization and chemical composition. *Journal of Dairy Science* **84**, 1814–1821.

Li, H., Xin, H., Liang, Y. & Burns, R.T. 2008. Reduction of ammonia emissions from stored laying hen manure through topical application of zeolite, Al^{+}Clear, $Ferix^{-3}$, or poultry litter treatment. *The Journal of Applied Poultry Research* **17**, 421–431.

Loch, F.C., Oliveira, M.C., Silva, D., Goncalves, B.N., Faria, B.F. & Menezes, J.F.S. 2011. Quality of poultry litter submitted to different treatments in five consecutive flocks. *Revista Brasileira de Zootecnia* **40**, 1025-1030.

Miles, D.M., Branton, S.L. & Lott, B.D. 2004. Atmospheric ammonia is detrimental to the performance of modern commercial broilers. *Poultry Science* **83**, 1650–1654.

Miles, D.M., Brooks, J.P. & Sistani, K. 2011. Spatial contrasts of seasonal and intraflock broiler litter trace gas emissions, physical and chemical properties. *Journal of Environmental Quality* **40**, 176–187.

Miles, D.M., Owens, P.R. & Rowe, D.E. 2006. Spatial variability of litter gaseous flux within a commercial broiler house: ammonia, nitrous oxide, carbon dioxide, and methane. *Poultry Science* **85**, 167–172.

Miles, D.M., Rowe, D.E & Owens, P.R. 2008. Winter broiler litter gases and nitrogen compounds: temporal and spatial trends. *Atmospheric Environment* **42**, 3351–3363.

Miragliotta, M.Y., Nääs, I.A., Manzione, R.L. & Nascimento, F.F. 2006. Spatial analysis of stress conditions inside broiler house under tunnel ventilation. *Scientia Agricola (Piracicaba, Braz.)* **63**(5), 426–432.

Nikolakakis, J., Dotas, V., Kargopoulos, A., Hatzızısıs, L., Dotas, D. & Ampas, Z. 2013. Effect of natural zeolite (clinoptilolite) on the performance and litter quality of broiler chickens. *Turkish Journal of Veterinary and Animal Sciences* **37**, 682–686.

Shreve, B.R., Moore, P.A., Jr., Daniel, T.C., Edwards, D.R. & Miller, D.M. 1995. Reduction of phosphorus in runoff from field-applied poultry litter using chemical amendments. *Journal of Environmental Quality* **24**, 106–111.

Stevens, F., Bogaert, P., Van Oost, K., Doetterl, S. & Van Weswmael, B. 2014. Regional-scale characterization of the geomorphic control of the spatial distribution of soil organic carbon in cropland. *European Journal of Soil Science* **65**, 539–552.

Wallgren, M., Bergstrom, R., Bergqvist, G. & Olsson, M. 2013. Spatial distribution of browsing and tree damage by moose in young pine forest, with implications for forest industry. *Forest Ecology and Management* **305**, 229–238.

Wheeler, E.F., Casey, K.D., Gates, R.S., Xin, H. & Zajaczkowski, J.L. 2006. Ammonia emissions from twelve u.s. broiler chicken houses. *American Society of Agricultural and Biological Engineers* **49**(5), 1495−1512.

Xie, Y., Chen, T., Lei, M. & Yang, J. 2011. Spatial distribution of soil heavy metal pollution estimated by different ınterpolation methods: Accuracy and Uncertainty Analysis. *Chemosphere* 468–476.

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Development of a system for locating of persons by triangulation

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Abstract. Systems that monitor movement of persons are closely linked to ensuring the security of the entire monitored complex. The security of the buildings is mediated via different types of systems such as I&HAS, CCTV, EFS, and others. These systems are combined with each other in order to achieve more optimal security of the guarded building. Patrol, attendance and other surveillance systems that do not provide the exact location of a person via coordinates are also used to monitor specific groups of people. For this reason, our goal is to design a system that is able to locate the monitored person (employee) in the building with minimal deviation.

Key words: triangulation, security, employees, monitoring.

INTRODUCTION

The basic elements designed to detect the movement of employees are access and attendance systems, which primarily detect the presence of employees at the worksite (Lukáš, 2011). There are many of these simple systems on the market today and many more are being added. Their differences are usually very small, and they frequently vary in terms cost and reliability.

When designing a security system and systems for monitoring people, it is necessary to realize that monitoring the movement of employees in the area is mainly associated with the Act on the Protection of Personal Data, which has reservations about the constant surveillance of persons in a building. For this reason, only the presence of persons in the worksite from the perspective of their arrival and departure is addressed. These systems are fully utilized in many companies where there is no need to ascertain the movement of people in all areas of the worksite (Heřman, 2008; Lukáš, 2011).

The system design for the localization of persons on the basis of triangulation is based on determining the position of employees in real time. It is intended primarily for use in companies where it is necessary to track the location of a particular employee at a particular moment. This is not an intrusion detection system.

MEASUREMENT AND METHODS

Monitoring people is associated with a number of aspects. Among the most important is the actual method of monitoring an area, where it is a matter of monitoring access to the building by an intruder, monitoring entry to the building by an authorized person and the passage through the building (Valeš, 2006). All of these options are associated with the security of the buildings.

Access control systems are also widely used to monitor the entry of authorized persons to the worksite. Persons entering the building are classified as employees, visitors and intruders (Rak, 2008). Persons who have access to the building, typically employees, have a security feature in the form of an identification card or chip. This feature allows the authorized person to enter the building. The validity of the security feature is addressed in terms of time, i.e. the validity of the pass for an indefinite period of time, or more often for a fixed period, such as 1 year or 1 month. Another alternative is one-time access, usually used for one-time visitors (Damjanovski, 2005; Cieszynski, 2007).

Walkthroughs through the guarded area apply to an area with increased security requirements for employees, or for visitors to this area. These are most often areas with valuable information, data or materials. This method of monitoring people is divided into walkthroughs according to:

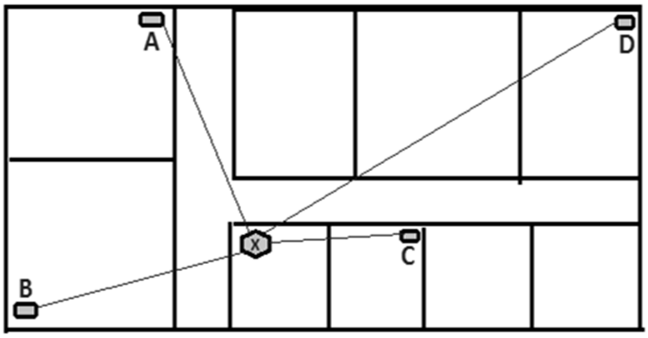
a time perspective – after applying a particular media serving for opening, the opening of the passage for a certain time period with regard to the length of the section; this is a short time interval and a small area (1 door, hall, etc.) (Damjanovski, 2005; Valeš, 2006).

a sectional perspective – after applying a particular media serving for opening, a certain section of a given area is opened (Damjanovski, 2005; Valeš, 2006).

an area-based perspective – after applying a particular media serving for opening, a relevant section is opened, e.g. and entire floor (Damjanovski, 2005; Valeš, 2006).

All of these types of monitoring of persons are associated with many systems for individual monitoring of people, the most important of which are security systems, access control systems and CCTV systems. Other systems providing access to a building include, for example, attendance or patrol systems, etc. (Cieszynski, 2007; Nilsson, 2008).

At present, the Czech University of Life Sciences in Prague is conducting research that seeks to build on the existing transmitters a system that will be able to monitor the movement of persons with accuracy almost to the centimetre. The monitoring functions on the basis of triangulation of a person using four receivers that determine the distance and spatial location of the monitored person – see Fig. 1.



A, B, C, D – receiver
X – transmitter

Figure 1. Principle of monitoring persons in a guarded area.

The principle of this equipment is that at a certain point the transmitter sends a signal to all receivers within range. These receivers, which are time-synchronized, will send information to the central unit about the time of the message was received (from the transmitter). After entering times into the algorithm, the system is able to give the coordinates where the transmitter is situated. On the basis of this information, using three such receivers, on which will be ascertained the response time of the transmission, it will be possible to determine the distance of the detected chip, and, through their combination and using triangulation, the precise location of the chip in the plane. At least four receivers will be required if it will be necessary to measure in the range of multiple floors.

All of the testing was conducted on wireless communications in the 868MHz band. A space was determined that was to simulate the actual building in which it is necessary to monitor the position of an employee (see Fig. 1). The figurant, who was to simulate the employee, had a miniaturized transmitter attached to his belt, which was compatible with receivers from the Teco a.s. Foxtrot series – see Fig. 2. The current method of detection only allows for precise localization in an open area, or in an area that is separated by plasterboard walls. Thus far, it has been ascertained that the attenuation of a broadcast that arises in the event of passage through solid obstacles (brick or concrete wall), affects the accuracy of localizing a person. At present, an algorithm is being developed that should remedy these deficiencies.

Once this system is fully functional, during practical use it will not be necessary to limit to the use of four receivers, but it will be possible to freely expand it according to the requirements of the end customer. Logically, the larger the area that must be guarded, the more receivers will be needed.

Figure 2. Miniaturized transmitter.

RESULTS AND DISCUSSION

After the tests were carried out, it was necessary to compare the system with the existing technology. The Orthos system was selected for this comparison, which is designed to monitor the movement of persons, focused on departure from the allocated space (room). The average response time of both systems in relation to the distance was compared, see Fig. 3.

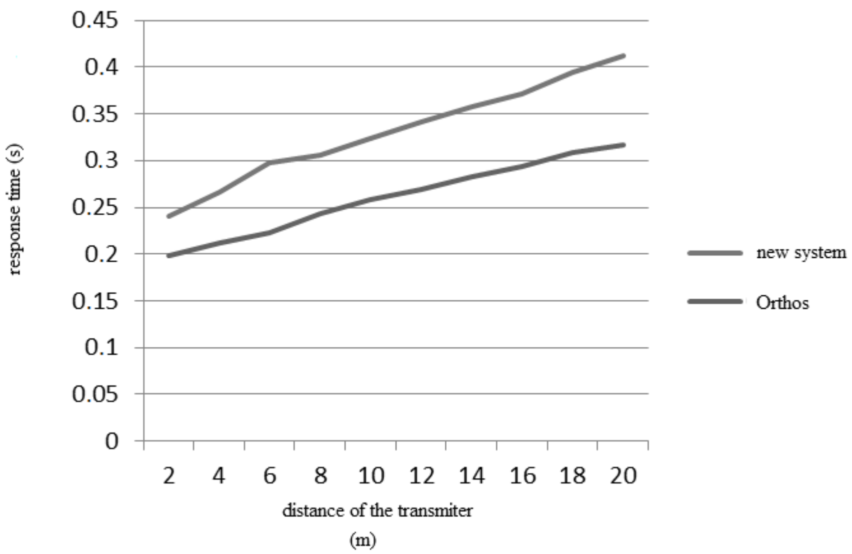


Figure 3. Comparison of the response time of both systems.

The measured data showed that the relationship of distance dependence on the response time in the new system based on triangulation corresponds to the response time of the existing technologies. The resulting values of the new system were slightly higher.

The ability of the existing Orthos system is only based on ascertaining a presence in an allotted space. Adversely, the new system is able to identify the specific position of the monitored person with a similar response time.

We are constantly working on accurate and reliable detection of people. Many of the technologies used to it. Tassos Dimitriou wrote in the article ‘Key evolving RFID systems: Forward / backward privacy and ownership transfer of RFID tags’ use RFID readers to monitor people (Dimitriou, 2016). The authors of the article ‘Fusion of Different Height pyroelectric Infrared Sensors for Person Identification’ trying to monitor people using PIR detectors (Xiong, 2016). Both methods are functional but not provide precise positioning, as it allows our system.

CONCLUSIONS

The monitoring of persons system serves as an automated control system that provides instantaneous monitoring of the movement of employees in all guarded risk areas, and at any time. This is a feature that streamlines the monitoring of the movement of these employees. The advantage of this control is primarily the monitoring of the movement of employees in terms of the safety of the employer and the employees. This system would be suitable for monitoring employees at airports, medical facilities, premises, warehouses, halls and other specific areas.

The basic function of the system is the ability to monitor the location of a particular employee in real time with a response time in milliseconds, according to the distance of the monitored people from different receivers. The speed of the system's response is therefore dependent on the response time of the farthest receiver. The test area is currently focused on areas with plasterboard partitions, where the monitored location of the employees is focused on ascertaining an occurrence in a plane where system deviations in the order of a few centimetres were found.

The overall solution of this system is advantageous for several reasons. In addition to the attendance control and partial departures, it is mainly used to determine the movement of employees in any time period during working hours.

REFERENCES

Cieszynski, J. 2007. Closed Circuit Television: Third Edition. 3 edition. [s.l.]: *Newnes*, 336 p.

Damjanovski, V. 2005. CCTV, Second Edition: Networking and Digital Technology. 2 edition. [s.l.]: Butterworth-Heinemann, 584p.

Dimitriou, T. 2016. Key evolving RFID systems: Forward/backward privacy and ownership transfer of RFID tags. *Elseiver* **37**, 195–208.

Heřman, J. 2008. Electrical and telecommunication installations. Praha: Verlag Dashöfer. (in Czech)

Lukáš, L. 2011. Security Technologies, Systems and Management I. 1. vyd. Zlín: VeRBuM, 316p. (in Czech)

Nilsson, F. 2008. Intelligent Network Video: Understanding Modern Video Surveillance Systems. Har/Dvdr edition. [s.l.]: CRC Press. 416 p.

Rak, R., Matyáš, V. & Říha, Z. 2008. Biometrics and identity of man - in forensic and commercial applications, 664 p. (in Czech)

Valeš, M. 2006. *Smart house*. Brno: ERA. 123 p. (in Czech)

Xiong, J., Li, F.M. & Liu, J. 2016. Fusion of Different Height Pyroelectric Infrared Sensors for Person Identification. *Ieee Sensors Journal* **16**(2). 436–446.

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New security elements in biometric systems and systems I&HAS

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Abstract. New security features or upgrades to existing features in biometric and security alarm systems and emergency formed at the Czech University of Life Sciences Prague, mainly due to the teaching of subjects with similar themes. When developing new technologies also help us grants, personal experience with a real installation, cooperation with manufacturers (or with distributors) security systems and a testing ground for current security features.

Key words: development, innovation, biometric systems, intrusion and hold-up alarm system, detector.

INTRODUCTION

In modern times, when the increasing crime rate led to the mass production of low-quality and cheap security systems, it is important to develop testers and measuring systems that help determine how are 'safe' and 'quality' for I&HAS (intrusion and hold-up systems). It is also very important to increase the already mentioned quality and safety of these systems (Damjanovski, 2005; Lukáš, 2011). It is for this reason that at the moment when there is a development of a new technology, so someone already working on sabotage techniques, how to sabotage this technology (Křeček, 2006).

This article is dedicated to representatives from among the testers, active protection and biometric systems, which were developed at CULS Prague. Engineered systems modify the existing solutions and provide insight on the issues solved entirely from a different perspective than it was before. Simultaneously, also these systems extend the full portfolio of security technology on the market today. It is important for the continuous development of protection and of various technological improvements get into a phase of stagnation. This would eventually led to a decline of the modern development of security technologies.

Svoboda bypass tester established balancing resistors PUV 2011–24387 – see Fig. 1. It consists of a body tester (1), for which the two brought from the switchboard loop (3), potentiometer (4) and display (5). Using the display is possible to determine the current and the resistance according to the response panel (2) will assess how much resistance tolerated (Uhlář, 2005; Hart, 2010).

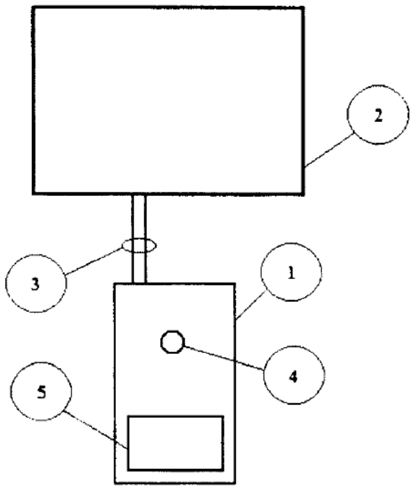

Figure 1. Svoboda tester.

Launcher defense active gas – technical solution concerns the design of active defense launchers gas used in electrical security systems such as active protection against intrusion guarded area. This design allows drain defensive gas from the gas chambers without the process of gradual release of gas (Damjanovski, 2005; Heřman, 2008).

At present, as the active protection of objects often uses smoke hoods that blurs guarded space innocuous, but completely opaque smoke. Furthermore, the use of high-frequency acoustic sirens and strobe lights (Křeček, 2006).

Launch Defence (see Fig. 2) use gas systems that emit gas gradually defensive. Their effect therefore occurs after a relatively long time. Their effectiveness is relatively small, and that because of their insufficient range defense gradually discharged gases (Lukáš, 2006; Heřman, 2008).

At the moment when the launcher defensive gas running, so the body (2) launchers, through the ejector (6) extends above the critical position. This position is bounded box (7) launcher. Fuse (3) remains under this threshold through spring (8) fixed and releases the lid (5) sinus pressure (1). They are due to pressure, rapidly opened and the entire contents of pressurized cavities launches into space. This effect gas infest the whole surrounding area, and potential intruders actively prevented from continuing his criminal activities. Re-gassing is possible by tightening screws (4) that fix the eyelid (Hart, 2010).

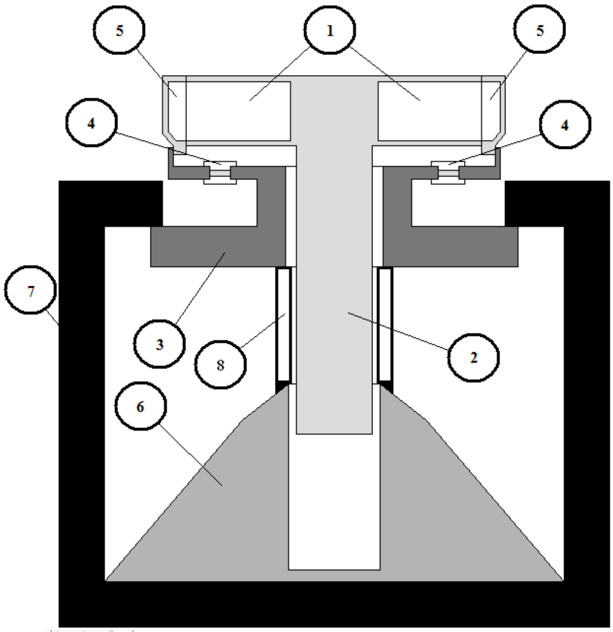

Figure 2. Launcher defense active gas.

The biometric authorization for the use of the service vehicle – this solution is used to prevent movement of company vehicles by unauthorized persons and records of persons who use a company vehicle.

At present, the control of the use of official vehicles only use log book and tachographs. In this way, however, can not fully determine what a person actually manages company vehicle. Company cars are then used for purposes other than those for which they are intended (Damjanovski, 2005).

The technical solution is to create a system for biometric authorization for the use of a company car, which is used to identify the person who wants to use a company vehicle. Biometric authentication for use company vehicles consists of the inlet system that is composed of a biometric fingerprint reader and a biometric identification system for taking 3D scan face.

The input system consists of a biometric fingerprint scanner is positioned to handle the vehicle. Used to identify the person, where there is a fingerprint images and the evaluation of the compliance of a fingerprint with a database of employees for subsequent unlocking of the vehicle. The next step is the identification of 3D face scanner, which is located in the rearview mirror and it is connected to the starter motor unit. After a person's entry into the vehicle and ensuring the safety belt when you press the start button starts the 3D scanner face. If thus the scanned facial scan and to compare with the database staff. In case of a tie the vehicle is started and all components shall be adjusted according to the parameters of the person (personal settings) (Heřman, 2008).

Fig. 3 shows the mirror (1) which are attached to the sensor (2) for 3D face scan and starter cancel the marked file (3).

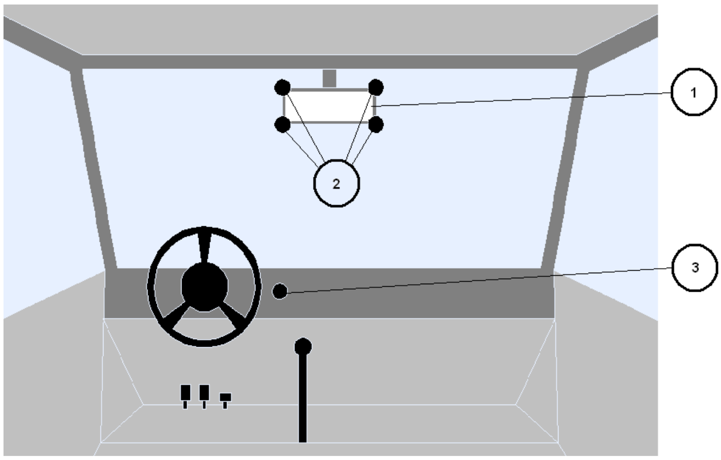

Figure 3. Rearview mirror with four sensors for 3D scan.

RESULTS AND DISCUSSION

At present tests were carried out only on Svoboda bypass tester. These tests demonstrated full functionality of this tester.

There are methods that allow bypass of the classical loop of security systems with end of line resistance, which reduces their safety. In this case it is important to know the boundary resistance that panel can accept . Svoboda bypass tester is designed so that the potentiometer change continuously resistance in this loop so it can deduct the value of resistance, which can accept. That the resistance is shown in Fig. 4, where it was selected for testing change continuously resistance 1,1 kΩ.

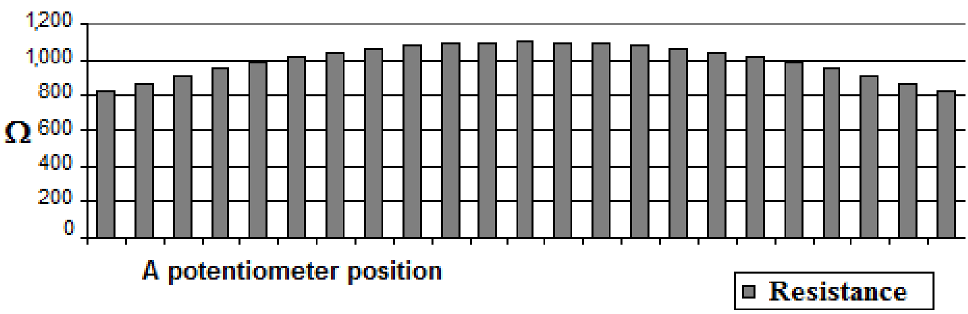

Figure 4. Course of the transition potentiometer.

In order to prevent the possibility of sabotage of security systems, it is very important to continually improve systems. Authors like Hanáček and Sysell in their article ‘The Methods of Testing and Possibility to Overcome the Protection Against Sabotage of Analog Intrusion Alarm Systems’ and ‘Universal System Developed for

Usage in Analog Intrusion Alarm Systems' have the same views. And similarly to this problem is _ Urbančoková, Valouch and Adamek in their article 'Testing of an intrusion and hold-up systems for electromagnetic susceptibility – EFT / B'.

CONCLUSIONS

Testing and improvement of existing technologies is very important. Practical tests performed on loop switchboards bring insight into their functionality and practicality. Tests also showed that all types of loop switchboards can be better or worse sabotage. The tests can be used to draw principles for assault loop switchboards and thus develop and testers that help determine the quality and safety of the I&HAS.

Due to the continuous development of sabotage techniques is always important to continue to develop new and better detectors, modules, switchboards and all components of the systems I & HAS. It is important also to develop new testers that could test the existing schemes and thus determine their safety and quality.

The moment comes when any new or innovative element I&HAS (detector, data logger, the principle of evaluation, etc.) is already a way to circumvent it (sabotage). The biometric and security alarm and emergency systems is therefore very important to always act in the development of new technologies, principles, evaluation, protection detectors and innovation of existing elements I&HAS and biometrics. It is therefore, more difficult to attack as much as possible of the object and of course optimized price-performance ratio of the elements.

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REFERENCES

Damjanovski, V. 2005. *CCTV, Second Edition: Networking and Digital Technology*. 2 edition. [s.l.]: Butterworth-Heinemann, 584 pp.

Hanacek, A. & Sysel, M. 2015. The Methods of Testing and Possibility to Overcome the Protection against Sabotage of Analog Intrusion Alarm Systems. *4th Computer Science On-line Conference (CSOC)*, Volume: 348, 119–128 p.

Hanacek, A. & Sysel, M. 2015. Universal System Developed for Usage in Analog Intrusion Alarm Systems. *4th Computer Science On-line Conference (CSOC)* **348**, 129–138 p.

Hart, J. 2010. *Analysis of security risks of building using system ESS*. Prague: CULS in Prague, 2010. 73 pp. (in Czech)

Heřman, J. 2008. *Electrical and telecommunication installations*. Praha: Verlag Dashöfer. (in Czech).

Křeček, S. 2006. *Handbook of security technology*. Blatná: Circetus. 313 pp. (in Czech).

Lukáš, L. 2011. *Security Technologies, Systems and Management I*. 1. vyd. Zlín: VeRBuM, 316 pp. (in Czech).

Uhlář, J. 2004. *Technical protection of objects, Part I, Mechanical barrier systems II*. Praha: PA ČR. 179 pp. (in Czech).

Uhlář, J. 2005. *Technical protection of objects, Part II, electrical security systems II*. Praha: PA ČR. 229 pp. (in Czech).

Urbancokova, H., Valouch, J. & Adamek, M. 2015. Testing of an intrusion and hold-up systems for electromagnetic susceptibility – EFT/B. *International Journal of Circuits, Systems and Signal Processing* **9**, 40–46.

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Workers' representation in OHS activities: Example of Estonian industrial sector

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Abstract. The safety level in 11 Estonian enterprises was investigated. Some of them have implemented OHSAS 18001 or belong to foreign corporations. These enterprises have generally good or very good safety level. The larger the enterprise is, the better are the possibilities to give regular training for the work environment representative (WER) in occupational health and safety. The study includes quantitative and qualitative study. The MISHA method is used as the tool for quantitative study. The parts from the interviews with the enterprises representatives' (management and employees) concerning the role of the WER in the safety performance (qualitative study) are included. The clarification and appropriate application of the WER's role and position are the key elements to raise the safety level at enterprises. Two hypothesis: 1) on the connections between the real and formal safety elements concerning WERs and 2) OHSAS 18001 implementation effectiveness on safety activities (including WERs' role improvement) were proved with statistics: Factor analysis were carried out with *KMO and Barlett's* test, *ANOVA and T-square test with Wilks' Lambda row*. Additionally, knowledge management in safety may enhance the activities among WERs and thus, increase the safety performance in enterprises.

Key words: work environment, safety and health management, management responsibilities in safety and health, work environment representative, safety activities at small and medium-sized enterprises.

INTRODUCTION

Work environment is a broad term and means all surroundings when worker is engaged in the work process. The physical work environment contains work tools, inconvenient indoor air, noise, insufficient lighting, vibration, electromagnetic fields, but also chemicals and biological agents. Furthermore, the work environment includes the psychological aspects such as work organization and the worker's wellbeing at work.

The previous study for improvement of safety and health at workplace (Paas et al., 2015a, b, c) determined the nature of real, formal and combined safety elements and the importance and possibilities to harmonize the safety level in advanced companies (e.g. enterprises which possess OHSAS 18001) and companies without any systematic work in occupational health and safety (OHS). In an enterprise where safety is a priority and safety activities are regular and systematic, usually three levels of management line in OHS exist: the top or product manager, the work environment specialist (WES) or safety manager and the work environment representative (WER). The latter may be the weakest link in the chain, especially because of lack of time to devote oneself on safety and health matters. The legislation (Occupational Health and Safety Act of Estonia (OHS Act),

1999) allows the WER to perform OHS duties for two hours per week. Often, this seems not to be enough.

The activities of WER often depend on company's type: either locally owned small or medium-size enterprise or belonging to a bigger corporation. The implementation of OHSAS 18001, due to systematic audits, improves the knowledge of all the key employees in the safety and health management chain. The previous research has also suggested possibilities of offering safety training through MISHA questionnaire, used as the tool for assessment of safety level in both OHSAS 18001 implemented and non-implemented Estonian enterprises (Paas et al., 2016).

Work environment representatives shall safeguard the interests of staff in matters relating to the working environment (WE) and ensure that the regulations on OHS are followed. The WER is elected by the employees of the company and his/her main role is to represent the employees in issues related to OHS. Additionally, if the company's size exceeds 50 workers, a working environment council must be formed. This is an internal association where OHS-related issues are discussed and possibly resolved. Employer and employee representatives are members of the council in equal part. The WER has the duty, among other things, to represent the workers in work environment-related issues. OHS Act (1999) states that the employer and the employee should co-operate and work together managing working environment. As the WERs know the best the workers and workplace connected health and safety problems, it is important to involve them in positive progress of safety level in the company. It is also clear that employee's behaviour is one of the greatest determinants in workplace safety that can be influenced by WER's good examples.

By the Occupational Health and Safety Act (1999), WER has been guaranteed with a number of rights. The WER has, among other things, the authorisation to: a) receive training, b) be a part of actions that concern the relationships in the WE and c) participate during the planning of new premises as well as changes in the premises (OHS Act, 1999).

Special attention is needed for enterprises who belong to small-sized enterprises, with 10-49 employees who tend to see less practical value in WER activities and often excuse with other priorities (Sorensen et al., 2007; Paas et al., 2015a).

The research question is the following: is it possible to raise the safety level in a small and medium-scale enterprise prioritizing the role of the work environment representative?

Hypothesis H1. The firm type has a significant impact on real safety performance?

Hypothesis H2. Implementation of OHSAS 18001 helps effectively to organise OHS activities in the companies?

THEORETICAL APPROACH

Organizational culture is a concept that is often used to describe the values that influence members' attitudes and behaviours. Safety culture is a sub-facet of organizational culture (Cooper, 2000). There are three components in the organization that it is necessary to follow: focusing on physical workplace, focusing on people, focusing on management issues (Makin & Winder, 2008).

The work accidents in industrial enterprises continue to happen. The decrease of accidents could be foreseeable with the change of safety culture. Safety culture has been identified as a critical factor that sets the tone for importance of safety within an organization (O'Toole, 2002). Different levels of safety culture can be distinguished: pathological, reactive, calculative, proactive and generative (Parker et al., 2006). Creating the better safety culture requires not only stronger surveillance from the side of Labour Inspectorate (state surveillance), but also a mental change and an authentic commitment from firms, where everyone participates and commits themselves to OSH (Fernandez-Muniz et al., 2007; 2009).

To the development of a good safety management system positively influences the employees' involvement and participation in safety activities. Safety researchers have become increasingly interested in understanding how social exchange processes help to shape the safety-related perceptions and behaviours of employees (DeJoy et al., 2010). Various theories have been used to explain the exchange relationship between organizations and employees, but theories involving organizational support have been most common (DeJoy et al., 2010).

A major incident is generally the result of a number of interacting human, technological, environmental and organisational factors all influenced by the prevailing safety culture. However, extensive time and resources are often required to undertake a detailed assessment. Factor analysis was used to structure eight underlying dimensions: management commitment, leadership, learning, risk, communication, competence, processes and procedures, and engagement. In order to help an organisation diagnose the extent of behavioural failures, the factor structures were grouped to assess learning, compliance, intervention, reporting and progressive (cultural sustainability) sub-cultures (Fernandez-Muniz et al., 2007; 2009). It is an advanced approach for analyse the accidents' possible mechanism scientifically.

In DeJoy et al. (2004), the employees were asked about the extent to which their organization has specific policies and programs related to such matters as safety training, hazard communication, and personal protective equipment. The safety level at enterprise was improved. Employee behaviour is arguably one of the greatest determinants in workplace safety, especially as employees interact with varying issues. Nevertheless, every person's behaviour is unique, and even one particular person's behaviour can change from day to day. No employee can think about safety continuously.

According to Wachter & Yorio (2013), the most important tools for improvement of employee's behaviour are improvement of communication, the leadership commitment to health and safety, working and solving problems in teams, adequate training, risk assessments with practical value, reporting of near-accidents, quality-based improvement processes.

In the ageing society, beside workers' safety, also health and well-being of workers have become important topics at the workplaces (Danna & Griffin, 1999). First, health and well-being can refer to the actual physical health of workers; second, health and well-being can refer to the psychological and emotional aspects of workers as nowadays trends in illnesses structure (Danna & Griffin, 1999).

The paper of Hovden et al. (2008) examines the role of WERs in the modern working environment. The data from Norwegian offshore oil and gas sector showed that employers rely more on the capacity of the formal health and safety management systems, than do the WER put more emphasis on the need for daily and continuous health and safety consultations. The study also revealed that the climate of participation and collaboration is assessed by the safety representatives as being less conductive to the overall objectives of the health and safety regulations than perceived by the managers. The results of the study also demonstrate a lack of consistency between identified problems in the role of WERs and proposed measures of improvements in their role and functions.

There is a need for safety climate measurement instruments (Hall et al., 2013). Measurement of safety climate requires an instrument to record employees' self-reported perceptions on safety issues. The safety climate instrument has to be theory-based. The method worked out by Hall et al. (2013) consists of the following parts: 1) manager and supervisor attitude toward safety, 2) risk, 3) group norms, 4) workplace pressure, 5) competence, 6) safety system. They all are directed to intention to follow safety procedures. Testing the Hall model among managers, supervisors and other employees, the result showed that managers and supervisors self-reported a significantly higher safety climate than other participating employees.

There is a strong connection between worker representation and participation and the establishment of an effective preventive OHS system at the workplace (Walters et al., 2005). Working in small enterprises, there is a bigger risk to get into accident or get injury than in big enterprises (Sorensen et al., 2007; Kongtip et al., 2008). In small enterprises:

1) there is a higher risk of severe and fatal accidents;
2) there is a higher risk of minor accidents if all accidents are reported;
3) OHS management system is less common;
4) there is only scattered data about other hazards.

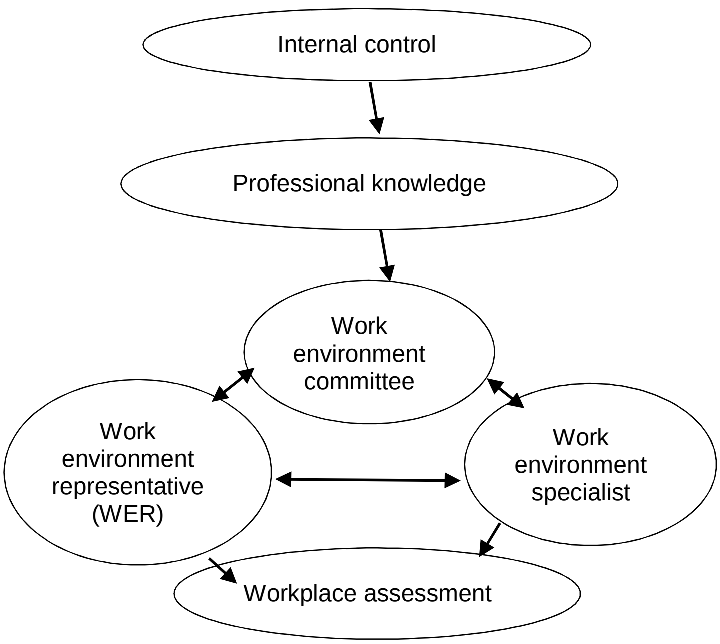

Figure 1. The arrangement of OHS command at workplace.

The OHS activities in the Nordic countries are organized (Karlsen & Lindoe, 2006), combining a top-down and a bottom-up approach to the organizing of health and safety activities to be effectuated as a part of the line organization (Fig. 1), where everyone at his/her level has a particular responsibility to improve the OHS quality of the workplace. The overall responsibility rests with the employer, who will seek the support both from his professional staff and from the participants in the OHS organization of the company. The same model applies to Estonia as well; nowadays Labour Inspectorate offers free consultancy in OHS expertize for those enterprises where professional knowledge is lacking.

OHS experts are not available in small enterprises in Estonia, therefore the professional knowledge has to be ordered outside.

Four areas in MISHA: A) organization and administration (including safety activities in practice (**A2,** the numbering in Kuusisto, 2000)), including in turn WER activities (**A2.6**), B) participation, communication, and training; C) work environment, D) follow-up.

Formal safety elements include (in parenthesis given the influence of OHSAS 18001 implementation in Estonian enterprises to the safety key element, correlated to the total safety level (score)): safety documents, contents of the safety policy ($R = 0.895$), revising the safety policy ($R = 0.972$), written policy ($R = 0.964$), assignment of tasks and responsibilities ($R=0.885$), safety policy's connections to the company's other activities ($R = 0.964$) and follow-up of accidents statistics ($R = 0.929$) (Paas, 2015a). These were the most correlated safety key elements that influenced on the total safety level positively.

Real safety elements include the safety key elements from the part **A2** as follows: top management's, line management's and supervisor safety knowledge; resources**.** From this part, OHSAS 18001 implementation in the enterprise influences only on resources (Paas, 2015a, p.30).

Combined safety elements include the safety key elements from the part **A2** as follows: 1) safety committee/ and or other cooperative teams, safety manager, safety representatives (WER) and/ or other cooperative teams (**A2.6**). The results (Paas, 2015a) show that all these elements have no correlation with the total safety score at the enterprise.

The safety activities in practice (**A2**) include (MISHA, Kuusisto, 2000): 1) top management's safety knowledge, 2) line management's safety knowledge, 3) supervisor's safety knowledge, 4) safety committee and/ or other safety team, 5) safety manager, 6) **safety representative (WER)** and/or other personnel representative(s) (**A2.6**), 7) occupational health services and 8) resources.

MATERIAL AND METHOD

Eleven Estonian manufacturing enterprises (Table 1) were examined with modified MISHA method (Kuusisto, 2000) for clarifying the role of the WER in OHS matters as well as for studying the perspectives to improve the safety level of the enterprise through more effective WER activities.

The qualitative study was carried out in these 11 companies in the form of interviews of before given persons. The interviewing of employer or WER both give the information about the present and possible role of WER. The interviews were assessed independently by all the authors of the current paper. The interviews were also taken as the basis for the quantitative study.

For assessment to the MISHA questionnaire, the Likert scale (1 – poor, 2 – average, 3 – good, 4 – very good, 5 – excellent) was used.

The safety key elements connected with the WER activities at enterprises are presented in Table 3. The questions from the MISHA questionnaire that concern the WER activities in enterprises and analysed in the current study, are as follows:

A1.5. Participation in the preparation of the policy: the participation of employers, WER and other workers' representatives is very important as so the information motion inside the enterprise is achieved.

A1.6. Initial status review: contains the first description of the work environment situation included into the safety policy.

A1.10. Informing external bodies about the policy: it is suggested that somebody outside (e.g. the inspector from the Labour Inspectorate or from the accreditation authorities) has examined the content of the policy. This part also includes how the temporary workers, sub-contractors and clients can access the safety policy of the current enterprise.

A2.4. Safety committee: if the enterprise has the safety committee, containing from the workers 'representatives (WERs) and the representatives of the employers, the safety and health questions at work are better dealt with and improvements in the field of OHS are possible.

A2.5. Safety manager: if the enterprise has the occupation as safety manager, the questions of safety certainly are in the foreground and the safety level could be improved. Usually, in Estonia, the enterprises are small-scale or medium-sized and they cannot afford the occupation 'safety manager'. The responsibilities are usually taken by the production manager or even by the manager of human resources.

A2.6. Safety representative: (or called working environment representative) is the workers' delegate in the safety committee. His (her) possibilities to improve the safety level at enterprises are very large. Enough time to deal with the safety matters has to be given to WER. He (she) has to be trained and the employer and safety manager have to be in good relations with the WER.

A3.3. Selection of the line management: the candidates have to be able to evaluate how the personnel copes with the work, to motivate the personnel, to be able to identify the health and safety hazards and handle the problems related to the human relations.

B3.1. Safety training needs: it has to be insured that the employees can to participate in the evaluation of the safety trainings. The safety training has to cover all the personnel groups.

D1.2. Accident investigation: the question concerns if there in the company, a person who investigates the accidents, is defined. If the corrective actions have been identified in the safety policy how to prevent similar accidents to occur, this gives the extra points to the safety level.

D3.1. Assessment of the social environment: does the company have a system for measuring social climate (e.g. climate surveys)? Are the corrective actions done immediately when problems to social relations have been observed?

In some of these companies, employees from three different level in the line of the safety management system were interviewed: the employer, the work environment specialist and the work environment representative. In locally owned companies, where the safety level is rather low, the managers did not recommend to have interviews with WER as their knowledge in OHS tends to be low. This presented the quantitative study.

The possibilities to improve and subsequently to use the knowledge of the WER in OHS are different in corporated or OHSAS 18001 implemented companies compared with small and medium- sized locally owned companies.

The statistics used in the paper involved IBM SPSS Statistics 22.0 and R.2.15.2. The following statistical methods were used: correlation, MANOVA, factor analysis, principal component method, independent T-test (Field, 2013).

RESULTS

The results of the quantitative analysis are given in Table 1. In the first columns the characterization of the investigated enterprises is given. The interviews with the enterprises' representatives (column 5) carried out and recorded, were afterwards listened and analysed by the four authors of the paper independently. The total average score (column 6) is derived with MISHA method.

Table 1. The characterization and results of quantitative study by the MISHA method in the investigated enterprises (N = 11)

1	2	3	4	5	6
Id. of the company	The activity area	Size, employees	OHSAS company /corporated company	The person interviewed: position, age	Total average score (100 max)
I	Plastic industry	50–249	+/	Quality manager, 41 Safety manager, 62WER, 25	78 76 78
II	Electronics	> 250	/+	Quality manager, 35 Safety specialist, 42 WER, 53	84 90 80
III	Food industry	> 250	/+	Safety manager, 62 WER I, 34 WER II, 39	75 80 58
IV	Electronics	> 250	+/	Quality manager, 59 Safety manager, 39 WER, 66	92 88 78
V	Textile industry	50–249	-/-	Production manager, 38	47
VI	Printing industry	< 50	-/-	Production manager, 36	29
VII	Glass industry	< 50	-/-	Production manager, 41	41
VIII	Chemical industry	50–249	+/	Management's representative, 55 WER, 62 External auditor, 34	88 85 78
IX	Chemical industry	50–249	+/	Management's representative, 45 WER, 40 External auditor, 34	87 87 78

Table 1 (continued)

X	Metal industry	50–249	-/-	Management's representative, 40	61
				WER, 53	55
				External auditor, 53	50
XI	Metal industry	> 250	-/+	Safety manager, 35	89
				Trade union representative, 60	86

Quantitative study:

The total scores given on the safety level, derived with the MISHA method (Paas et al., 2015a) from employer, WES and WER were compared. In the corporated companies and OHSAS 18001 companies, the total scores are high (80–85 from 100 possible). In locally owned companies, the scores are lower (below 50 from 100 possible). There is no significant difference between the scores given by three employees involved in safety in the same company in the corporated or OHSAS 18001 implemented companies. In some companies, only a slight decrease in the case of WER compared to employer representative was observed. The situation varies in locally owned companies. The scores do not differ significantly, but the knowledge of WER in these companies about safety matters was negligible and was clearly seen and heard in the interviews carried out by the safety experts.

The difference between the meanings of the assessors (employer, auditor or WES and WER) was until 24.7% in some of the subareas, like A) organization and administration (including safety activities in practice, including in turn WER activities), B) participation, communication, and training; C) work environment, D) follow-up) containing in the MISHA method.

The correlation analysis connected with safety activities areas (including WER)

The most correlated safety key elements in the studied enterprises were: top management commitment to the safety policy & resources (R = 0.99); revising the safety policy & resources (R = 0.96); written safety policy & resources (R = 0.95); safety policy's connections to company's other activities & resources (R = 0.95); assignment of tasks and responsibilities & resources (R = 0.93); dissemination of the policy & resources (R = 0.93); follow-up of accidents and illnesses & resources (R = 0.93); participation in the preparation of the policy & resources (R = 0.92); contents of the policy & resources (R = 0.91); resources & assessment of the social work environment (R = 0.9); WER & the content of the policy (R = 0.9).

The results can be interpreted as follows: a) the safety overall safety level depends on the resources given to the OHS activities by the employer in the enterprise; 2) the psychosocial work environment is getting gradually more attention by the employees; 3) the workers are not involved on practical issues of safety policy development, yet.

Among OHSAS 18001 implemented enterprises, there is a strong correlation between safety activities in practice **A2** & personnel management (R = 0.7); safety activities in practice **A2** & personnel safety training (p = 0.05). Among non-OHSAS the correlation between safety activities in practice **A2** & personnel management is 0.94

(p = 0.1); safety policy & safety activities in practice **A2** R is 0.90; safety activities in practice **A2** & hazard analysis procedures has correlation coefficient R = 0.88.

Safety activities in practice **A2** (MISHA) has good correlation in all non-OHSAS companies in Estonia (Fig. 2).

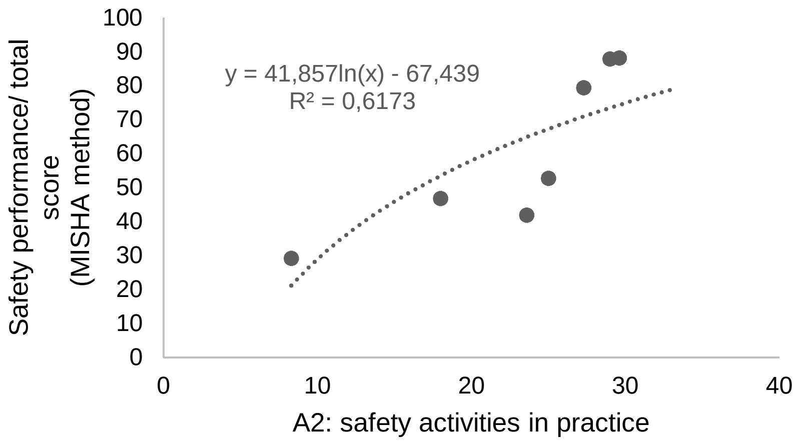

Figure 2. The influence of safety activities (including WER) on the total safety score in non-OHSAS companies.

Hypothesis H1

Factor analysis were carried out with KMO and Barlett's test (Field, 2013). The alpha correction (ANOVAs with Tukey's HSD post-hoc tests) was implemented and so the **H1** and **H2** were confirmed.

From **A2,** the following key elements were taken into the statistical analysis: top management, line management and supervisor safety knowledge, safety manager, WER, occupational health services activities and resources for these activities (Table 2).

The result showed that there was a statistically significant difference in real safety performance based on a firm type (OHSAS or non-OHSAS), F (26.2) = 17.311, p < 0.1. Wilk's $\Lambda = 0.000$, partial $\eta^2 = 0.996$. Power to detect the effect was 0.854.

It can be concluded from the Table 2 that at the present time, the firm type influences the safety policy part in the OHSAS implemented and non-OHSAS companies (p = 0.000), but only concerning the safety activities in practice on the top management's safety knowledge (p = 0.039). The role of WER is not significant (p = 0.350). At the same time, the firm's type is significant on the supervisor/employee communication (p = 0.001) and on general communication procedures (p = 0.006).

Table 2. Correlation between the safety key elements **H1**

Safety key element	Sum of squares (KMO and Barlett's test)	p-value
A1.2.Top management commitment to the safety policy	22.250	0.000
A1.9.Dissemination of the policy	21.007	0.000
A2.1. Top management's safety knowledge	3.005	0.039
A2.2. Line management safety knowledge	0.854	0.383
A2.3. Supervisor's safety knowledge	0.410	0.412
A2.5.Safety manager	0.540	0.450
A2.6. Safety representative	**0.250**	**0.350**
A2.7. Occupational health services	2.410	0.193
A2.8. Resources	22.688	0.000
A3.4. Promotion, rewards and career planning	4.264	0.006
B1.1. Supervisor/employee communication	**5.672**	**0.001**
B2.1. General communication procedures	**2.896**	**0.006**
B2.3. Suggestions for improvements	5.500	0.027
B2.4. Campaigns	9.797	0.039
C1.2. Chemical hazards	3.563	0.021
C1.8. Maintenance	4.500	0.002

Hypothesis H2

There was a statistically significant difference in both formal and real safety performance based on a firms type (OHSAS and non-OHSAS), F (26.2) = 11.472, $p < 0.1$; Wilk's $\Lambda = 0.000$, partial $\eta^2 = 0.993$. Power to detect the effect was 0.730.

The type of the firm (Table 3) influences on the policy section (A1, p = 0.000-0.001). We can see from the Table 3 that the safety committee's (p = 0.214), safety manager's (p = 0.220) or WER's (p = 0.282) position in Estonian enterprises is very low. At the same time, the significance of selection of a safety manager (personnel policy), safety training needs (p = 0.000), assessment of social environment (0.000) were very high. These are the areas in the enterprise, where WER can influence in case her/his position is supported by the regulations and the employer.

Table 3. Correlation between the safety key elements **H2**

Safety key element	Sum of squares (KMO and Barlett's test)	p-value
A1.5. Participation in the preparation of the policy	21.250	0.000
A1.6. Initial status review	13.375	0.001
A1.10. Informing external bodies about the policy	17.241	0.001
A2.4. Safety committee	**3.200**	**0.214**
A2.5. Safety manager	**1.194**	**0.220**
A2.6. Safety representative	**1.521**	**0.282**
A3.3.Selection of the line management	3.063	0.017
B3.1. Safety training needs	8.491	0.000
D1.2.Accident investigation	4.125	0.007
D3.1. Assessment of the social work environment	19.125	0.000

Qualitative study:

Case A: a company, belonging to the foreign concern with a high safety level has 16 WERs per 250 workers, one in each department. The safety committee meetings are carried out regularly; all the WERs are included in the mailing list of the meetings. Written reports of the meetings are distributed to the WERs after the meeting, the distribution of information in the company is very good. Even when WERs are informed well, they are not involved in decision-making processes concerning OSH such as preparing safety policy, conducting risk assessments etc.

The question (**1**) to the work environment specialist (WES): '*Are the WERs as the representatives of workers allowed to make changes in the safety policy?'*

The answer: '*No, the safety policy is given in the written form to the subsidiary company (in Estonia) from the owner of the corporation (in Finland)' (Company A, Int 1)*

Case B: a small locally owned company (15 employees), where OHS matters are not a priority and no systematic OSH work is visible. A production manager (PM) has shortly signed to fulfil the responsibilities of WES, on labour inspector's request. The risk levels of occupational hazards in manufacturing department are high. Before the visit of the labour inspector, the responsibilities in OHS were delegated to the accountant. At present, she represents workers as WER, however no formal elections have been organized and her knowledge in OSH is questionable. There are several areas where WER can be involved; however, the PM and WES do not see the potential in her. Many safety shortages were identified during the interview, for example how to maintain the protective clothing or educate experienced workers in safety matters or how to involve the workers to risk assessment process.

The question (**2**): '*How do you carry out the protective clothing maintenance? Is there a washing machine in the enterprise or is it performed by the subcontracting firm?'*

The answer of the PM: '*We have the washing machine, but we do not use it, as the workers wash the work clothes at home together with the other everyday clothes*.' *(Company B, Int 2)*

Additionally, the PM confessed that the workers have not been told about the danger of the sharp particles that can be found in the work clothes and the work clothes are not allowed to wash together with the everyday ones. No WER is involved in this problem.

The question (**3**): '*Has the car driver educated in slippery road driving (the courses are available in Estonia) or has he provided with sunglasses for creating the better driving conditions*?'

The answer of the PM: *'The driver has worked already 40 years without sunglasses and he knows how to drive the car in winter. Training is not necessary.' (Company B, Int 2)*

The question (**4**): '*Is the risk analysis carried out and improved according to the changes in the industrial process regularly? Is the action plan to reduce the risk level compiled in the enterprise?'*

The answer of the PM: '*We have carried out measurements of noise and conducted risk analysis after the visit of labour inspector, but as the noise level was not over the norm, we have not had time to compile the action plan.' (Company B, Int 2)*

The PM of the company pointed out that template for work descriptions would be useful from the side of Labour Inspectorate to support the overall improvement of the OHS level in small and medium-sized enterprises in Estonia.

Case C: a locally owned company with 40 workers. The production manager (PM) was questioned. A lot of OSH shortages were identified; no systematic work and no representation of workers in OSH matters were detected. No clear answer was given about safety policy and it is quite clear that workers are not informed about it.

The question **(5)**: '*Do you have the safety policy at the enterprise? Who has compiled it?'*

The answer of the PM: '*We had something when the ISO (?) was implemented; something has still remained from it. We have no WES, also no WERs. Everything is explained during the production process. If a new machine is obtained, then the providers train the workers in safety matters.' (Company C, Int 4)*

The question (**6**): '*Have you visited the occupational health doctor lately? Do you have the plan for medical examinations of workers?'*

The answer of PM*: 'No, we have not the plan, but I visited the doctor over 5 years ago.' (Company C, Int 4)*

Case D: a corporated enterprise with 25 employees. The production manager (PM) was questioned. The safety level in the company is high. WERs have been elected, no WE committee needed, but two workers in the production area are continuously following the hazards in the work environment (using measurement devices). Safety as seen as an investment and not as an expense by the management. Line and top managers possess high knowledge in safety matters. Recently, a special meeting concentrating on safety matters, was organized internationally, were all 10 subcontractors from different countries participated. However, some shortages were identified during the interview, mainly about safety policy and dissemination of the document among workers – where WER can be involved. The management had an attitude that workers do not need to know the general policy about safety, they should concentrate on their workplace safety only.

The question (**7**): '*Do you have the safety policy? Are workers aware of this policy?'*

The answer of the PM: '*The policy has been worked out by the foreign owner (some corrections from Estonian side were possible). The workers need not know about the details of the policy.' (Company D, Int 6)*

DISCUSSION

Our study revealed that management plays an essential role in WER's systematic and active work and workers' participation on workplace health and safety matters. In O'Toole (2002), it is also postulated that management leadership is influencing the employee perceptions of the safety management system. Those perceptions appear to influence employee decisions that relate to at-risk behaviours and decisions on the job. Organizational commitment did affect perceived safety at work, but not on work accidents (DeJoy et al., 2010). According to our study, management commitment to safety policy forms a positive starting point for regular activities of WERs. Studies of occupational safety program effectiveness have also highlighted safety policies and programs as important ingredients of effective programs (DeJoy et al., 2004). Neal et al.

(2000) also found a relationship between general organizational climate and safety climate: when the organizational climate improves (the standards are implemented), the safety climate also will be better.

Our study examined three different types of companies: OHSAS certified companies, corporated companies and small and medium-sized locally owned companies. It turned out that the definition of ‘small enterprises’ is not sufficiently specific. Small enterprises cover many types of work activities, which naturally lead to large differences in the work environment. Small enterprises are more susceptible to influence from various ‘external’ sources e.g., though the ownership structure. It might be important whether the small enterprise is part of a larger organization and whether it is publicly or privately owned (Sorensen et al., 2007). This problem remains for the future research.

Compared to Estonian OHS system in companies, Nordic OHS regime contains three different collaborating arenas or structures within the company: 1) a work environment or safety committee with balanced representation from the parties; 2) safety representatives elected by the employees; 3) in-house or external health and safety experts employed by and representing the management (Lindoe et al., 2001). According to the OHS Act (1999), based on EU Framework Directive 89/91, the employer and employees have to co-operate and there have to be opportunities for both parties to consult on the relevant OHS matters. The ensuring right of worker participation is stated in mandatory forms of industrial health and safety national legislation and in the EU Framework Directive 89/391. In Estonia, WER has to be trained following the 24-h training programme provided in the regulation. In Norway, the social partners agree that a 40-h course covers the basic training necessary to function as a WER (Hovden et al., 2008).

In our qualitative study, we concluded that WERs assessed the time for dealing with OHS matters unsatisfactory. The results in Nordic countries (Hovden et al., 2008) show similar pattern – often WERs complained about lack of time. The examples of the best experiences of the Nordic countries should be used in order to increase workers’ participation and representation in health and safety matters.

CONCLUSIONS

The answer to the *hypothesis H1*: the firm type (OHSAS-implemented and non-OHSAS enterprises) has an impact on real safety performance.

The answer to the *hypothesis H2*: the type of the firm has a significant impact both on formal and real safety performance.

The general conclusions are following:

1. The position of safety representative has often a low status in the company.
2. WERs do not have enough time to fulfil their safety functions to keep employees safe.
3. There is a limited understanding among employers about the role of WER. The study showed that in small enterprises, the WER has a formal position, although required by the law. In that case, employers do not understand the need of the WER and while electing them only formally, there is no practical value and often, employees are unaware of the position. The interviews also revealed that it is complicated to find the candidates to the WER position even in larger companies, especially in locally owned companies

as managers do not know how to motivate workers on taking an additional responsibility. Safety management system plays a role in effective work of WERs. If the management does not give enough priorities to OHS, the employees will follow the example of the employer. WER should be elected among the peers rather than using WERs from other departments.

4. The WER of the organization is not well known or acknowledged by all the employers and subcontractors. The subcontracting work may cause several accident and near-accident situations. The importance of the person (WER), who knows how to deal with the problems in OHS, becomes evident only after the accident has occurred or some of the workers are already seriously ill with occupational disease, such as musculoskeletal disease. The MSD is, at the present time, the number one occupational illness in almost every European country (Kaergaard & Andersen, 2000).

5. Doing WER work successfully is difficult due to conflicting expectations from employer and colleagues. The interviews revealed that nobody in the enterprise wants to be the resolver of a risky situation or even accident. Therefore, it is particularly important to prevent these situations by increasing the knowledge on OHS. For this occasion, WER and his/her knowledge and activities are a very good solution. It is important to mention that he/she needs enough time to gather the information on OHS and his/her activity has to be acknowledged by the employer.

REFERENCES

Cooper, M.D. 2000. Towards a model of safety culture. *Safety Science* **36**, 111–136.

Danna, K. & Griffin, R.W. 1999. Health and well-being in the workplace: a review and synthesis of the literature. *Journal of Management* **25**(3), 357–384.

DeJoy, D.M., Della, L.J., Vanderberg, R.J. & Wilson, M.G. 2010. Making work safer: testing a model of social exchange and safety management. *Journal of Safety Research* **41,** 163–171.

DeJoy, D.M., Schaffer, B.S., Wilson, M.G., Vandenberg, R.J. & Butts, M.M. 2004. *Journal of Safety Research* **35**, 81–90.

Fernandez-Muniz, B., Montes-Peon, J.M. & Vazquez-Ordas, C.J. 2007. Safety culture: analysis of the causal relationships between its key dimensions. *Journal of Safety Research* **38,** 627–641.

Fernandez-Muniz, B., Montes-Peon, J.M. & Vazquez-Ordas, C.J. 2009. Relation between occupational safety management and firm performance. *Safety Science* **47**, 980–991.

Field, A. 2013. Discovering Statistics Using IBM Statistics. Fourth Edition. SAGE Publications Ltd., http://www.uk.sagepub.com/field4e/main.htm

Hall, M.E., Blair, E.H., Smith, S.M. & Gorski, J.D. 2013. Development of a theory-based safety climate instrument. *Journal of Safety, Health & Environmental Research* 9(1), 58–69.

Hovden, J., Lie, T., Karlsen, J.E. & Alteren, B. 2008. The safety representative under pressure. A study of occupational health and safety management in the Norwegian oil and gas industry. *Safety Science* **46**, 493–509.

Kaergaard, N & Andersen, J.H. 2000. Musculoskeletal disorders of the neck and shoulders in female sewing machine operators: prevalence, incidence, and prognosis. *Occupational and Environmental Medicine* **57**, 528–534.

Karlsen, J.E. & Lindoe, P.H. 2006. The Nordic OHS model at a turning point? *Policy and Practice in Health and Safety* **4**(1), 17–30.

Kongtip, P., Yoosook, W. & Chantanakul, S. 2008. Occupational health and safety management in small and medium-sized enterprises: An overview of the situation in Thailand. *Safety Science* **46**, 1356–1368.

Kuusisto, A. 2000. Safety management systems: audit tools and reliability of auditing [dissertation]. Tampere: Tampere University of Technology.

Lindoe, P.H., Karlsen, J.E. & Lie, T. 2001. *A Nordic way of handling occupational health and safety regulations*. Nordic Council of Ministers, Copenhagen.

Makin, A.M. & Winder, C. 2008. A new conceptual framework to improve the application of occupational health and safety management systems. *Safety Science* **46**, 935–948.

Neal, A., Griffin, M.A. & Hart, P.M. 2000. The impact of organizational climate on safety climate and individual behaviour. *Safety Science* **34**, 99–109.

OHS Act (Occupational Health and Safety Act). 1999. RT I 1999, 60, 616. https:/www.riigiteataja.ee/akt/108102014007. Accessed 31.01.2015 (in Estonian).

O'Toole, M. 2002. The relationship between employees' perceptions of safety and organizational culture. *Journal of Safety Research* **33**, 231–243.

Paas, Õ. 2015a. *Development of the safety management system at enterprises*. PhD thesis. Tallinn University of Technology, 164 pp.

Paas, Õ., Reinhold, K. & Tint, P. 2015b. Estimation of safety performance by MISHA method and the benefits of OHSAS 18001 implementation in Estonian manufacturing industry. *Agronomy Research* **13**(3), 792–809.

Paas, Õ., Reinhold, K. & Tint, P. 2015c. OHSAS 18001 contribution to real and formal safety elements of safety management in manufacturing companies: results of statistical analysis. *Agronomy Research* **13**(5), 1260–1274.

Paas, Õ., Reinhold, K. & Tint, P. 2016. Learning through questioning in occupational health and safety. *Scientific Journals of Poznan University of Technology series of 'Organization and Management'* **67**, 17 pp. (forthcoming).

Parker, D., Lawrie, M & Hudson, P. 2006. A framework for understanding the development of organizational safety culture. *Safety Science* **44**, 551–562.

Sorensen, O.H., Hasle, P. & Bach, E. 2007. Working in small enterprises – Is there a special risk? *Safety Science* **45**, 1044–1059.

Wachter, J.K. & Yorio, P.L. 2013. Current practices related to the use of human performance improvement tools. *Journal of Safety, Health & Environmental Research* **9**(1), 70–80.

Walters, D., Nichols, T., Connor, J., Tasiran, A.C. & Cam, S. 2005. *The role and effectiveness of safety representatives in influencing workplace health and safety*. University of Cardiff: Research Report 363.

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Translocation of soil particles during primary soil tillage

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Abstract. The loss of soil particles due to water erosion is a crucial problem of current farming on the soil. However, soil tillage may also contribute to the undesirable transport of soil particles. It is to note that the effects of particular working elements used on implements for soil tillage have not been described in a sufficient way. To determine the translocation of soil particles, measurements were done in the Central Bohemian region. Three basic machines for soil tillage were used for measurements: disc tiller, tine cultivator and five-share plough. Measurements were performed on sandy-loamy Cambisol after harvest of a spring cereal crop. White limestone grit was used for the indication of soil particle translocation. Great translocation of soil particles was observed after soil tillage with tine cultivator and mouldboard plough - the average translocation rates ranged between 0 and 0.9 m. Disc tiller displaced the soil particles into smaller distance (into 0.3–0.45 m). The dependence of tracer weight on a distance from the original location could be described for disc tiller and tine cultivator by an exponential function. The type of soil particle translocation by a mouldboard plough was completely different from the translocation by a disc tiller and tine cultivator. Topsoil turning over by a plough showed the lengthwise and crosswise movement of tracers with a typical dependence of their weight on a distance from the original location. The dependence of tracer weight on a distance from the original location could be described for mouldboard ploug by an quadratic function. Individual machines for primary tillage have a different character of translocation of soil particles.

Key words: soil particles transport; soil erosion; machines for soil tillage.

INTRODUCTION

Different soil tillage and sowing methods have a significant effect on soil structure, soil bulk density, soil penetration resistance, total and air-filled porosity, soil moisture and yield (Šimanskaitè, 2008). Another effect of soil tillage is the influence on soil erosion conditions. Of the factors influencing soil erosion are distinguished erosivity: action of the eroding agent (rainfall, but also the action of tillage) and erodibility: the resistance of the soil to detachment and transport. Soil resistance to erosion (erodibility) depends on slope steepness and on intensity of disturbance during soil tillage. Soil erodibility is impacted by soil texture, aggregate stability, plant cover, infiltration capacity, organic and chemical content and other soil properties (bulk density, moisture content) – Morgan (2005). Effects of soil erosion are particularly important on agricultural land where it causes the redistribution of soil within a field, the loss of soil from field and the breakdown of soil structure. Another serious consequence of soil erosion is the decline in organic matter and nutrient result in a reduction of soil cultivable depth and a decline of soil fertility. Tillage erosion is the net downslope movement of soil brought about by tillage operations. Soil tillage erosion and the related study of soil particle translocation by working operations and machines during soil tillage belong to the little examined area of soil erosion research (Govers et al., 1999). Based on findings from Ontario, Canada, Lobb et al. (1995) stated that tillage erosion accounts for at least 70% of the total loss of soil on hilltops. There is not a sufficient description of the influence of particular groups of machines and their implements on soil with regard to the translocation of soil particles – it is mainly applicable to secondary soil tillage and sowing. More information is available about the movement of soil particles by operations and machines for primary soil tillage (ploughing with mouldboard ploughs, loosening with chisel ploughs). There is also a lack of data on the translocation of soil particles when the sequences of working operations of soil tillage are applied for cultural practices (Tiessen et al., 2007). The extent of tillage erosion depends on the erosivity of tillage operations and erodibility of the landscape (Lobb et Kachanoski, 1999). Tillage erosion is largely influenced by the design of a tillage implement (type of equipment, the geometry and arrangement of the cutting tools) and how the tillage is operated – frequency of tillage operations, tillage speed and depth, the behavior of the operator (Li et al., 2007). Tiessen et al. (2007) concluded that the erosivity of a pneumatic seed drill was comparable with the erosivity of a cultivator during primary soil tillage if the sowing was performed shortly after seedbed preparation.

To measure the translocation of soil particles during soil tillage is not easy. Logsdon (2013) presented an overview of tracers that were incorporated into the soil by some authors in order to indicate the topsoil translocation during soil tillage (Al cubes, dyed limestone, steel nuts, Cs^{137}).

The objective for the study was to evaluate the displacement of soil particles in the primary tillage with the use of three machines: disc tiller, tine cultivator and mouldboard plough. White limestone grit was used to indicate the soil particles translocation.

MATERIALS AND METHODS

The translocation of soil particles was measured in June 2015 after harvest of common oat in the green ripeness phase. Basic data on a field where measurements were done: the locality Nesperska Lhota near Vlasim, altitude of 420 m a.s.l., sandy loamy Cambisol. The soil on the plot is shallow, slightly stony. The field was after harvest of common oat (*Avena sativa*) for green forage. Before the translocation of soil particles started to be measured, soil samples (5 pieces at each depth) were taken to determine the basic physical properties of soil at a depth of its tillage. Soil physical properties have been evaluated employing Kopecky's cylinders with volume 100 cm^3 and subsequently analysed in the laboratories of the CULS Prague. Soil moisture content was measured with a ThetaProbe sensor (Delta Devices, UK). A digital clinometer (BMI, Germany) was used to measure the angle of slope of a part of the field where measurements were performed. The average slope of area is 2.7°. The content of particles < 0.01 mm: 29% weight. Soil moisture in the soil tillage depth: 10.7% vol. Soil bulk density and porosity before tillage is given in Table 1. The table shows the average values. Colected samples are showing a high content of macropores in the soil. Macropores are evident even at a depth from 0.15 to 0.20 m. It cannot therefore demonstrate the influence of oat plants to physical properties of soil.

Table 1. Soil bulk density before tillage

Depth (m)	Bulk density (g cm^{-3})	Porosity (%)
0.05–0.10	1.49	43.8
0.10–0.15	1.52	43.3
0.15–0.20	1.51	43.2

For tillage passes the chosen direction was 'downslope orientation'. The machines that were chosen to measure the translocation of soil particles in the operations of primary soil tillage:

Akpil X 3.0 disc tiller of working width 3 m, Ross Kon-375 tine cultivator of working width 3.5 m and Ross PH-1-535 five-share plough of working width 1.75 m.

To indicate the translocation of soil particles white limestone grit (particle size 10–16 mm) was used. Grits were incorporated into grooves 0.20 m in width and 1 m in length. The longer side of the grooves was oriented perpendicularly to the direction of subsequent passes of tillage machines. The groove depth was chosen to match the working depth of tools of tillage machines. Soil tillage depth: disc tiller – 0.08–0.10 m, tine cultivator – 0.15 m, mouldboard plough – 0.20 m. The travel speed of machines in the field was chosen according to the manufacturers' recommendations: disc tiller 10 km.h^{-1}, tine cultivator 5.5 km h^{-1}, mouldboard plough 4.5 km h^{-1}.

After the tractor with a respective implement passed across the field, the tracers were picked by hand from the soil in segments of 0.30 m (tine cultivator, mouldboard plough) or 0.15 m (disc tiller), in the direction of machine movement. After the machines passed across the field, the segments were divided into three segments of 0.33 m also in a crosswise direction. By weighing the tracers their weight was determined in each segment as an indicator of soil particle translocation by soil tillage. Data were processed by the programmes MS Excel (Microsoft Corp., USA) and Statistica 12 (Statsoft Inc., USA). From the statistical methods regression and the average evaluation were used.

RESULTS AND DISCUSSION

The first evaluated machine was an Akpil disc tiller of the working width 3 m. The machine had a conventional 'X'-shaped design with discs on a common shaft with working tools. A groove of 0.12 cm in depth was made and it contained 25 kg of crushed limestone. Subsequently, the tractor with the disc tiller passed the groove while the groove centre was in the middle of the working width of the machine.

After the tillage operation the segment was divided by 0.15 m. In a crosswise direction the groove width (1 m) was always divided into three segments (of 0.33 m). The evaluation of acquired data shows a noticeable translocation of particles in the direction of the machine movement. Fig. 1 shows the curve representing the average values of translocation in the particular segments. There is a steep fall in the weight of translocated particles at a longer distance from the original location. The relationship of the tracer weight to a distance from the original location can be described by an exponential function. The graph shows that the particles are translocated by the discs of the cultivator only to short distances. The mechanism of the translocation is the movement of soil particles bouncing off from the cultivator discs as a result of the angle of their slant. So the disc geometry influences also the translocation of particles.

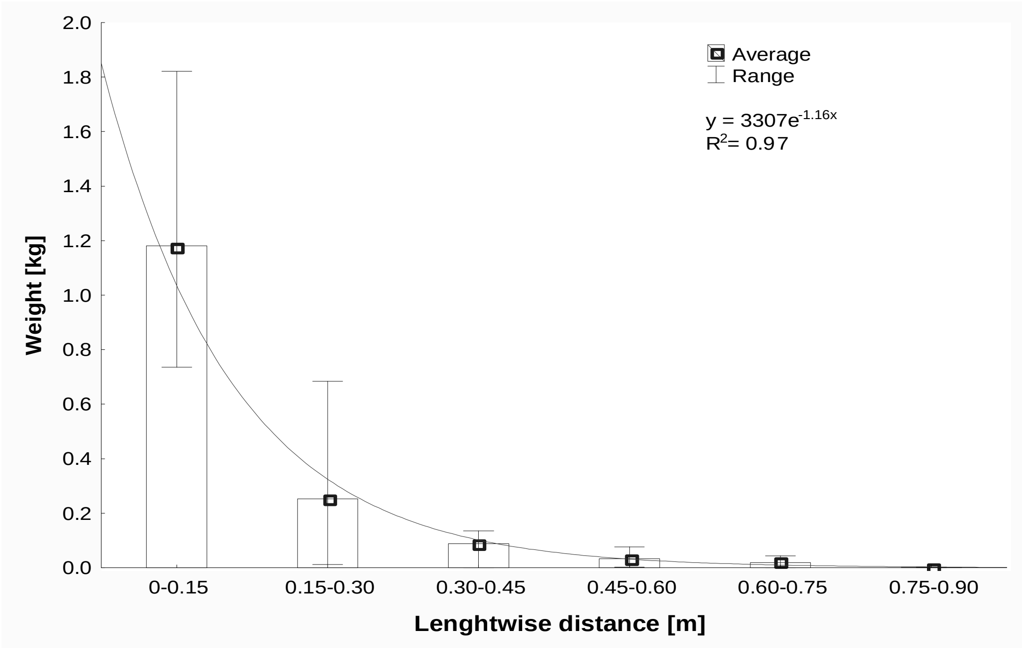

Figure 1. Average values of translocated particles in a lengthwise direction for a disc tiller. Lenghtwise segment: 0.15 m, average values from 3 crosswise segments Interpolation: exponencial function.

Fig. 2 illustrates the translocation of particles in partial segments. Obviously, the highest translocation of particles was measured in the central segment. It is most likely a result of the cultivator design, where the 'X' type design creates a slightly crest profile of the tilled soil after the tillage operations, leading to the more intense translocation.

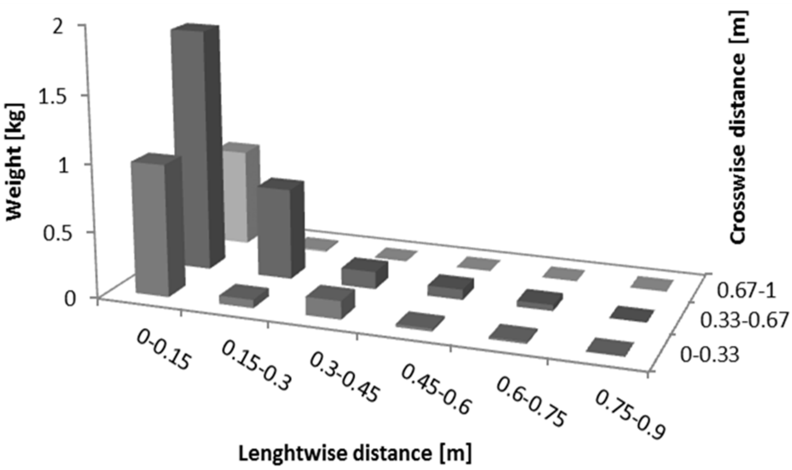

Figure 2. Translocation of particles in the particular segments for a disc tiller. Lenghtwise segment 0.15 m, crosswise segments 0.33 m.

Further measurements were done after the soil tillage operation with a Ross tine cultivator of the working width 3.5 m. Fig. 3 shows a relation of the weight of translocated tracers to a distance from the original location. To express this relation an exponential model of the function was used again. Tracers were translocated to a much longer distance from the original location than in soil tillage with a disc tiller. For the tine cultivator the most distant tracers were found at a distance of more than 1.50 m while after soil tillage with a disc tiller they were at a distance of 0.90 m.

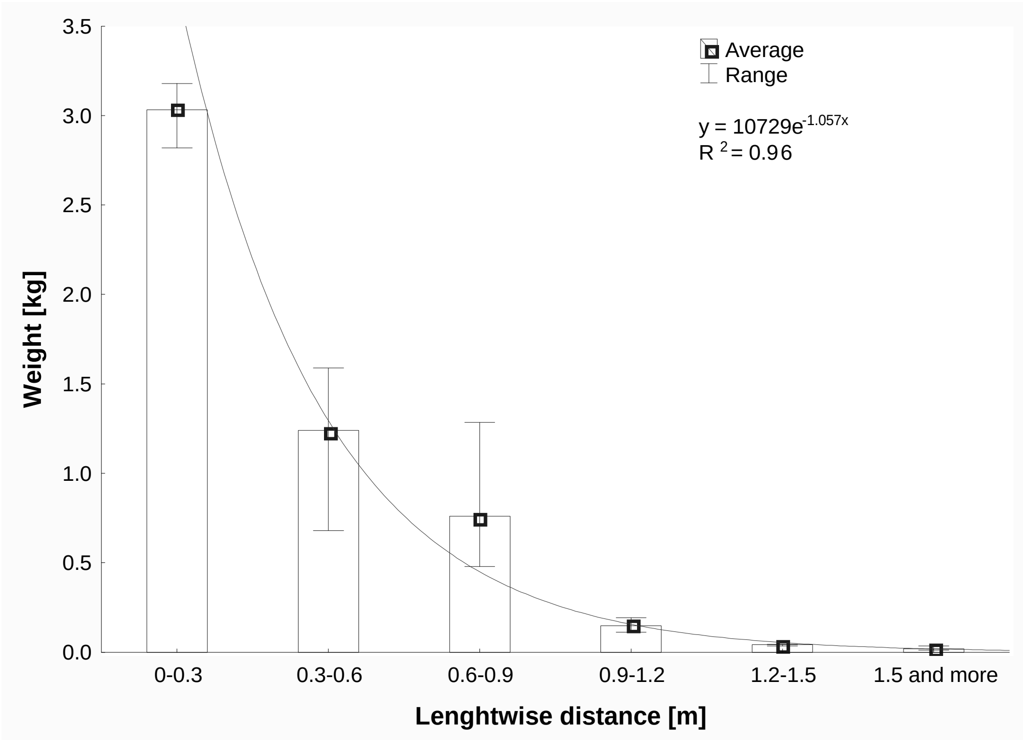

Figure 3. Average values of particle translocation in a lengthwise direction for a tine cultivator. Lenghtwise segment: 0.3 m, average values from 3 crosswise segments. Interpolation: exponencial function.

Fig. 4 illustrates the translocation of particles in the particular segments. After soil tillage with a tine cultivator no greater crosswise translocation of particles was observed. However, among all the evaluated machines, the lengthwise translocation was unambiguously the greatest.

The third machine evaluated with regard to the translocation of soil particles was a Ross five-share plough. The type of particle translocation was completely different from preceding measurements (Fig. 5). The reason is the turning over of a part of the soil profile by the bottoms. The turning over operation causes both the lengthwise and crosswise translocation, which can be seen in Fig. 6. Especially the evaluation of the particular segments (Fig. 6) reveals a crosswise translocation, when all tracers from a part of the groove were displaced both in lengthwise and crosswise direction from the original location.

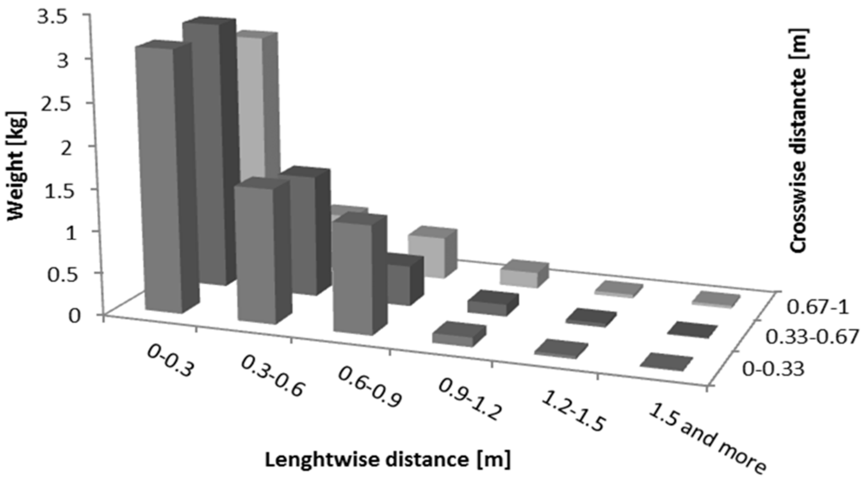

Figure 4. Particle translocation in the particular segments for a tine cultivator. Lenghtwise segment 0.3 m, crosswise segments 0.33 m.

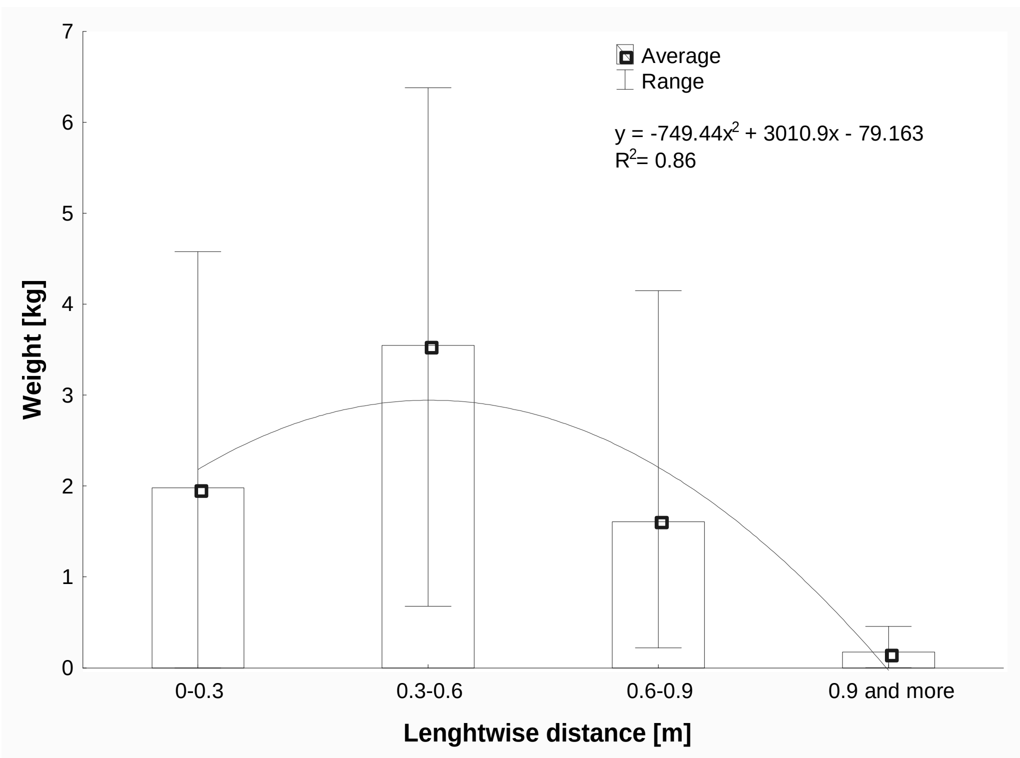

Figure 5. Average values of particle translocation in a lengthwise direction for a mouldboard plough. Lenghtwise segment: 0.3 m, average values from 3 crosswise segments. Interpolation: quadratic function.

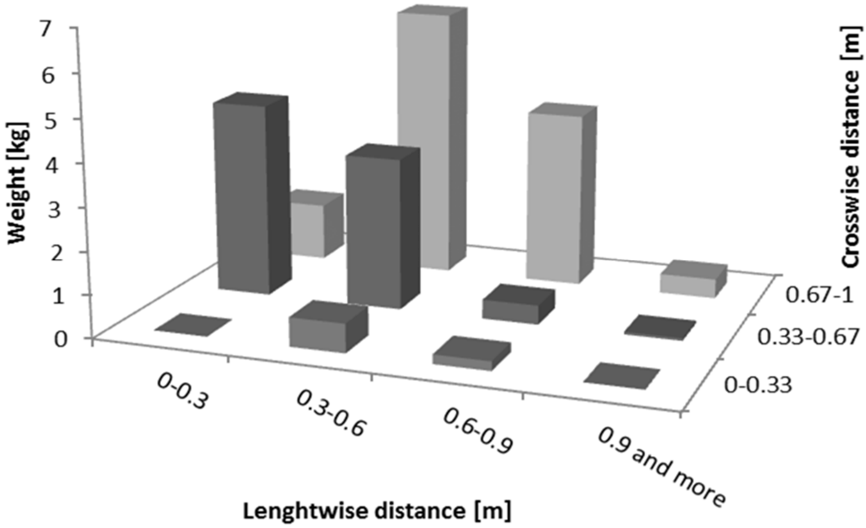

Figure 6. Translocation of particles in the particular segments for a mouldboard plough Lenghtwise segment 0.3 m, crosswise segments 0.33 m.

The performed measurements of the translocation of soil particles by three machines during primary soil tillage showed a considerable translocation of particles in the direction of machine movement and in a crosswise direction. It confirmed the conclusions drawn by Tiessen et al. (2007) about great differences in the translocation of soil particles during soil tillage by machines with different design of working tools. Van Muysen et al. (2006) found out that during a typical tillage including use of multiple of mouldboard plough, chisel tiller and disc tiller the average translocation rates ranged between 0 and 0.9 m. During our research the particles were displaced in this range of distance after tillage by time cultivator and mouldbroad plough. Disc tiller displaced the soil particles into smaller distance (into 0.3–0.45 m). The presented results are consistent with the conclusions of Tiessen et al. (2007) about the crucial influence of the type of working tools acting on the soil, their geometry and adjustment of machines. It is to emphasize the importance of tillage speed and depth and soil tillage frequency. Logsdon (2013) reported the lengthwise translocation of tracers placed on the soil surface to a distance of 2–3 m for soil tillage with a chisel plough – in our measurement the most distant particles at primary soil tillage were found out at a distance of 2.25 m from the location of their incorporation into soil. The 'down slope orientation' direction was chosen for driving the machines.

However, it is actual to evaluate the displacement of soil particles during repeated work operations in the choice of different driving direction (Van Muysen, 2006). It is also necessary to focus on tillage erosion during the secondary tillage and seeding (Li et al., 2007).

CONCLUSIONS

The results of measuring the translocation of soil particles document the fact that has been neglected until now: soil tillage may translocate soil particles to a different extent both in the direction of the machine movement and in a crosswise direction. The choice of machines for soil tillage can substantially influence the intensity of undesirable soil translocation especially in sloping fields. At the same time it is necessary to conduct research on the translocation of soil particles not only by single implements for soil tillage but also by sequences of implements when the particular operations of soil tillage and sowing succeed each other. Furthermore, the intense development in technology and machinery for soil tillage continues. It is therefore current to evaluate the effect on the translocation of soil particles in unconventional tillage. An example is strip tillage.

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REFERENCES

Govers, G., Lobb, D.A. & Quine, T.A. 1999. Tillage erosion and translocation: emergence of new paradigm in soil erosion research. *Soil & Tillage Research* **51**, 167–174.

Li, S., Lobb, D.A. & Lindstrom, M.J. 2007. Tillage translocation and tillage erosion in cereal-based production in Manitoba, Canada. *Soil & Tillage Research* **94**, 164–182.

Lobb, D.A., Kachanoski, R.G. & Miller, M.H. 1995. Tillage translocation and tillage erosion on shoulder slope landscape positions measured using ^{137}Cs as a tracer. *Canadian Journal of Soil Science* **75**, 211–218.

Lobb, D.A. & Kachanoski, R.G. 1999. Modelling tillage erosion in topographically complex landscapes of southwestern Ontario, Canada. *Soil & Tillage Research* **51**, 261–278.

Logsdon, S.D. 2013. Depth dependence of chisel plow tillage erosion. *Soil & Tillage Research* **128**, 119–124.

Morgan, R.P.C. 2005. Soil Erosion and Conservation. Blackwell Publishing, 304 pp.

Šimanskaitė, D. 2008. The impact of soil tillage minimization on sandy light loam soil. *Agronomy Research* **6**, 349–357.

Tiessen, K.H.D., Lobb, D.A., Mehuys, G.R. & Rees, H.W. 2007. Tillage erosion within potato production in Atlantic Canada: II. Erosivity of primary and secondary tillage operations. *Soil & Tillage Research* **95**, 320–331.

Van Muysen, W.V., Oost, K.V. & Govers, G. 2006. Soil translocation resulting from multiple passes of tillage under normal field operating conditions. *Soil & Tillage Research* **87**, 218–230.

Agronomy Research **14**(2), 400–406, 2016

Effect of gasoline contamination on the quality of arctic diesel fuel

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Abstract. Fuel quality is affected predominantly during its transport between producer and user as hired transporting companies may use one transport vehicle for more different fuels. Therefore, gasoline from previous transport may cause contamination of diesel fuel in next transport. Many drivers add gasoline as additive to diesel fuel to improve start of engine avoiding difficulties of cold winter temperatures. Therefore, the objective of this article is to assess maximum gasoline content added still compliant with default values of standard EN590 and values certified by producer. Only 2% maximal gasoline content in arctic diesel fuel was found safe for both machine and operator. Distillation curve, kinematic viscosity, density, lubricity and cetane index were influenced unimportantly. Cloud point, CFPP were not changed at all.

Key words: diesel, gasoline, distillation, blend, limits.

INTRODUCTION

Purposeful cheating allowing excise duty reduction, price decrease diesel fuel dilution by technical gasoline and by HC oil appears often, but is not discussed in this article. The purpose of this article is to observe arctic diesel fuel quality in official distribution channel, which can be compromised by accident. Usually, residual fuel from previous transport may cause the most serious contamination of diesel fuel due to lacking technological treatment of transporting tank. Therefore, quality of delivered diesel fuel is sampled, analysed and fuel quality differences from norm are reported at petrol station or fuel storage (Kamimura & Sauer, 2008; Arapatsakos, 2009; Catillo-Hernández et al., 2012; Pirs & Gailis, 2013; Aydogan, 2015).

Flash point, eventually diesel fuel distillation properties are the most seriously affected in such cases. Volume of gasoline added or diesel fuel properties of casual impurities damaging engine (Mužíková et al., 2010; Hönig et al., 2015) were discussed. Therefore, objective of this article is to assess still acceptable gasoline contamination of diesel fuel excluding any damage of engine.

Fuel allowing proper diesel engine performance has to overcome problems of:

- density, viscosity, lubricity, purity and in winter also filter ability being timely, regularly and in needed volume transported to cylinder;
- viscosity and composition of fractions by precise dispersion and evaporation;
- composition of fractions, density and cetane number to shorten ignition delay allowing normal combustion;
- ending distillation, carbonization residue, purity, ash, content of aromatic hydrocarbons and methyl esters of fatty acids to avoid sediments in fuel system, filters, injections and combustion chamber;
- oxidation stability, sulphur content, water, eventually quality of added methyl ester of fatty acids preventing corrosion of flue (Yuksel & Yuksel, 2004; Rakopoulos et al., 2008; Schlaub & Vetter, 2008; Karabektas & Hosoz, 2009; Singh et al., 2015).

MATERIALS AND METHODS

It was expected that gasoline may appear in diesel fuel during transport and storage about few tenth or units of percents. Therefore, gasoline concentration in diesel fuel samples with 1%, 2%, 3% and 5% (vol.) were prepared to find impacts on fuel system. Sample of diesel without methyl esters of fatty acids was compliant with EN 590 for second class conditions for extremely cold arctic climate. Content of polycyclic aromatic carbohydrates was 7% wt. Gasoline complying with EN 228 for winter period of first class containing 32.21% (vol.) of aromatic carbohydrates, 10.31% (vol.) olefins and 0.57% (vol.) of benzene was used to simulate contamination of diesel in samples. Water content of samples was 51.00 mg kg^{-1} and oxidation stability has exceeded 360.0 minutes.

Three groups of sampled diesel with immision of gasoline in repeated experiments were performed according to quality norm (Table 1).

Table 1. Limiting values of EN590 standard

Limiting values	
Distillation 10%	min 180 °C
Distillation 90%	max 340 °C
Flash point	min 55 °C
Kinematic viscosity at 40 °C	min 1.5 mm^2 s^{-1}
Density at 15°C	800–845 kg m^{-3}
Cetane index	min 46
Lubricity	max 460 μm
Cloud point	max -22 °C
CFPP	max -32 °C

Laboratory tests were performed according to the requirements of standard EN 590:
Distillation test according to EN ISO 3405;
Cetane index according to EN ISO 4264;
Flash point according to EN ISO 2719;
Density at 15 °C according to EN ISO 3675;
Kinematic viscosity at 40 °C according to EN ISO 3104;
Cloud point according to EN 23015;

Cold Filter Plugging Point (CFPP) according to EN 116;

Lubricity HFRR (corrected wear surface diameter WSD 1.4 mm) at 60 °C according to EN ISO 12156-1.

Above listed standards have allowed us to indicate changes only due to tested diesel fuel contamination of each sample. Each experiment was repeated three times, arithmetic averages was calculated from measured values and used for presentation of final results according to general conditions for reproducibility and conformance for experimentation. The High Frequency Reciprocating Rig (HFRR) was used to measure wear area in environment of sampled fuels.

RESULTS AND DISCUSSION

Three groups of experiments were performed to distinguish different points of view on contaminated diesel fuels by gasoline according to conditions set in methodology.

The first group of diesel fuel with added gasoline has strongly influenced flash point. Compliance with EN 590 was lost with gasoline above 0.5% vol. in diesel (Fig. 1).

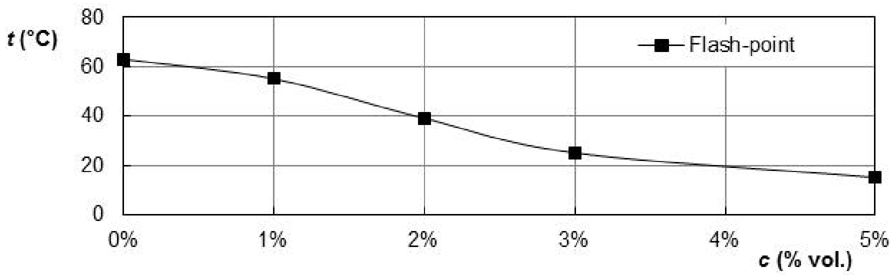

Figure 1. Flash point affected by gasoline content.

Distilled volume in % (vol.) on horizontal and temperature in °C on vertical axis are shown. Defined and below limit flash point values in interval 0.5 and 0.75% (vol.) of diesel contaminated by gasoline depend also on how full the tank is and how much time is needed for evaporation of volatile hydrocarbon vapours.

Second group pushing quality parameters out of reach of experimental methods but, still under compliance with EN 590, are:

1. Distillation experiment according to EN 590 is distilled volume up to 180 °C temperature is reached.

2. Kinematic viscosity and density below reproducible results (Fig. 2) in comparison with default values of pure diesel with added 1.5–2% (vol.) of gasoline. But, 5% (vol.) of gasoline in diesel keeps the fuel performance above minimum fuel viscosity and density according to EN 590.

3. Worsened lubricity was found from 3% (vol.) of gasoline immission upwards (Fig. 6), but found values are still reproducible.

Volume in % (vol.) of gasoline on horizontal, density by 15 °C on primary vertical and kinematic viscosity by 40 °C in $mm^2 s^{-1}$ on secondary vertical axis are shown. Low concentration of gasoline in diesel decreases density seriously.

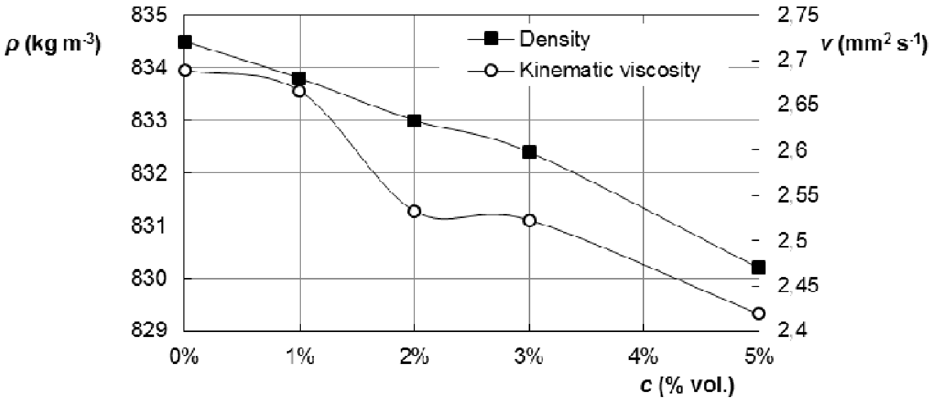

Figure 2. Effect of gasoline on diesel fuel density and kinematic viscosity.

But, high 5% (vol.) concentration of gasoline in diesel keeps density still above default value min. 820 kg m^{-3} at 15 °C. Decreased density corresponds to difference of densities between diesel and gasoline. Therefore, the higher gasoline concentration the lower performance of diesel engine occurs due to volume based fuel injection into diesel engine. Volume of injected fuel increases with specific weight. Engine performance decreases from 0.4% to 1.6% if density (specific weight) is decreased below 10 kg m^{-3}.

Values of kinematic viscosity under 40 °C (Fig. 2) develop differently than values of density. Bigger bias of viscosity curve can be explained by both higher gasoline content and carbohydrate chain. Tested maximal content 5% (vol.) of gasoline didn't moved viscosity out of default values in range from 2.0 to 4.5 $mm^2 s^{-1}$ according to EN 590. Therefore, tested maximal gasoline content cannot harm moving parts of fuel system due to low viscosity causing lost thin lubricity layer. Similarly, neither pumped nor filtered fuel volume or fuel dispersion are threatened.

Horizontal axis shows distilled fuel % (vol.) and main vertical axis temperature in °C.

Distillation curve (Figs 3 and 4) allows fuel quality assessment. 1% (vol.) of gasoline decreases temperature of diesel distillation seriously in its beginning. 2.5% (vol.) of gasoline content has moved 10 and 20% values of diesel distillation point out of reproducible range. And, 5% (vol.) of gasoline has moved 30 and 40% values of diesel distillation point out of reproducible range. Absence of values of distillation points in EN 590 allows to emphasize that maximum 5% of gasoline added to diesel keeps distillation still in compliance with EN 590 (Figs 3 and 4).

Horizontal axis x shows changes of distilled fuel volume in % (vol.) and main vertical axis is showing temperature in °C.

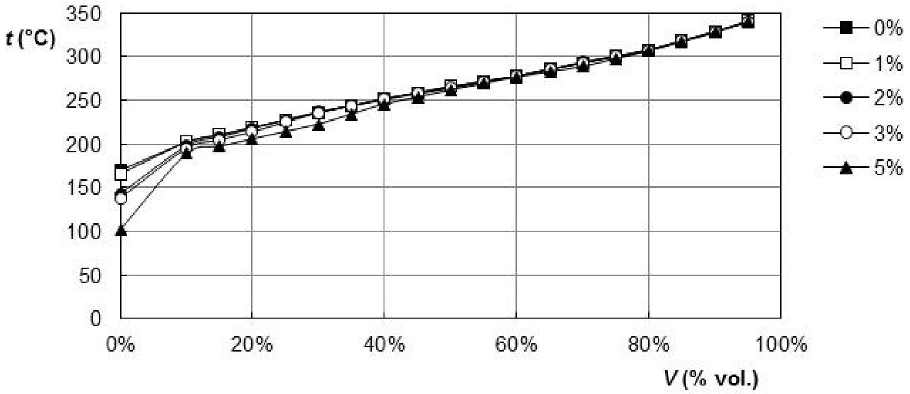

Figure 3. Distillation curve of diesel containing gasoline.

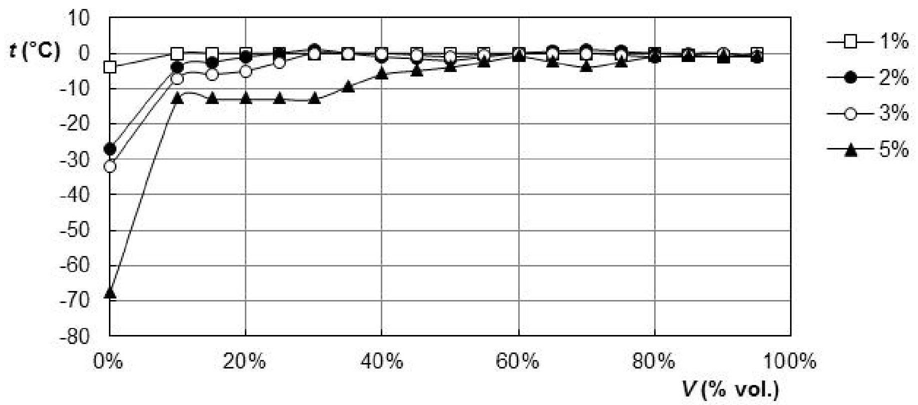

Figure 4. Change in distillation temperature of diesel blends with gasoline.

Gasoline content in % (vol.) at horizontal axis x and temperature in °C at vertical axis y (Fig. 5). Added gasoline is decreasing CFPP point down to gasoline crystallization. This property may explain why some drivers are adding gasoline to diesel during winter period to improve low temperature properties of diesel. If Arctic diesel was used, significant difference of temperatures on measured parameters was not shown.

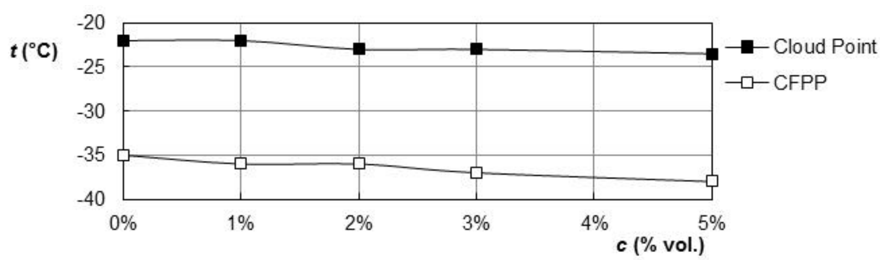

Figure 5. Cloud point and cold filter plugging point of diesel affected by gasoline.

Gasoline content in % (vol.) at horizontal axis x, cetane index on primary vertical and lubricity (HFRR) in $mm^2.s^{-1}$ on secondary vertical axis are shown.

The third group follows parameters expectedly not affecting or without found impact of gasoline added on diesel quality. Predominantly, these parameters are as follows:

1. Cetane index (Fig. 6);
2. Could point (Fig. 5);
3. CFPP Cold filter plugging point (Fig. 5);
4. Sulphuric content (if gasoline has less sulphur than diesel);
5. Content of PAH (polyaromatic hydrocarbons);
6. Content of methyl esters of fatty acids (not in gasoline).

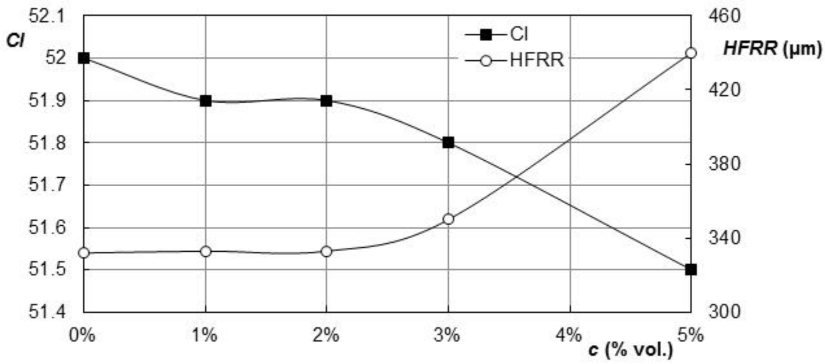

Figure 6. Cetane index and lubricity of diesel affected by gasoline added.

Gasoline added to diesel is decreasing cetane index (Fig. 6). The decrease depends on initial value of pure diesel. Fuels with high octane number as gasoline, has low cetane index and vice versa. Serious problem may occur if frost resistance of diesel is increased (HFRR). 5% (vol.) of gasoline added in diesel has approached closely to limiting value of EN 590. Found loss of lubricity of diesel due to presence of gasoline may cause serious problems, which are associated with loss of operability of machine. Diesel engine performance is affected by following parameters: distillation, density, viscosity, carbon sediment, cetane number or index, corrosiveness of fuel and its flue, purity and also filterability and temperature of emergence of paraffin in winter period. Flash point is informing about evaporation of diesel fuel and is related to initial boiling point but, is not related to combustion in combustion chamber of diesel engine. Therefore, default value of diesel flash point is set and should be understood as fire protection for safety of garages (III. flammable class is decreased to I).

CONCLUSIONS

Three serious consequences of contamination by added gasoline to diesel fuel was found above 2% in performed experiments affecting kinematic viscosity, density and distillation. Firstly, any contamination by gasoline is affecting safety of manipulation and storage of diesel fuel. The flash point with 5% of gasoline in diesel fuel has reached first class of flammability. Secondly, distillation curve, kinematic viscosity, density and lubricity were influenced by gasoline in diesel fuel but still in accordance with standard for diesel fuel EN 590. Thirdly, no impact on values of cloud point, CFPP with unimportant change of cetane index were found.

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REREFRENCES

Arapatsakos, Ch. 2009. Application of diesel - ethanol mixtures in tractor engine, *International journal of energy and environment* **3**, 77–84.

Aydogan, H. 2015. Prediction of diesel engine performance, emissions and cylinder pressure obtained using Bioethanol-biodiesel-diesel fuel blends through an artificial neural network, *Journal of Energy in Southern Africa* **26**(2), 74–84.

Catillo-Hernández, P., Mendoza-Domínguez, A. & Caballero-Mata, P. 2012. Analysis of Physicochemical Properties of Mexican Gasoline and Diesel Reformulated with Ethanol, *Ingeniería, investigación y tecnología* **13**(3), 293–306.

EN 228. 2009. Automotive fuels – Unleaded petrol – Requirements and test methods, ČSNI, 16 pp. (in Czech).

EN 590. 2013. Automotive fuels – Diesel – Requirements and test methods, ČSNI, 16 pp. (in Czech).

Hönig, V., Orsák, M., Pexa, M. & Linhart, Z. 2015. The distillation characteristics of automotive gasoline containing biobutanol, bioethanol and the influence of the oxygenates. *Agronomy Research* **13**(2), 558–567.

Kamimura, A. & Sauer, I.L. 2008. The effect of flex fuel vehicles in the Brazilian light road transportation. *Energy Pol.* **36**(2), 1574–1576.

Karabektas, M. & Hosoz, M. 2009. Performance and emission characteristics of a diesel engine using isobutanol-diesel fuel blends, *Renewable Energy* **34**(6), 1554–1559.

Mužíková, Z., Pospíšil, M. & Šebor, G. 2010. The use of bioethanol as a fuel in the form of E85 fuel. *Chemické listy* **104**(7), 678–683 (in Czech).

Pirs, V. & Gailis, M. 2013. Research in use of fuel conversion adapters in automobiles running on bioethanol and gasoline mixtures, *Agronomy Research* **11**(1), 205–214.

Pospíšil, M., Mužíková, M & Šebor, G. 2007. Volality and distillation properties of ethanol-petrol blends. *Goriva i maziva,* **46**(4), 335–353.

Rakopoulos, D.C., Rakopoulos, C.D., Karakas, E.C. & Giakoumis, E.G. 2008. Effects of ethanol–diesel fuel blends on the performance and exhaust emissions of heavy duty DI diesel engine, *Energy Conversion and Management* **49**, 3155–3162.

Schlaub, G. & Vetter, A. 2008. Biofuels for Automobiles – An Overview, *Chemical Engineering and Technology* **31**, 721–729.

Singh, S.B., Dhar, A. & Agarwal, A.K. 2015. Technical feasibility study of butanol-gasoline blends for powering medium-duty transportation spark ignition engine, *Renewable Energy* **76**, 706–716.

Yuksel, F. & Yuksel, B. 2004. The use of ethanol-gasoline mixture as a fuel in an SI engine. Renewable Energy **29**, 1181–1191.

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Influence of lammas shoots on height of young Scots pines in Latvia

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Abstract. Scots pine is a commercially important tree species in northern Europe. Climate changes in combination with genetics cause differences in the tree growth rhythm, including the formation of lammas shoots. The aim of the study was to assess the relation between the occurrence of lammas shoots and the height of young Scots pines and its implications in tree breeding. Tree height was repeatedly measured, and the presence of lammas shoots was assessed at the end of the 4th through 8th growing seasons in two open-pollinated progeny trials (Daugmale and Norupe, both including the same 61 families) in the central part of Latvia. The proportion of trees with lammas shoots (max. 23%) decreased over the observation years. In both trials, at the age of 7 years, trees that had formed lammas shoot during at least one of the observed years were significantly ($P < 0.001$) higher than trees with no lammas shoots: 226 ± 3.5 cm vs 213 ± 3.3 cm in Norupe and 146 ± 3.9 cm vs 121 ± 1.9 cm in Daugmale, respectively. When only dominant trees (1,000 ha^{-1}) were considered, the height superiority of trees with lammas shoots remained in Daugmale (trial with highest proportion of trees with lammas shoots), but not in Norupe. The earliest formed lammas shoots (assessed in the 4th growing season) had the strongest effect on the tree height. A correlation between the mean height and the proportion of trees with lammas shoots in the particular family was not found ($P > 0.05$).

Key words: second flushing, dominant trees, height superiority, open-pollinated family.

INTRODUCTION

Scots pine is a commercially important tree species in northern European countries that occupies > 30 million ha of forest land, with a total growing stock of ca. 3,300 million m^3 (41% of the wood resources in the region) (Rytter et al., 2013). It is also a dominant tree species in forest land in Latvia (Lazdins et al., 2010; Kaleja et al., 2013).

Due to the economic importance of the species, substantial amount of dendrochronological analysis and modelling has been conducted to understand the possible effects of climatic changes on growth. These studies have shown a significant effect of meteorological conditions on radial and height increments, and shifts in the periods of year with significant influence of particular meteorological parameters on growth, as the climate is changing (Jansons et al., 2013a; Jansons et al., 2013b; Henttonen et al., 2014; Jansons et al., 2015). Moreover, climatic changes are expected to affect the ratio of radial and height growth due to increased inter-annual variation and time-lag of correlations between these two increments (Salminen et al., 2009). This ratio, presumably, might also be affected by the occurrence of lammas growth – the second flushing in the end of the vegetation period.

Increasing occurrence of lammas shoots has been reported over the last years in Norway and has been attributed to a possible effect of changing climatic conditions (Søgaard et al., 2011). Links between meteorological conditions and occurrence of lammas shoots has also been suggested by other studies of Norway spruce (Neimane at al., 2015), Scots pine (Ehrenberg, 1963), and other pine species (Kushida, 2005) as well as fir species (Hallgren & Helms, 1988).

Modelling efforts (using both dendrochronology data and physiological parameters, i.e., process-based models) have been made to predict the effect of climatic changes on the yield of forest stands in different conditions (Sabaté et al., 2002). In boreal forests, increased productivity of the most common tree species, including Scots pine, is expected (Briceño-Elizondo et al., 2006).

Tree growth as well as its predicted changes is affected by genetics (Jansons, 2005; Jansons et al., 2006; Rieksts-Riekstins et al., 2014). Genetics are also the cause of differences in tree growth rhythm, formation of the increments (Rone, 1975; Ununger et al., 1988; Søgaard et al., 2011) and, in combination with favourable meteorological conditions, also of the formation of lammas shoots. Genetic differences in formation of lammas shoots have been well studied for spruce at the provenance level (Danusevičius & Persson, 1998) as well as the family level (Skrøppa & Steffenrem, 2015); however, fewer studies have addressed it for the Scots pine. The aim of our study was to assess the relation between the occurrence of lammas shoots and the height of young Scots pines in Latvia and its implications in tree breeding.

MATERIALS AND METHODS

The study was carried out in two open-pollinated progeny trials, both including the same 61 families of Scots pine plus trees selected across Latvia. The trials are located in the central part of Latvia (56º50´N, 24º38´E – Norupe and 56º47´N, 24º30´E – Daugmale), both established using one-year-old containerised seedlings at the spacing of 1.5 × 2 m in the *Vacciniosa* forest type (Bušs, 1976), site index $H_{100} = 26$ and $H_{100} = 24$, respectively. Inventoried trees were planted in block plots (seven trees in four rows in Norupe and five trees in two rows in Daugmale) randomly distributed in three (Norupe) or four (Daugmale) replications. According to the data of the Latvian Environment, Geology, and Meteorology Centre, the mean annual temperature in the region is +7.7°C, and the mean annual precipitation is 690 mm. Both sites had similar meteorological conditions, as suggested by their location in the same climatic research unit data point (Jones et al., 1999) as well as measurements of temperature carried out directly in both sites for short periods of time during May-September, including in years of lammas shoot inventories.

Tree height was measured for 3,295 trees at the end of the 4th through 7th growing seasons. For all these trees, the presence of lammas shoots was assessed at the end of the 4th through 8th growing seasons, excluding the 7th season in Norupe. The lammas shoot was defined as the second flushing of the apical or lateral bud (at the base of the terminal bud) of the top shoot, reaching the length of at least 1 cm and producing a terminal cluster. After the 10th growing season, the presence of the additional whorls formed as a result of lammas shoots at the particular season was assessed. No frost damage of the shoots was observed in any of the seasons. The relationship between the tree height and the presence of lammas shoots was assessed for dominant trees (corresponding to 1,000 trees ha^{-1}) of each block plot.

The *t*-test was used to assess the differences of the tree height in both trials (in particular age) and between the height of trees with and without lammas shoots in each trial. The chi-squared (χ^2) test was used to assess the differences in the distribution of the proportion of trees with lammas shoots among the tree height classes and to assess whether trees with lammas shoots in the current season form lammas shoots in the next season more frequently than trees without lammas shoots in the current season. The Pearson correlation test was used to assess the relation of the proportion of trees with lammas shoots in the families between the years and between the trials and to assess the relation between mean tree height of family and the proportion of trees with lammas shoots.

RESULTS AND DISCUSSION

In both trials, the proportion of trees with lammas shoots was decreasing during the observation period. From the age of 4 to 8 years, it decreased from 11% to 4% in Daugmale and from 23% to 1% in Norupe (Fig. 1). These results are consistent with previous studies that have found a decreasing tendency to form lammas shoots for pine and spruce with increasing tree age (Ehrenberg, 1963; Rone, 1985). For example, Ehrenberg (1963) noted that the average percentage of proleptic pines decreased from the age of 7 to the age of 11 years. Aldén (1971) explained this tendency by the fact that small trees (plants) have limited storage capacity of nutrients; therefore, the surplus of carbohydrates is directly used to form lammas shoots, in contrast to larger trees, which can store the excess nutrients.

The trend of a decreasing proportion of trees with lammas shoots with an increase in tree age was broken in the last observation period in the Daugmale trial, where they were in higher frequency than in the two previous seasons. Presumably, it might be due to meteorological conditions. There were no notable differences in monthly mean air temperature from April till September during the observation period; however, a sharp temperature increase at the end of July in the 8th growing season in comparison to a slight decrease or no changes at the same period in previous years was observed. In this season, minor changes in precipitation in the first week of August in comparison to the last week of July were also observed (in the closest meteorological station).

It suggests that the relative changes, not necessarily the mean values of any of the meteorological parameters (temperature or precipitation) at the right period of the annual cycle of tree growth could trigger the formation of lammas shoots. It is in line with findings by Carvell (1956) in a 6-year-old *Pinus resinosa* plantation, noting that lammas shoots were much more abundant after a late rainy period in the dry summer than in ‘normal’ summers (three previous observation years). The trend of decreasing frequency of trees with lammas shoots with increasing age was not disrupted in Norupe, presumably due to higher capacity to store excess nutrients (larger trees) or some unfavourable factors (i.e., more intense competition between the trees due to their size or low precipitation, which is impossible to determine exactly due to lack of measuring devices inside the trials).

West & Ledig (1964) have shown a significant effect of both the year of assessment and the local conditions on the proportion of trees with lammas shoots. The latter is supported also by other studies of pine (Ehrenberg, 1963; Aldén, 1971) and spruce (Rone, 1985; Søgaard et al., 2011; Neimane et al., 2016) that emphasise the increased formation of lammas shoots on nutrient rich soils. Rikala (1992) found positive correlation between the occurrence of lammas shoots and the nitrogen concentrations of both soil and needles. Consequently, in two seasons when the highest proportion of trees with lammas shoots was noted (i.e., the 4th and 5th seasons), it was twice as high in Norupe (with a slightly higher soil fertility) than in Daugmale.

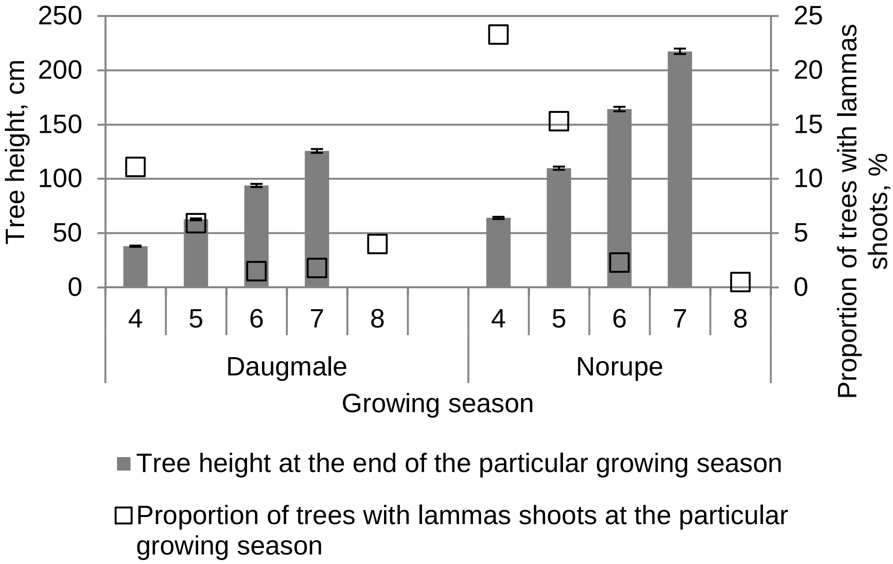

Figure 1. Tree height and proportion of trees with lammas shoots in Daugmale and Norupe.

The appearance of the lammas shoots was significantly affected by genetics (family). The highest proportion of trees per family with current year lammas shoots reached 41% and 48% in Daugmale and Norupe, respectively. The highest proportion of trees per family with lammas shoots at least in one growing season reached 65% in Daugmale and 68% in Norupe. There were only two families with no trees with lammas shoots in any of the years during the observation period in Daugmale and none in Norupe.

These results are consistent with a number of studies that acknowledged the genetic control of the tree growth rhythm and the formation of lammas shoots for pine and spruce, including the differences of frequency of the lammas shoot formation between provenances and between families (Ehrenberg, 1963; West & Ledig, 1964; Hoffmann, 1965; Rone, 1975; Danusevičius & Persson, 1998; Søgaard et al., 2011; Skrøppa & Steffenrem, 2015). Rudolph (1964) noted that the occurrence of lammas shoots between seed sources showed a clinal or continuous pattern and suggested that the trait could be controlled by multiple genes. Similar clinal trends in proportion of trees with lammas shoots ranging from 5% (northernmost origins) to more than 40% (southernmost origins) were found also in the analysis of 8-year-old *Picea sitchensis* trials in Norway (Magnesen, 1986).

Interaction between the genetics (provenance) and environment (site) on the formation of lammas shoots had been found in studies of *Abies* species at the age of 3 years (Hansen et al., 2004). In our study the proportion of trees with lammas shoots in the family between trials (Table 1) correlated at a similar level as tree height: at the end of the 4th growing season $r = 0.28$ ($P < 0.05$), 5th growing season $r = 0.46$ ($P < 0.001$), 6th growing season $r = 0.15$ ($P > 0.05$), and 8th growing season $r = 0.27$ ($P < 0.05$). The strongest relationship ($r = 0.56$; $P < 0.001$) between trials was observed between the proportion of trees in the family with lammas shoots in at least one growing season.

Between observation years, the proportion of trees with lammas shoots in the families correlated significantly, reaching up to $r = 0.54$ and $r = 0.43$ (both $P < 0.001$) in Daugmale and Norupe, respectively, between the 4th and 5th seasons. Similarly, strong correlation between the proportion of trees with lammas shoots in the family has been observed in the spruce progeny trial at the age of 5 years in Norway and 21 years in Finland (Søgaard et al., 2011). Also, the family mean height correlated significantly between the years and was $r > 0.89$ and $r > 0.78$ (both $P < 0.001$) in Daugmale and Norupe, respectively.

Table 1. Pearson's correlation coefficients between the proportion of trees with lammas shoots at the age of 4 to 6 years, based on the family means

Trial and Season of Lammas Shoots Assessment	Daugmale-4	Daugmale-5	Daugmale-6	Norupe-4	Norupe-5
Daugmale-5	0.54^{***}				
Daugmale-6	0.29^{*}	0.34^{**}			
Norupe-4	0.28^{*}	0.29^{*}	0.14		
Norupe-5	0.40^{***}	0.46^{***}	0.32^{**}	0.43^{***}	
Norupe-6	0.39^{**}	0.15	0.15	0.08	0.34^{**}

* $P < 0.05$; ** $P < 0.01$; ** $P < 0.001$.

During the study years, trees in Norupe were significantly ($P < 0.001$) higher than in Daugmale, exceeding the latter by 75% (Fig. 1). In both trials, at the end of the 7th growing season, trees that had formed lammas shoots during at least one of the assessment seasons were significantly ($P < 0.001$) higher than trees with no lammas shoots: 226 ± 3.5 cm vs 213 ± 3.3 cm in Norupe and 146 ± 3.9 cm vs 121 ± 1.9 cm in Daugmale, respectively (Fig. 2). Similar trends – more frequent lammas shoots for the highest trees within the provenance – had also been observed in studies of Scots pines in Sweden (Ehrenberg, 1963) and in analyses of spruce (Rone, 1985; Neimane et al., 2015).

For example, Neimane et al. (2015) found that trees with lammas shoots (at least in one of the three assessment seasons) were 14% to 20% higher than trees without them at the age of 13 years. Hoffmann (1965) reported even higher differences in spruce trials at the same age, at 33%; moreover, he found a tendency of the differences to increase with tree age. Analysis of other tree species (e.g., *Pinus banksiana* and *Pinus resinosa*) also linked the presence of lammas shoots with tree vigour and superior height as well and found that lammas shoots in the current year do not have a negative effect on the length of height increment in the next year (Carvell, 1956; Rudolph, 1964).

When only dominant trees (corresponding to a density of 1,000 trees ha^{-1}) were considered, the height superiority of trees with lammas shoots over the trees without them remained (166 ± 4.6 cm vs 149 ± 2.8 cm, respectively) in Daugmale; however, it was less pronounced. The superiority of all trees with lammas shoots was 20%, while the superiority of such dominant trees was 11%. In Norupe, the height superiority of all trees was 6%, but the dominant trees showed the opposite (non-significant, $P > 0.05$) trend; the height of the dominant trees with and without lammas shoots was 248 ± 3.6 cm and 251 ± 3.0 cm, respectively.

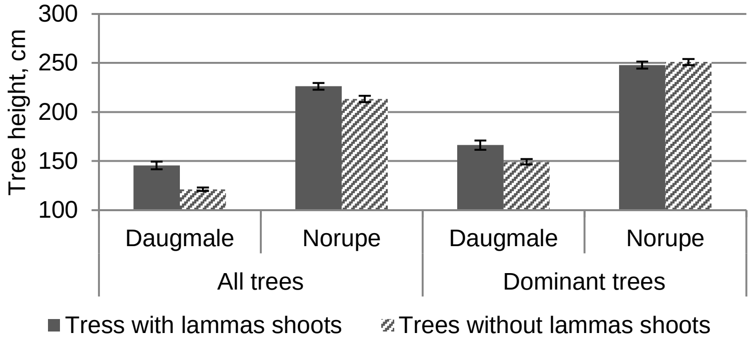

Figure 2. Height of the 7-year-old trees with and without lammas shoots at the end of at least one assessment season.

Other types of analysis showed similar results. In Daugmale, the proportion of trees with lammas shoots from all trees ($P < 0.001$) and dominant trees ($P < 0.001$; Fig. 3) differed significantly among the height classes, but in Norupe, the proportion of trees with lammas shoots was largest among the highest trees only when all trees were included in the analysis ($P < 0.001$), but not when dominant trees were evaluated.

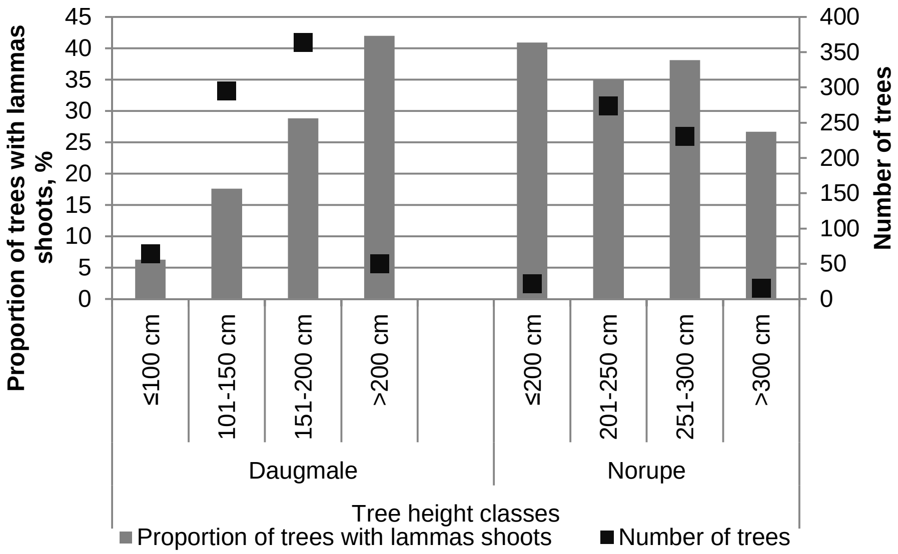

Figure 3. Proportion of dominant trees with lammas shoots at the end of at least one assessment season among the tree height classes.

The link between tree height and the presence of lammas shoots is rather straightforward for spruce since, for this tree species, lammas shoots are most often formed by the apical bud, directly increasing the height increment (Neimane et al., 2015). However, for Scots pine, for 22% of trees, lammas shoots were formed both at the terminal and lateral buds and only 5% were solely by terminal buds (Rikala, 1992), indicating that some indirect link between growth and presence of lammas shoots might exist, and presumably, better growth is cause for formation of lammas shoots not *vice versa*. Better-growing trees produce excess nutrients at an early age, which are used to form lammas shoots (Aldén, 1971) and since no damage of the lammas shoots occurs (according to our field observations), this further boosts the growth superiority of those trees, forming a self-reinforcing loop.

This hypothesis is supported by the fact that, in both trials, the earliest formed, i.e., assessed in the 4th growing season, lammas shoots had the strongest effect on the tree height. In Daugmale, at the end of the 4th growing season, the height of trees with lammas shoots significantly ($P < 0.001$) exceeded that of trees without lammas shoots by 31% (Fig. 4). After the 5th growing season, trees that had formed lammas shoots in the previous but not in the current year (4+5-) exceeded the height of trees without lammas shoots by 33% ($P < 0.001$), and trees that had lammas shoots in the both current and previous year (4+5+) exceeded by 24% ($P < 0.001$). However, trees that had lammas shoots only in the current year (4-5+) had similar (difference 8%, $P = 0.053$) height to trees without lammas shoots. In Norupe, at the age of 4 years, the height of trees with lammas shoots exceeded ($P < 0.001$) the height of trees without lammas shoots by 10%, and the trend indicated by other values (4+5- = 7%, $P < 0.001$, 4+5+ =6%, $P < 0.05$ and 4-5+ =3%, $P > 0.05$) was similar to that observed in Daugmale, even so the differences were smaller (Fig. 4). The effect of the early (formed in the 4th growing season) presence of lammas shoots on the tree height remained significant during the study years. For trees with lammas shoots during this season, height at the age of 7 years exceeded that of trees without lammas shoots by 30.0% and 8.4% in Daugmale and Norupe, respectively.

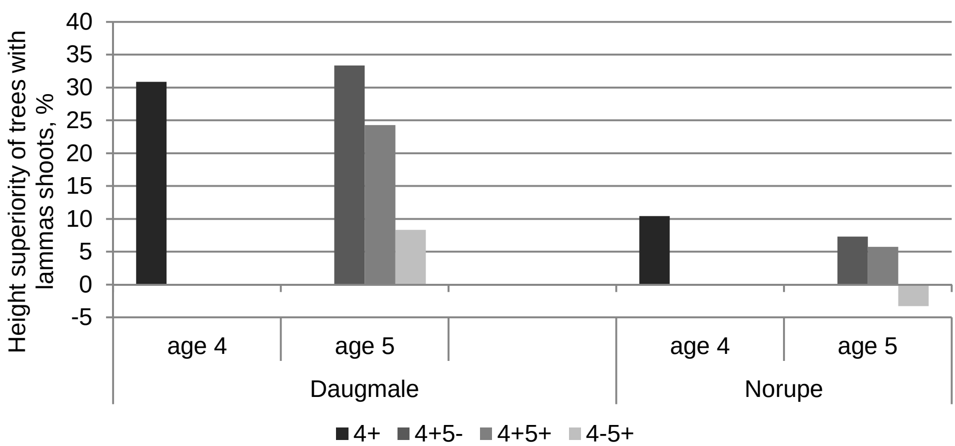

Figure 4. Height superiority at the age of 4 and 5 years for trees with lammas shoots: at the end of the 4th season (4+); only at the end of 4th, but not at the 5th season; in both at the end of the 4th and 5th seasons (4+5+); only at the end of the 5th, but not in the 4th season. Height of trees without lammas shoots is represented as 0.

The influence of lammas shoots is reinforced by their repeated appearance; statistically, trees with lammas shoots more frequently formed lammas shoots also in the following growing season. For instance, in Norupe, 31% of trees that had lammas shoots in the 4th growing season also formed them in the 5th growing season, but from trees without lammas shoots in the 4th growing season only 11% formed them. In Daugmale, the corresponding values were 23% and 4%. Such a trend has been noted by Ehrenberg (1963), who observed lammas shoots on pines in a progeny trial at the age of 8 to 10 years; the proportion of trees with lammas shoots varied between 0.5 to 43.7%, and within the provenance with the most abundant lammas shoots, 4.3% of trees had a second flushing in the four following years. Likewise, West & Ledig (1964) and Rikala (1992) have noted this trend for young (1- to 3-year-old) pines.

The mean height of trees with lammas shoots at any of the assessment seasons from a particular family exceeded the mean height of trees without them from the same family on average by 26 ± 5.9 cm (for the dominant trees 19 ± 6.6 cm) in Daugmale and 12 ± 6.2 cm (for the dominant trees 0.8 ± 5.4 cm) in Norupe. At the family mean level, correlation between height and the proportion of trees with lammas shoots was not found ($P > 0.05$) in any of the trials, contrary to expectations from the positive relation between the tree height and the presence of lammas shoots at the individual tree level discussed above (Figs 2, 3). This is in disagreement with studies of spruce (Hoffmann, 1965; Rone, 1985; Danusevičius & Persson, 1998; Neimane et al., 2015), where a positive relation between the tree height and the presence of lammas shoots has been found at the provenance and family mean levels. However, this is in agreement with the earlier studies of pine, where no significant relationship between the presence of lammas shoots and height growth at the provenance mean level was found (Ehrenberg, 1963).

Association between onset and cessation of pre-determined growth and formation of lammas shoots has been well established for spruce (Danusevičius & Persson, 1998; Neimane et al., 2015; Skrøppa & Steffenrem, 2015). For example, Skrøppa & Steffenrem (2015) found that families with an early growth start had the highest frequency of trees with lammas shoots (r = -0.69...-0.78; $P < 0.01$), and a similar but weaker link with growth cessation was also noted (r = -0.33...-0.55; $P > 0.01$).

In contrast to this, for Scots pines, mostly indirect evidence links early cessation with an increasing chance of lammas growth (Lanner, 1976). Also, in our study, bud-set was not assessed; therefore, the link between those traits and formation of lammas shoots could not be analysed. Notable differences in growth rhythm or too long growth of lammas shoots in the autumn would link the presence of lammas shoots to the increased frequency of frost damage and consequently stem defects. However, no frost damage was observed in our study. Stem defects observed in our trials included additional branch whorls of the main stem caused by lammas growth of apical bud, but its frequency was low. At the age of 10 years, it was noted only for 4.2% (in Norupe) and 5.0% (in Daugmale) of trees with lammas shoots in the particular year.

It corresponds well to a study by Rikala (1992) noting that only 5% of pines had lammas shoots solely from the terminal bud (leading to formation of additional branch whorls). Lammas shoots might result in formation of spike knots (Carvell, 1956; Rudolph, 1964; West & Rogers, 1965; Ehrenberg, 1970; Søgaard et al., 2011), notably deteriorating the stem quality (Ståhl et al., 1990). However, a longer time-lag is important to evaluate which shoot will develop as a spike knot and which will level out and become indistinguishable from an ordinary branch; therefore, this matter needs to be addressed in further, separate studies.

CONCLUSIONS

A strong and positive link between the occurrence of lammas shoots and tree height was observed. Moreover, the earliest formed lammas shoots have the strongest effect. The results suggest that the selection of trees with lammas shoots might result in selection of the highest trees within the family. However, it is not possible to improve the juvenile height growth by the selection of families with a high proportion of trees with lammas shoots.

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REFERENCES

Aldén, T. 1971. Influence of CO_2, moisture and nutrients on the formation of Lammas growth and prolepsis in seedlings of *Pinus silvestris* L. *Studia Forestalia Suecica* **93**, 1–21.

Briceño-Elizondo, E., Garcia-Gonzalo, J., Peltola, H., Matala, J. & Kellomäki, S. 2006. Sensitivity of growth of Scots pine, Norway spruce and silver birch to climate change and forest management in boreal conditions. *Forest Ecology and Management* **232**, 152–167.

Bušs, K. 1976. *Forest classification in Latvian SSR.* Silava, Riga, 24 pp. (in Latvian).

Carvell, K.L. 1956. Summer shoots cause permanent damage to red pine. *Journal of Forestry* **54,** p. 271.

Danusevičius, D. & Persson, B. 1998. Phenology of natural Swedish populations of Picea abies as compared with introduced seed sources. *Forest Genetics* **5**, 211–220.

Ehrenberg, C.E. 1963. Genetic variation in progeny tests of Scots pine (*Pinus silvestris* L.). *Studia Forestalia Suecica* **10**, 1–135.

Ehrenberg, C. 1970. Breeding for stem quality. *Unasylva* **24**, 23–31.

Hallgren, S.W. & Helms, J.A. 1988. Control of height growth components in seedlings of California red and white fir by seed source and water stress. *Canadian Journal of Forest Research* **18**, 521–529.

Hansen, O.K., Nielsen, U.B., Edvardsen, Ø.M., Skúlason, B. & Skage, J. 2004. Nordic provenance trials with *Abies lasiocarpa* and *Abies lasiocarpa* var. *arizonica*: three-year results. *Scandinavian Journal of Forest Research* **19**, 112–126.

Henttonen, H.M., Mäkinen, H., Heiskanen, J., Peltoniemi, M., Laurén, A. & Hordo, M. 2014. Response of radial increment variation of Scots pine to temperature, precipitation and soil water content along a latitudinal gradient across Finland and Estonia. *Agricultural and Forest Meteorology* **198-199**, 294–308.

Hoffmann, K. 1965. Bedeutung des Austriebes für den Fichtenbau im Pleistozän der DDR. *Die Sozialistische Forstwirtschaft* **7**, 204–207.

Jansons, Ā. 2005. Distinguish between the effect of seed material and forest type on Scots pine stand productivity. In Gaile, Z. (ed.): *Proceedings of the international scientific conference Research for Rural Development*. LLU, Jelgava, Latvia, pp. 227–233.

Jansons, Ā., Baumanis, I., Dreimanis, A. & Gailis, A. 2006. Variability and genetic determination of Scots pine quantitative traits at the age of 32 years. In Gaile, Z. (ed.):

Proceedings of the international scientific conference Research for Rural Development. LLU, Jelgava, Latvia, pp. 289–295.
Jansons, A., Matisons, R., Baumanis, I. & Purina, L. 2013a. Effect of climatic factors on height increment of Scots pine in experimental plantation in Kalsnava, Latvia. *Forest Ecology and Management* **306**, 185–191.
Jansons, A., Matisons, R., Libiete-Zālīte, Z., Baders, E. & Rieksts-Riekstiņš, J. 2013b. Relationships of height growth of Lodgepole pine (*Pinus contorta* var. latifolia) and Scots pine (*Pinus sylvestris*) with climatic factors in Zvirgzde, Latvia. *Baltic Forestry* **19**, 236–244.
Jansons, Ā., Matisons, R., Zadiņa, M., Sisenis, L. & Jansons, J. 2015. The effect of climatic factors on height increment of Scots pine in sites differing by continentality in Latvia. *Silva Fennica* **49**(3), id 1262, 14 p.
Jones, P.D., New, M., Parker, D.E., Martin, S. & Rigor, I.G. 1999. Surface air temperature and its variations over the last 150 years. *Reviews of Geophysics* **37**, 173–199.
Kaleja, S., Grinfelds, A. & Lazdins, A. 2013. Economic value of wood chips prepared from young stand tending. In Gaile, Z. (ed): *Proceedings of the 19th international scientific conference Research for Rural Development*. LLU, Jelgava, Latvia, pp. 66–72.
Kushida, T. 2005. Effect of high summer temperatures on lammas shoot elongation and flowering in Japanese red pine. *Phyton* **45**, 215–221.
Lanner, R.M. 1976. Patterns of shoot development in *Pinus* and their relationship to growth potential. In Cannell, M.G.R. & Last, F.T. (eds.): *Tree Physiology and Yield Improvement*. Academic Press, London, UK. pp. 223–243.
Lazdins, A., Lazdina, D. & Liepa, I. 2010. Characterization of naturally afforested farmlands in Latvia. In Gaile, Z. (ed): *Proceedings of the 16th international scientific conference Research for Rural Development*. LLU, Jelgava, Latvia, pp. 176–182.
Magnesen, S. 1986. *The international Sitka spruce-provenance trial in western Norway*. Report from the Norwegian Forest Research Institute, 1/86, 12 pp. (in Norwegian).
Neimane, U., Zadina, M., Sisenis, L., Dzerina, B. & Pobiarzens, A. 2015. Influence of lammas shoots on productivity of Norway spruce in Latvia. *Agronomy Research* **13**, 354–360.
Neimane, U., Zadina, M., Jansons, J. & Jansons, A. 2016. Environmental factors affecting formation of lammas shoots in young stands of Norway spruce in Latvia. *Baltic Forestry* (submitted).
Rieksts-Riekstins, J., Jansons, A., Smilga, J., Baumanis, I., Ray, D. & Connolly, T. 2014. Climate suitability effect on tree growth and survival for Scots pine provenances in Latvia. In Gaile, Z. (ed): *Proceedings of the 19th international scientific conference Research for Rural Development*. LLU, Jelgava, Latvia, pp. 57–62.
Rikala, R. 1992. Effect of nursery fertilization on incidence of summer shoots and field performance of Scots pine seedlings. *Folia Forestalia* **794**, 19 pp.
Rone, V. 1975. The family and clonal selection for Norway spruce. In: *Genetic Researches of Trees in Latvian SSR*. Zinatne, Riga, pp. 34–44 (in Russian, English summary).
Rone, V. 1985. Juvenile growth and breeding strategy of Norway spruce clones. *Jaunākais Mežsaimniecībā* **27**, 10–16 (in Latvian).
Rudolph, T.D. 1964. Lammas growth and prolepsis in jack pine in the Lake States. *Forest Science Monograph* **6**, 70 pp.
Rytter, L., Johansson, K., Karlsson, B. & Stener, L.-G. 2013. Tree species, genetics and regeneration for bioenergy feedstock in Northern Europe. In Kellomaki, S., Kilpeläinen, A. & Alam, A. (eds): *Forest BioEnergy Production. Management: Carbon sequestration and adaption*. Springer, pp. 7–16.
Sabaté, S., Gracia, C.A. & Sánchez, A. 2002. Likely effects of climate change on growth of *Quercus ilex*, *Pinus halepensis*, *Pinus pinaster*, *Pinus sylvestris* and *Fagus sylvatica* forests in the Mediterranean region. *Forest Ecology and Management* **162**(1), 23–37.

Salminen, H., Jalkanen, R. & Lindholm, M. 2009. Summer temperature affects the ratio of radial and height growth of Scots pine in northern Finland. *Annals of Forest Science* **66**(8), 810–810.

Skrøppa, T. & Steffenrem, A. 2015. Selection in a provenance trial of Norway spruce (*Picea abies* L. Karst) produced a land race with desirable properties. *Scandinavian Journal of Forest Research*, DOI: 10.1080/02827581.2015.1081983.

Søgaard, G., Fløistad, I.S., Granhus, A., Hanssen, K.H., Kvaalen, H., Skrøppa, T. & Steffenrem A. 2011. Lammas shoots in spruce – occurrence, genetics and climate effects. In Granhus, A., Hanssen, K.H. & Søgaard, G. (eds.): *Forest management and silviculture in the north - balancing future needs. Book of abstracts for the conference in Stjørdal, Norway, September 6-8, 2011.* Rapport fra Skog og landskap 14/11, pp. 57–58.

Ståhl, E.G., Persson, B. & Prescher, F. 1990. Effect of provenance and spacing on stem straightness and number of stems with spike knots in *Pinus sylvestris* L. - Northern Sweden and countrywide models. *Studia Forestalia Suecica* **184**, 16 pp.

Ununger, J., Ekberg, I. & Kang, H. 1988. Genetic control and age related changes of juvenile growth characteristics in *Picea abies*. *Scandinavian Journal of Forest Research* **3**, 55–56.

West, R.F. & Ledig, F.T. 1964. Lammas shoot formation in Scots pine. In: *Proceedings of 11th Northeast. Forest Tree Improvement Conference.* New Brunswick, New Jersey, pp. 21–30.

West, R.F. & Rogers, R. 1965. The effect of lammas shoot growth on the stem form of young Scotch pine. Published as a Paper of the Journal Series, New Jersey Agricultural Experiment Station, pp. 14–20.

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Influence of nitrogen fertilizer on Cd and Zn accumulation in rapeseed (*Brassica napus* L.) biomass

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Abstract. Diffuse soil contamination with heavy metals and Cd in particular is a matter of serious concern. Application of conventional remediation methods usually is not feasible due to the large territories and relatively low heavy metal content. Thus, phytoremediation is seen as an alternative. Rapeseed was grown on Cd and Zn contaminated as well as clean soil under the greenhouse conditions. Solid and liquid nitrogen fertilizers were applied during the pot experiment in order to test their influence on heavy metal accumulation in plant tissues. Vegetative parameters were measured four times during the pot experiment and it was concluded, that the elevated concentrations of Cd and Zn in the soil did not disrupt the development of rapeseed plants. Furthermore, plants from contaminated soil produced significantly bigger seeds in comparison to plants from uncontaminated soil. Calculated Bioconcentration factors for rapeseed grown on Cd and Zn contaminated soil in all cases were below unity, thus possibility to use this plant species for phytoextraction purposes is limited, but it can be successfully grown on contaminated land as an energy crop. Application of nitrogen fertilizers had a significant effect on heavy metal accumulation and decreased Cd and Zn concentrations in rapeseed roots and stems with leaves were recorded. Accumulation differences between the liquid and solid fertilizer applications were negligible.

Key words: cadmium, zinc, contaminated soil, phytoremediation, nitrogen fertilizer.

INTRODUCTION

Biomass is one of the most abundant sources for the renewable energy. However, due to the shortage of arable lands energy cropping is enforced to compete with traditional agriculture (Campbell et al., 2008). Furthermore, there is another serious concern regarding the upper soil layer pollution with trace elements as a consequence of intensive farming. This problem is faced in many regions worldwide (Nagajyoti et al., 2011; Witters et al., 2012). Soils with exceeding threshold values for heavy metals (HM) are no longer proper for food and feedstock production (Lithuanian…, 2004; Oves et al., 2012).

Many remediation techniques, such as soil flushing, vitrification, thermal destruction, etc., are not reasonable in the case of diffuse pollution due to the large areas of contaminated land, therefore phytoremediation is being proposed as an alternative. On the other hand, plants–hyperaccumulators used for this purpose usually grow slowly and produce low–yield biomass. Thus, a numerous rotation cycles are required for tolerable soil clean up (Bhargava et al., 2012; Ali et al., 2013). Those are the main reasons why phytoremediation exhibits a scanty number of the successfully carried out field–scale projects.

Quite recently a new approach emerged (Meers et al., 2010), which suggests that combining traditional phytoextraction with energy cropping could help not only to reduce heavy metal concentrations in soil, but also to use biomass grown on contaminated land for energy recovery.

Worldwide use of mineral fertilizers is still increasing in large numbers. On one hand, it is well acknowledged, that mineral fertilizers, especially phosphoric, are responsible for carrying HM to the arable lands (Nagajyoti et al., 2011). On the other hand, information about the influence of fertilizers on HM bioavailability is still insufficient. Due to the fertilizer application, plant development is improved and consequently physiological stress, induced by contaminants in the soil, is reduced. Furthermore, fertilization increases the competition for membrane carriers between additional macronutrients and HM ions, so less contaminants gets through plant cell barriers (Sarwar et al., 2013).

As crop fertilization is such a common practise in agriculture, alleviation of HM induced toxicity to plants and reduction of accumulated concentrations in the biomass hereby could be seen as a relatively low–cost, time saving and effective aid for the phytoremediation.

The results presented in this paper are a part of a larger research study. The research is designated to investigate the possibility to grow high biomass yielding plants on heavy metal contaminated soil and to use harvest for bioenergy purposes. The aims of the research in particular are 1) to investigate vegetative parameters of rapeseed (*Brassica napus* L.) plant when cultivated on HM contaminated soil; 2) to determine rapeseed capability to extract Cd and Zn from contaminated soil and 3) to analyse the possible effects on HM accumulation in rapeseed tissues due to the application of liquid and solid nitrogen fertilisers.

MATERIALS AND METHODS

Soil sample collection

A contaminated soil used in this experiment was taken from the former septic drain fields in Molainiai. This territory covers 96.4 ha area and is located in Panevėžys city in mid–Lithuania. Septic drain fields were used for wastewater biological filtering purpose not only by households but also by several heavy industry companies which did not have their own wastewater treatment facilities. Because processes like tin dipping and galvanisation were involved, varying content of heavy metals was brought along with the wastewater and sank in the soil. Although, septic drain fields were used only for 3 years in the early sixties of the 20th century, soil pollution with heavy metals did not withdraw.

A composite contaminated soil sample was pooled from sub–samples taken at three spots. Soil was taken from 0–20 cm depth using plastic shovel, sieved to pass 20 mm mesh screen, homogenized and then brought to the lab for the pot experiment.

Soil without known contamination was taken from agricultural field of Aleksandras Stulginskis University plant–growing experimental station (mid–Lithuania).

A composite uncontaminated soil sample was pooled from three spots as well. This soil was also sieved and thoroughly homogenized.

Primary analytical characteristics including pH, electrical conductivity (EC), macronutrients (NPK) and heavy metal content were detected for both soils. Soil type was identified as well.

Pot experiment

Both soils after homogenization were separately subdivided and put into the plastic buckets of 26 L volume and placed at the greenhouse. Each bucket was seeded with 100 seeds of summer rapeseed cultivar 'Fenja' in mid–May. Temperature in the greenhouse chamber was maintained at 25° ± 2 °C; plants were watered with tap water. The experiment was implemented in triplicates and lasted 13 weeks. In order to determine plant development and HM accumulation rate differences induced by the excess of HM in the soil and addition of macronutrients, plants were thinned thrice: at the initial stem growth phase (I), at the bud formation phase (II) and at the flowering phase (III). Rapeseed was harvested in late August (IV). Pods were cut with scissors and chuckled, whereas roots were separated from stem. Roots were washed with distilled water and as well as stem and leaves air–dried at room temperature.

Fertilizers

To improve plant growth and biomass yield as well as to test HM interaction with fertilizers, two of them were chosen for this pot experiment: liquid fertilizer with amide nitrogen and magnesium 'Lyderis Mg' and solid nitrogen urea fertilizer 'Karbamidas'. Liquid and solid nitrogen fertilizers were applied 5 weeks after the seeding, just before flowering.

Liquid amide nitrogen fertilizer with magnesium 'Lyderis Mg' is designated to supplement the plants with nitrogen and to intensify photosynthesis. The fertilizer contained 15% of amide nitrogen, 7% of magnesium (as MgO) and 14% of sulphur (as SO_3). The recommended application is by spraying it out onto the leaves during the vegetation period. The intended dose for activation of the photosynthesis is 15 L ha^{-1} and it is recommended to dilute concentrate with water up to 200 L. Such solution would supplement the soil with 1.5 kg of MgO and 3.2 kg of N ha^{-1}. Therefore, for the spraying rapeseed in the buckets with the surface area of 0.0875 m^2, only 2 ml of prepared solution (15 ml of concentrated fertilizer diluted up to 200 ml of distilled water) were used. The volume of one spraying click was measured and then the same amount of clicks were used to dispense the solution for all buckets.

Solid fertilizer containing 46.2% of urea nitrogen 'Karbamidas' was used as an alternative for liquid fertilizer 'Lyderis Mg'. Urea is considered as a main supplement of nitrogen for the spring crops, tuber-plants, various vegetables and berry–bushes. The proposed application for summer rapeseed is 160–230 kg ha^{-1} before sowing and smaller dose of 60–100 kg ha^{-1} during flower budding period. However, for this experiment dose of solid urea fertilizer was recalculated to match on the dose of nitrogen in liquid fertilizer 'Lyderis Mg'. Thus, to reach 3.2 kg ha^{-1} dose, 6.86 kg of urea should be applied. The surface area of buckets with rapeseed plants was 0.0875 m^2, so approximately 0.065–0.075 g were added. The pellets were distributed evenly on the freshly watered soil surface. It is assumed, that the temperature in the greenhouse

(25° ± 2 °C) was not too high to cause evaporation loses. The pellets of the urea dissolved within 24 hours.

Analytical procedure

Rapeseed stem with leaves, roots, pods and seeds were separately grinded into a powder using lab grinder mill. Wet digestion was performed adding 2 ml of 30% H_2O_2, 5 ml of oncentrated HNO_3 and 1 ml of deionized water step–wisely into the aliquots (0.500 ± 0.005 g) of plant sample. The Teflon bombs containing wet samples were heated for 10 minutes at a temperature of 195 °C in a microwave digestion oven (CEM Mars 5). After cool down, samples were diluted with deionised water up to 100 ml and filtered using PVDP syringe filters (pore size 0.45 µm). Inductively coupled plasma optical emission spectrometry (Perkin-Elmer Optima 8000 ICP–OES spectrometer) was carried out and HM concentrations were detected in the liquid plant samples. Reference material was analysed to verify the reliability of the results.

Data evaluation

Average concentrations of accumulated Cd and Zn in single rapeseed plant parts were calculated from mg L^{-1} to mg kg^{-1} of dry weight (DW). Plant capacity to accumulate HM from the soil and rapeseed potential to be used for phytoremediation purposes was evaluated by calculating Bioconcentration factor (BCF) using Equation (1) (Malik et al., 2010).

$$BCF = C_{roots} \div C_{soil} \quad (1)$$

where: C_{roots} is a metal concentration in the roots and C_{soil} is a metal concentration in the soil where plant was grown.

Significance of the obtained average differences was evaluated using *t-Test* (two sample assuming unequal variances with α = 0.05) in MS Office Excel.

RESULTS AND DISCUSSION

Soil properties and heavy metal content

Analytical characteristics of the two soils are given in Table 1. Soil type identification was based on granulometric composition and both soils were characterized as sandy loams. Uncontaminated soil exhibited pH 7.4 (slightly alkaline), while contaminated soil had slightly higher pH 8.0 (alkaline). Soil pH is one of the most important factors influencing plant nutrient as well as heavy metal bioavailability. Uptake of most of the nutrients is favoured at pH range 6.5–7.5, while HM, such as Cd, Pb or Zn, are usually less mobile at circumneutral pH. Soils used in this pot experiment exhibited rather low electrical conductivity: 290 µS m^{-1} for contaminated soil and 245 µS m^{-1} for uncontaminated one. Soil EC usually have correlations with organic matter content, dissolved ions, soil drainage conditions, soil texture and cation exchange capacity, which in turn affect crop productivity.

Nitrogen (N), phosphorus (P) and potassium (K) are major plant nutrients and growth rate is directly related to them. Composition of NPK in the analysed soils was rather different. Uncontaminated soil contained 2.5 times more of total nitrogen, whereas mobile phosphorus and mobile potassium content was higher in contaminated soil by 2.6 and 1.7 times respectively.

Table 1. Average values of analytical characteristics of soil samples

Analytes	Contaminated soil	Uncontaminated soil
Soil type	sandy loam	sandy loam
pH	8.0 ± 0.2	7.4 ± 0.2
EC, $\mu S\ m^{-1}$	290 ± 5	245 ± 5
Mineral N, mg kg^{-1}	6.5 ± 1.1	16 ± 1.5
Mobile P (as P_2O_5), mg kg^{-1}	921 ± 55	348 ± 23
Mobile K (as K_2O), mg kg^{-1}	227 ± 14	127 ± 8

Concentration of Cd in contaminated soil was 26.8 ± 0.9 mg kg^{-1} DW and it is nearly 9 times higher than maximum permissible concentration (MPC) (3 mg kg^{-1} DW) and about 335 times higher than in uncontaminated soil (0.08 ± 0.05 mg kg^{-1} DW). While background concentration for Cd in the soil is only 0.15 mg kg^{-1} DW. Concentration of Zn in contaminated soil was 202.6 ± 7.8 mg kg^{-1} DW and it did not reach MPC (300 mg kg^{-1} DW), but it was 8 times higher than soil background concentration for Zn (26 mg kg^{-1} DW). Zinc concentration in uncontaminated soil was 28.9 ± 1.5 mg kg^{-1} DW (Lithuanian…, 2004).

Vegetative parameters of rapeseed plants

Vegetative parameters of rapeseed plants measured during the pot experiment at the initial stem growing phase (I), bud formation phase (II), flowering phase (III) and after harvesting (IV) are presented in Figure 1. Rapeseed plants grown on contaminated soil on average developed a slightly longer stem (Fig. 1(a)), however the differences were not statistically significant. Application of fertilizers did not influence stem development.

The longest roots (Fig. 1 (b)) were recorded for rapeseed grown on contaminated soil under the fertilizer addition. Though, the differences between effects of the liquid and solid fertilizers on root length were negligible. Plants from uncontaminated soil provided the shortest main root. Root length is an important parameter when incorporating certain plant species for phytoremediation: the longer the root, the thicker contaminated soil layer can be attenuated.

All plants exhibited the largest dry weight per plant (Fig. 1 (c)) during the flowering phase. Rapeseed from uncontaminated soil had significantly the highest dry weight on average per plant. It was visible during the greenhouse experiment that rapeseed on contaminated soil had fewer and smaller leaves. As shown in Fig. 1 (c) dry weight of rapeseed plants is lower after harvest than in the flowering phase. There are two reasons for this: 1) due to the natural vegetation slowdown, rapeseed lost most of the leaves in the end; 2) dry weight measurements excluded the weight of pods and seeds. The highest dry weight was recorded for plants from uncontaminated soil, whereas fertilization did not have significant effect on average dry weight.

Standard weight of 100 seeds of summer rapeseed cultivar ‘Fenja’ is 0.39 g (Descriptions…, 2013). It is an important trait when reckoning the future harvest. A hundred seeds matured by plants grown on uncontaminated soil weighted only 0.25 ± 0.04 g. This gap between Standard weight and results from our experiment might be due to the rather low phosphorus and potassium content in the soil as no additional macronutrients were added to the uncontaminated soil. Significantly higher weight of hundred seeds was measured for contaminated soil. Furthermore, fertilization using solid form of urea proved to be the most successful as a hundred seeds weighted 0.39 ± 0.02 g.

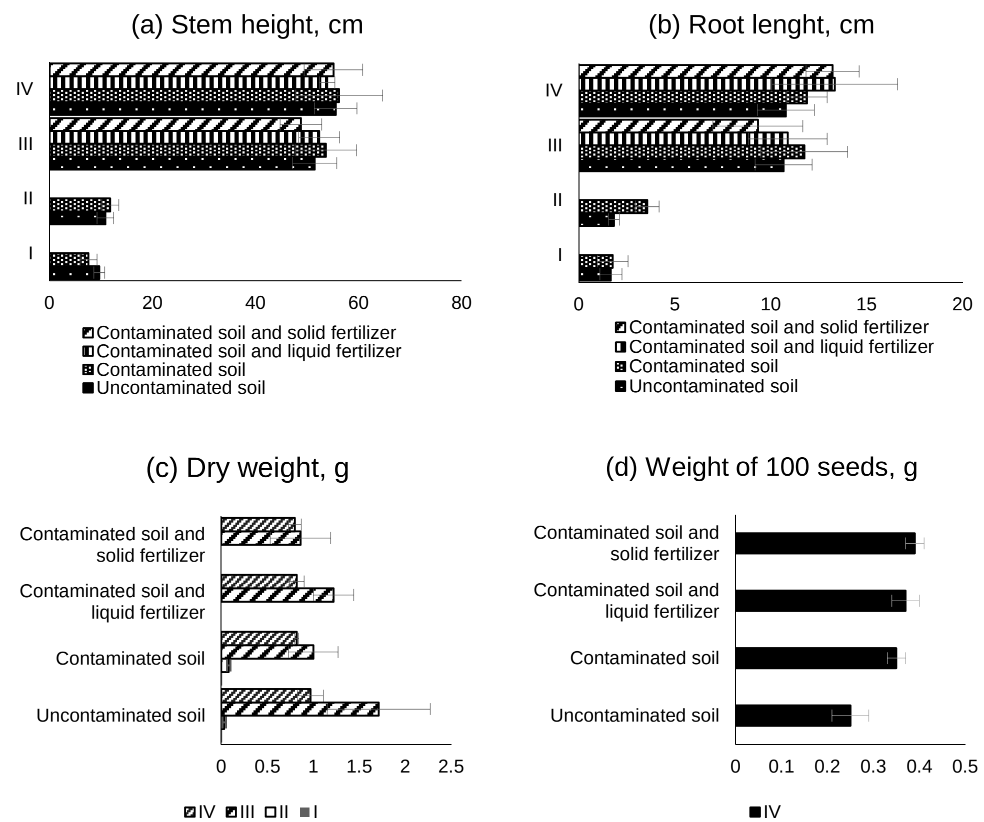

Figure 1. Vegetative parameters of rapeseed: (a) average stem height of a single plant; (b) average root length of a single plant; (c) dry weight of a single plant (pods and seeds excluded); (d) average weight of 100 seeds randomly picked from plants of one bucket. I: initial stem growth phase; II: bud formation phase; III: flowering phase; IV: harvest. Fertilizers applied before phase III.

Cadmium and zinc accumulation in rapeseed tissues

There is no linear reliance on microelements' uptake by plants as it is influenced by many abiotic factors (Kabata–Pendias, 2011). Thus, it is difficult to generalize what HM concentrations in certain plant species are normal or abnormal. On the other hand, it is clear enough that plant cultivated on HM contaminated soil will end up with higher HM concentrations in its tissues.

As shown in Table 2 significantly higher concentrations of Cd were detected in single plant parts when rapeseed was grown on HM contaminated soil in comparison to the rapeseed from uncontaminated soil. Already at the initial stem growth phase rapeseed started to uptake Cd intensively. This can be explained by a rapid breakdown of the physiological barrier controlling a metabolic absorption of this toxic metal (Kabata–Pendias, 2011). Even in the case of uncontrolled Cd accumulation in tissues, plant may grow without visual toxicity symptoms and show no significant yield loss (Sarwar et al., 2010). Significantly the highest Cd concentrations were found in roots (15.9 ± 1.8 mg kg^{-1} DW) and stems with remaining leaves (10.6 ± 0.5 mg kg^{-1} DW) after the harvesting in plants grown on contaminated but fertilizer–untreated soil. Rapeseed accumulated less Cd in stems (by 15%) and roots (by 38%) when nitrogen fertilizers were applied. The subsequent decrease of Cd concentration in roots and stems with leaves might have occurred due to the membrane carrier deficiency as the addition of fertilizers intensified the uptake of nutrients (Dheri et al., 2007). The difference on Cd accumulation in single rapeseed parts between the applications of solid and liquid nitrogen fertilizers was insignificant ($p > 0.05$). Rapeseed pods and, more importantly, seeds exhibited rather low concentrations of Cd. These plant parts turn up lastly, thus the concentrations did not exceed 2.5 mg kg^{-1} DW in our case.

Table 2. Accumulated average concentrations and standard deviations of Cd, mg kg^{-1} DW, in rapeseed tissues at different growth phases

Thinning and plant part		Uncontaminated soil	Contaminated soil	Contaminated soil and liquid fertilizer	Contaminated soil and solid fertilizer
I	stem and leaves, roots	0.85 ± 0.04	9.50 ± 0.93	-	-
II	stem and leaves	0.96 ± 0.02	8.15 ± 0.49	-	-
	roots	0.37 ± 0.07	6.69 ± 1.69	-	-
III	stem and leaves	0.46 ± 0.07	5.73 ± 0.47	5.95 ± 0.37	6.57 ± 0.50
	roots	0.27 ± 0.10	9.41 ± 1.54	7.69 ± 1.08	11.85 ± 2.06
	pods with seeds	0.25 ± 0.03	1.44 ± 0.11	0.77 ± 0.25	0.81 ± 0.19
IV	stem and leaves	0.45 ± 0.11	10.62 ± 0.44	8.99 ± 0.62	9.11 ± 0.57
	roots	0.26 ± 0.14	15.97 ± 1.80	10.98 ± 2.78	8.86 ± 2.66
	pods	0.20 ± 0.001	1.93 ± 0.16	1.49 ± 0.26	1.53 ± 0.27
	seeds	0.24 ± 0.001	2.20 ± 0.34	1.81 ± 0.03	1.81 ± 0.23

Accumulation of Zn is presented in Table 3. Zinc is an essential micronutrient and its importance for the plant development is beyond the doubt. Although, Zn contamination in soil used for greenhouse experiment did not exceed MPC value, an increased accumulation in plants was detected due to higher than background Zn concentration. Analysing the harvested biomass samples it was found that addition of nitrogen fertilizers decreased Zn concentration in stems and leaves, roots as well as seeds if compared with plants from contaminated but fertilizer–untreated soil. However, there were no significant differences ($p > 0.05$) between applications of liquid or solid fertilizer. Zinc is quite mobile in mildly alkaline environment and therefore it is distributed more uniformly through the plant parts than Cd. Only pods after harvesting contained rather low Zn amounts. While seeds of plants grown in uncontaminated soil exhibited unexpectedly high Zn concentrations–there were no significant differences between the latter and seeds from contaminated but fertilizer–treated soil. The reason behind high Zn accumulation in seeds is that this metal is incorporated in the structure of a variety of enzymes which are so abundant in vegetable oil (Kabata–Pendias, 2011).

Table 3. Accumulated average concentrations and standard deviations of Zn, mg kg^{-1} DW, in rapeseed tissues at different growth phases

Thinning and plant part		Uncontaminated soil	Contaminated soil	Contaminated soil and liquid fertilizer	Contaminated soil and solid fertilizer
I	stem and leaves, roots	33.46 ± 1.47	70.70 ± 7.82	-	-
II	stem and leaves	17.70 ± 2.05	55.50 ± 3.08	-	-
	roots	16.47 ± 1.77	50.60 ± 11.12	-	-
III	stem and leaves	15.99 ± 0.96	54.89 ± 3.78	57.37 ± 3.94	61.52 ± 4.40
	roots	17.13 ± 0.69	51.92 ± 6.26	57.85 ± 7.99	77.37 ± 11.23
	pods with seeds	23.17 ± 1.82	33.25 ± 2.42	27.60 ±2.80	27.74 ± 4.56
IV	stem and leaves	11.35 ± 2.53	79.04 ± 2.17	65.73 ± 3.97	66.11 ± 4.41
	roots	12.90 ± 1.81	95.10 ± 9.23	60.03 ± 18.49	51.71 ± 15.29
	pods	7.66 ± 2.12	9.52 ± 1.75	7.76 ± 1.02	6.40 ± 0.48
	seeds	57.31 ± 7.98	74.02 ± 6.54	59.31 ± 0.92	59.55 ± 3.28

Cadmium and zinc Bioconcentration factor for rapeseed

Bioconcentration factor as a ratio between a certain heavy metal concentration in roots and soil was calculated for rapeseed plants and is presented in Fig. 2.

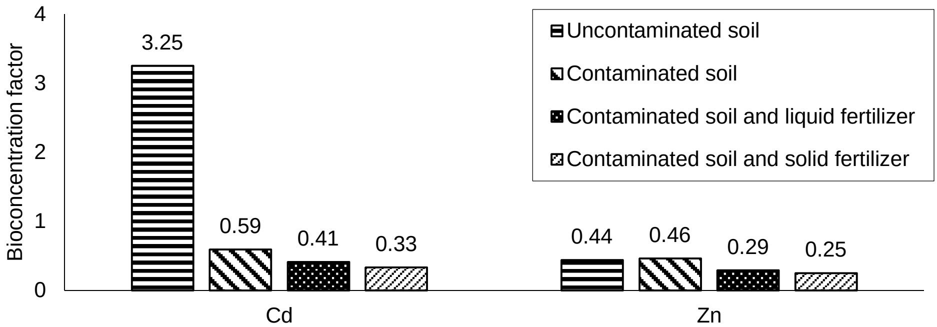

Figure 2. Biocentration factors of Cd and Zn for rapeseed.

Plants exhibiting BCF values higher than unity, can be considered as hyperaccumulators (Yoon et al., 2006). Some species in the *Brassicaceae* family, like Indian mustard (*Brassica juncea* L.) or Chinese cabbage (*Brassica rapa* L.) are considered to be effective in phytoextraction process, especially when chelants are used (Brunetti et al., 2011; Ali et al., 2013; Marques et al., 2013). However, in the case of our experiment, rapeseed, being a member of *Brassicaceae* family, exhibited BCF values lower than unity for both Cd and Zn when plants were grown on contaminated soil. This indicates that, usage of rapeseed as Cd or Zn accumulator for intensive phytoextraction is limited, or ortherwise alternative HM uptake–enhancing measures should be applied. On the other hand our experiment revealed, that application of nitrogen fertilizers had an inhibitory effect on Cd and Zn bioavailability in rapeseed tissues – Bioconcentration factor values were significantly lower when fertilizers were used. Rapeseed grown on uncontaminated soil exhibited BCF = 3.25 for Cd, it proves aforementioned statement that Cd can easily penetrate biomembrane and be translocated in plant tissues.

Nonetheless, in spite of so high BCF value, Cd concentration in rapeseed tissues from uncontaminated soil remained relatively low.

CONCLUSIONS

Our results showed that despite of higher than background Cd and Zn content in the soil, rapeseed development was similar to the control samples grown on uncontaminated soil. Moreover, rapeseed produced heavier seeds when cultivated on contaminated soil. This is a very important chracteristics for oil-bearing plants, such as rapeseed.

Calculation of Bioconcentration factor revealed, that rapeseed is not efficient enough for Cd or Zn phytoextraction purposes. Furthermore, usage of nitrogen fertilizers, despite of its application form (liquid or solid), even more decreased Cd and Zn accumulation in plants. Consequently, this would decrease overall Cd or Zn removal from the contaminated area, but lower accumulation would increase the utilization possibilities of rapeseed biomass for energetic purposes. However, to be able to use fertilizers as an aid for phytoextraction, further research is needed involving different fertilizers as well as application rates.

REFERENCES

Ali, H., Khan, E. & Sajad, M.A. 2013. Phytoremediation of heavy metals–Concepts and applications. *Chemosphere* **91**, 869–881.

Bhargava, A., Carmona, F.F., Bhargava, M. & Srivastava, S. 2012. Approaches for enhanced phytoextraction of heavy metals. *Journal of Environmental Management* **105**, 103–120.

Brunetti, G., Farrag, K., Rovira, P.S., Nigro, F. & Senesi, N. 2011. Greenhouse and field studies on Cr, Cu, Pb and Zn phytoextraction by *Brassica napus* from contaminated soils in Apulia region, Southern Italy. Geoderma 160, 517–523.

Campbell, J.E., Lobell, D.B., Genova, R.C. & Field, C.B. 2008. The global potential on bioenergy on abandoned agricultural lands. *Environmental Science and Technology* **42**, 5791–5794.

Descriptions of rapeseed varieties included in the national plant variety list. 2013. *http://www.vatzum.lt/uploads/documents/augalu_veisles/2013_raps_veisli_apraai_1.pdf.* Accessed 26. 01. 2016. (in Lithuanian).

Dheri, G.S., Brar, M.S. & Malhi, S.S. 2007. Influence of phosphorus application on groth and cadmium uptake of spinach in two Cd-contaminated soils. *Journal of Plant Nutrition and Soil Science* **170**, 495–499.

Kabata–Pendias, A. 2011. *Trace Elements in Soils and Plants, 4th Edition*. CRC Press, 548 pp.

Lithuanian Minister of Health Order on Approval of Lithuanian HN 60:2004 on *Maximum permissible concentrations of dangerous chemicals in soil*. 08. 03. 2004. No. V–114, Vilnius. (in Lithuanian).

Malik, R.N., Husain, S.Z. & Nazir, I. 2010. Heavy metal contamination and accumulation in soil and wild plants species from industrial area of Islamabad, Pakistan. *Pakistan Journal of Botany* **42**, 291–301.

Marques, A.P.G.C., Rangel, A.O.S.S. & Castro, P.M.L. 2013. Remediation of heavy metal contaminated soils: phytoremediation as a potentially promising clean–up technology. *Critical Reviews in Environmental Science and Technology* **39**, 622–654.

Meers, E., Van Slycken, S., Adriaensen, K., Ruttens, A., Vangronsveld, J., Du Laing, G., Witters, N., Thewys, T & ack, F.M.G. 2010. The use of bio–energy crops (*Zea mays*) for ‘phytoattenuation’ of heavy metals on moderately contaminated soils: A field experiment. *Chemosphere* **78**, 35–41.

Nagajyoti, P.C., Lee, K.D. & Sreekanth, T.V.M. 2011. Heavy metals, occurrence and toxicity for plants: a review. *Environmental Chemistry Letters* **8**, 199–216.

Oves, M., Khan, M.S., Zaidi, A. & Ahmad, E. 2012. Soil contamination, nutritive value, and human health risk assessment of heavy metals: an overview in Zaidi, A. et al. (eds). 2012. *Toxicity of heavy metals to legumes and bioremediation*. Springer–Verlag Wien, 1–28.

Sarwar, N., Saifullah, Malhi, S.S., Zia, M.H., Naeem, A., Bibi, S. & Farid, G. 2010. Role of mineral nutrition in minimizing cadmium accumulation by plants. *Journal of the Science of Food and Agriculture* **90**, 925–937.

Witters, N., Mendelsohn, R.O., Van Slycken, S., Weyens, N., Schreurs, E., Meers, E., Tack, F., Carleer, R. & Vangronsveld, J. 2012. Phytoremediation, a sustainable remediation technology? Conclusions from a case study. I: Energy production and carbon dioxide abatement. *Biomass and Bioenergy* **39**, 454–469.

Yoon, J., Cao, X., Zhou, Q. & Ma, L.Q. 2006. Accumulation of Pb, Cu, and Zn in native plants growing on a contaminated Florida site. *Science of the Total Environment* **54**, 441–446.

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Performance Evaluation of TDR Soil Moisture Sensor

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Abstract. Optimization of irrigation scheduling and water management greatly benefit from soil moisture sensors that accurately measure soil water content since accuracy of soil moisture sensor directly affects the irrigation efficiency. In this study, a performance evaluation of TDR-Slammer with a 40 cm waveguide was done under field conditions. Experimental data were collected in a drip irrigated pumpkin (Cucurbita pepo L.) field, Kayseri, Turkey during the 2015 growing season. Measured soil water content values on a loamy soil were compared with corresponding values derived from gravimetric samples. Results showed that TDR-Slammer could be safely used as an acceptable, reliable and accurate method for measuring soil water content on loamy soils.

Key words: Time domain reflectometry, soil water content, calibration, dielectric constant.

INTRODUCTION

A reliable determination of soil water content is important since it directly affects plant growth. Soil moisture measurements are also necessary for assessing the effect of irrigation management on agricultural crops. There are several different methods to measure or to estimate soil moisture contents using either destructive (gravimetric) or non-destructive methods (neutron probe, TDR, porous blocks, tensiometer, etc.). In irrigation scheduling studies, use of gravimetric methods are mostly defined as time consuming and labour intensive.

During the last 30 years, Time Domain Reflectometry (TDR) has become quite common and popular for measuring volumetric soil moisture content. The use of TDR is quite easy and gives reliable and accurate results without disturbing the soil. Since the TDR is not a direct method of measuring soil water content (ϴ), a calibration is required for different soil types. The TDR determines relative dielectric constant (K) of soil by measuring the propagation velocity of an electronic wave guide along electrodes. Topp et al. (1980) developed an empirical relationship (Equation 1) between the dielectric constant and volumetric moisture content of soil as independently of some soil parameters such as bulk density, temperature and salinity.

$$\theta = 4.3 \times 10^{-6} K^3 - 5.5 \times 10^{-4} K^2 + 2.92 \times 10^{-2} K - 5.3 \times 10^{-2} \quad (1)$$

TDR measurements commonly depend on apparent dielectric constant of soil which changes with moisture content. The advantages of TDR system over other methods are (1) calibration requirements are minimal, (2) effects of temperature and hysteresis (the relationship between matric potential and soil water content for a given soil is not unique and varies depending on whether the soil is drying or wetting) on TDR measurement are small, (3) simultaneous measurements are possible (Quinones et al., 2003; Miyamoto & Chikushi, 2006). A third-order polynomial equation proposed for mineral soils by Topp et al. (1980) is adequate for many soils except for organic and clayey soils. However, many researchers (Take et al., 2007; Ju et al., 2010) indicated that TDR measurements most probably could be influenced by soil bulk density, soil temperature, soil texture, soil structure, organic matter content and salinity. Therefore, a site specific calibration is required to obtain a higher accuracy instead of using universal Topp equation. Ju et al. (2010) showed that Topp equation could work well with coarse-textured soils with bulk densities between 1.0–1.78 g cm^{-3}.

The overall objective of this study was to determine accuracy of TDR-slammer for measuring soil water content under drip irrigated pumpkin field and also to investigate the need for a site-specific calibration for TDR-slammer in loamy soil.

MATERIALS AND METHODS

Experiments were conducted in 2015 over the experimental fields of Agriculture Research Station of Erciyes University, Kayseri, Turkey (1,094 m altitude, 38° 18′ N and 34° 56′ E coordinates) under drip irrigated pumpkin field. Irrigation water was supplied from a deep well with a quality class of C_2S_1 and pH and EC (electrical conductivity) values of irrigation water were 7.60 and 0.242 dS m^{-1}, respectively. The study site had 6 differt irrigation treatments starting from dry to full irrigation. Amount of water applied to treatments were increased from treatment 1 to treatment 5. The treatment 1 had the least irrigation water application while the treatment 5 had full irrigation. Irrigations were initiated on 19th of June in 2015 and stopped on 6th of August. The tests were repeated in different dates under different soil moisture levels of drip irrigated pumpkin. A total of twenty five data points (n = 25) were used in the analysis of volumetric soil moisture content. The soil properties of the site (FC_w – Field Capacity in weigth and PWP_w – Permenant Wilting Point in weigth) are provided in Table 1. There are several different types of available commercial TDR sensors to determine soil moisture content. The TDR-slammer is designed for inserting waveguides into hard, dry and compacted soils (Fig. 1).

Table 1. Soil properties of the study site

Depth (cm)	Texture	pH	EC (mmhos cm^{-1})	FC_w (%)	PWP_w (%)	Organic matter (%)	Bulk density (g cm^{-3})
0–20	Loam	8.00	0.226	21.2	9.7	0.98	1.30
20–40	Loam	8.25	0.214	25.7	11.8	1.51	1.28

In each irrigation treatment, the sensor was installed roughly 0.10 m apart from the dripper of the lateral. Data collection began in the late June and continued till the begining of August. The gravimetric samples were taken using a soil auger approximately 0.20 m away from each sensor location. The sensor was inserted vertically into soil and several soil water content readings were taken and then averaged. After each sensor reading, soil gravimetric samples were taken from the both sides of the TDR probe. The standard procedures was applied over the gravimetric samples to determine the gravimetric soil moisture content. Soil samples were always taken at different locations. In order to convert the gravimetric soil moisture into volumetric soil moisture content (VWC), the soil bulk density was considered. During the gravimetric samplings, soil tempeartures ranged between 22–35 °C in dry treatment, 23–28°C in treatment 1, 22–30 °C in treatment 2, 22–28 °C in treatment 3, 21–28 °C in treatment 4 and 22–25 °C in treatment 5.

Figure 1. TDR–slammer with a 40 cm waveguide.

Three statistical parameters were used to compare predicted (Pi) data from TDR measurements with the observed (Oi) gravimetric samples (*n*). The statistical measures were (a) the cofficient of determination (R^2), (b) mean bias error (MBE) and (c) root mean square error (RMSE) as defined by Chavez et al. (2011). Paired-sample *t test* was also applied to present statistical significance of differences between TDR measured VWC and actual VWC determined by gravimetric process.

$$MBE = n^{-1}\sum_{i=1}^{n}(Pi - Oi) \quad (2)$$

$$RSME = \left[n^{-1}\sum_{i=1}^{n}(Pi - Oi)^2\right]^{0.5} \quad (3)$$

RESULTS AND DISCUSSION

During the field calibration process, the volumetric soil moisture content was within the PWP to FC range of water contents. Fig. 2 shows the data of gravimetrically measured VWC versus TDR measured K values. The calculated RMSE and MBE values were 1.9 and -0.16, respectively. Chaves et al. (2011) found the MBE and RMSE values as 0.05 and 0.025, respectively for forest soil. Ju et al. (2010) obtained the RMSE as

0.06 for clay loam soil. These differences could be due to different soil texture and management conditions. Fig. 3 presents the comparison of VWC from TDR versus gravimetric method. The significant differences between water contents measured with TDR-slammer and gravimetric method are listed in Table 2. The paired-sample *t test* indicated that the difference between TDR-slammer and gravimetric method was insignificant at $p < 0.05$ level. The standard error of mean (SEM) was 0.90 and 0.78 for TDR and gravimetric method, respectively, while the standard deviation (SD) was 4.54 and 3.90, respectively. The changes of VWC obtained from gravimetric method and TDR Slammer are presented in Fig. 4.

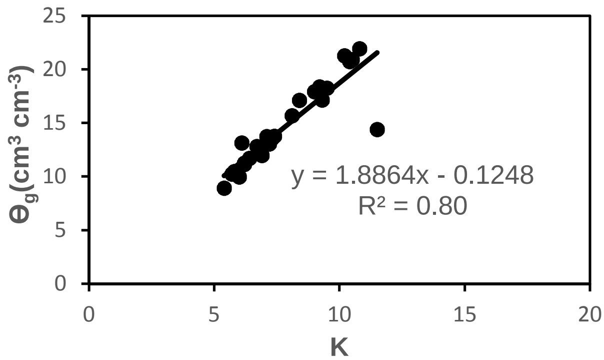

Figure 2. Comparison of measured VWC from the gravimetric procedure (Θ_g) versus measured dielectric constant (K).

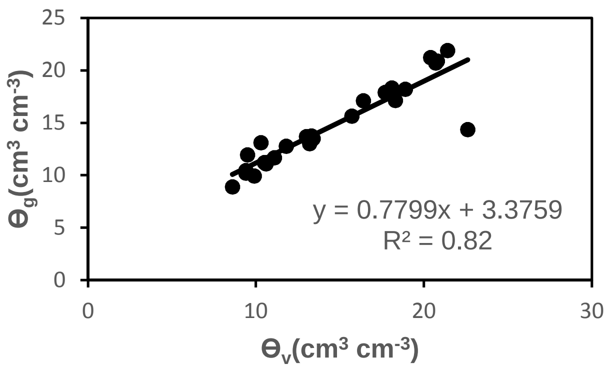

Figure 3. Comparison of measured VWC from the gravimetric procedure (Θ_g) versus TDR-Slammer (Θ_v).

Table 2. The significant differences between VWC measured with TDR-slammer and gravimetric method

	Mean	SD	SEM	*t-stat*	*p*
TDR-Slammer	14.60	4.54	0.90	0.13	0.89
Gravimetric method	14.80	3.90	0.78		

The Fig. 4 shows a very close relationship in VWC of TDR-slammer technique and gravimetric method. Fig. 2 presents that a simple linear model could be used to measure VWC in loamy soils (Θ_g = 1.8864×K-0.1248 with an R^2 of 0.80) instead of using polynomial Topp equation. The Fig. 3 showed that there was a very close relationship in measured VWC of TDR-slammer and gravimetric method. The test results showed that the TDR-slammer with the manufacturer's Topp equation could safely be used to measure VWC in loamy soils (Figs 3–4). Current study also confirmed that the Topp equation could be confidently used to estimate VWC accurately from dielectric data (K) in the loamy soils. The Topp equation known as universal was adequate for the studied soil type.

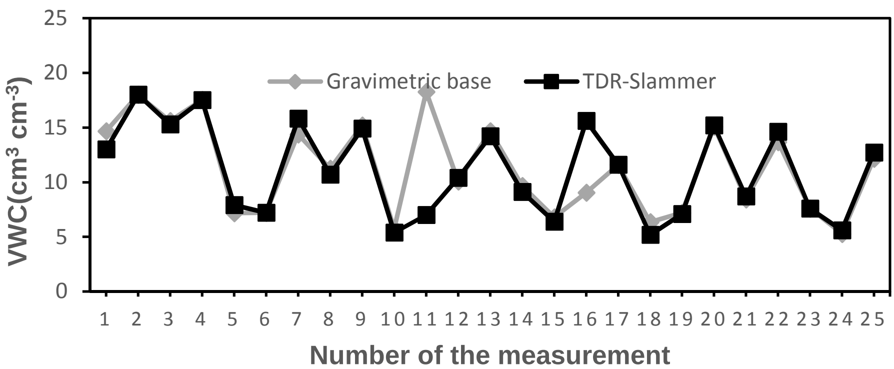

Figure 4. Changes of VWC obtained from gravimetric method and TDR Slammer.

The *t*-test between TDR technique and gravimetric method showed that there was no significant difference at $p > 0.05$ level. However, more studies including soil parameters should be done for the calibration of different types of TDR under different soil type and management conditions.

CONCLUSIONS

Major conclusions of this investigation are (1) The TDR-slammer could securely be used as an accurate soil moisture device for measuring soil water content in compacted loamy soils. (2) The TDR-slammer with manufacturer's Topp equation could safely be used without a site-specific calibration if necessary. (3) There was a clear relationship between the K and Θ_g and this relationship was best described (R^2 = 0.80) with a simple linear equation of the form Θ_g = 1.8864×K-0.1248. This simple linear model, instead of using polynomial Topp's equation, could be used for compacted loamy soils.

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REFERENCES

Chaves, L., Varble, J.L. & Andales, A.A. 2011. Performances evaluation of selected soil moisture sensors. In: *Proceedings of the 23rd annual central plains irrigation conference*. Kansas, USA, pp.29–37.

Ju, Z., Liu, X., Ren, T. & Hu, C. 2010. Measuring soil water content with TDR: An improved calibration considering soil bulk density. *Soil science* **175**(10), 469–472.

Miyamoto, H. & Chikushi, J. 2006. Calibration of column-attaching TDR probe based on dielectric mixing model. In: *Proceedings of TDR*, Purdue University, USA, 1–6.

Pumpanen, J. & IIvesniemi, H. 2005. Calibration of time domain reflectometry for forest soil humus layers. *Boreal Environment Research* **10**, 589–595.

Quinones, H., Ruelle, P. & Nemeth, I. 2003. Comparision of three calibration procedures for TDR soil moisture sensors. *Irrigation and drainage* **52**, 203–217.

Reeves, T.L. &Smith, M.A.1992. TDR for measuring soil water content in range surveys. *J. Range Manage.* **45**, 412–414.

Take, W.A., Arnepalli, D.N., Bracchman, R.W.I. & Rowe, R.K. 2007. Laboratory and field calibration of TDR probes for water content measurement. In: *Proceedings of OttowaGeo2007*. Canada, pp. 1865–1871.

Topp, G.C., Davis, J.L. & Annan, A.P.1980. Electromagnetic determination of soil water content: Measurements in coaxial transmission lines. *Water resources research* **16**(3), 574–582.

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The effect of soil tillage technologies on the surface of the infiltration speed of water into the soil

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Abstract. Water erosion is a problem of global significance. Water erosion causes destruction or damage to enormous areas of agricultural land every year (Morgan, 2005). Agricultural land in the Czech Republic is largely exposed to the risk of water erosion on grounds of habitat, but as well agro technology. More than half of agricultural land is endangered by water erosion in the Czech Republic (Janeček, 2005). Due to water erosion the soil is depleted of its most fertile part – topsoil. The physical and chemical properties of the Earth's surface are deteriorating, the content of nutrients and humus in the soil reduce, and the thickness of the soil profile decreases. However the grimness increases and prevents the growth of vegetation. The field trial was set up to evaluate the tillage technology. The measurements were carried out in Nesperská Lhota. The experiment was placed into a sandy loam Cambisol. The measurements took place in four variants of field trial which differed in soil tillage for maize. It was a different method combination of no-till and plough tillage. The simulation of intense rain was used to measure. A square area of the size 0.5 sq m was surrounded by sheet metal strips around the whole perimeter. The pantograph was placed on their underside and collected the runoff water. The soil washout was collected into the pipe and then into a graduated container. The surface runoff was collected in the container and weighed on automatic scales. Its values were recorded on a portable computer. The result of the measurement showed the difference between the various types of tillage. The beginning of the surface runoff at conventional tillage with ploughing was the shortest of all the variants. While the beginning of the surface runoff was reduced significantly longer by reduce tillage than by conventional tillage with ploughing. The results of the surface runoff speed and the speed of infiltration of water into the soil at the simulation of intense rains are in compliance with the results of those authors who report significant benefits of soil conservation tillage technology. This technology reduced the surface water runoff during the intense rainfall and increased water infiltration into the soil.

Key words: maize production; rainfall simulator; water erosion.

INTRODUCTION

The soil belongs to the most important and also the most valuable components on the planet Earth. The Earth is, however, compromised by various factors, among which water erosion belongs. During water erosion the uppermost – the most fertile part – is taken away. The way of tillage enormously influences the dimension of water erosion. Novak et al. (2012) report that conventional tillage (during sowing maize) significantly causes higher loss of soil by water erosion than processing soil conservation. An important factor for reducing water erosion is to leave crop residues on the soil surface. This is used in soil conservation tillage.

The increasing construction of biogas plants causes higher consumption of maize. This is related to increasing share of maize cultivation and also the danger of the increase of soil water erosion. The results confirm the importance of soil conservation technologies, tillage and seeding maize, in order to reduce the risk of soil degradation by water erosion. The positive impact on cover crop land was also confirmed in the space between the rows of maize (Novak et al., 2011).

The rate of water infiltration into the soil also affects the water supply of plants and water retention in the landscape during heavy rains, which is associated with the risk of flooding. Reduced technology has a significant influence on increasing the infiltration compared to the conventionally processed soil. It is all caused by the increased stability of the soil structure, more favourable distribution and pore size (Javůrek et al., 2010).

For the measurement of water erosion there is a possibility to use either natural rain or rain simulator. Although the studies are the best in natural conditions, the spatial and temporal layout of natural rain cannot be influenced and controlled. Therefore the collection of the data is slow, cumbersome and time consuming. In most cases the rainfall simulator is used. Its use diminishes the aforementioned time-consuming measurements in comparison to natural rainfall.

The aim of this measurement was to compare the dependence of the effect of tillage on the surface of water runoff during the simulated rainfall.

MATERIALS AND METHODS

Rainfall simulator was used for the measurement of the soil runoff, surface runoff and infiltration of water into the soil. Sprinkling equipment composes of sprinkling frame, on which a nozzle with a conical dispersion is placed. Water is pumped to the nozzle from the pump through a control valve and hose. With the control valve the spray pressure is controlled and regulates the intensity of watering as well as kinetic energy of drops (Kovaříček et al., 2008).

Measurements are performed on the experimental area of 0.5 sq m and a square shape. The measured area is bound by sheet metal strips. At the bottom part of the measured area the pantograph is placed. It concentrates drained soil and runoff water into the tube and subsequently into a volumetric container. The container is placed on automatic scale, which records the measured values every 5 s. The roughness of the soil surface in the direction of the fall line was evaluated by ‘chain method’ (Klick et al., 2002). Soil physical properties have been evaluated employing Kopecky’s cylinders with the volume of 100 cm^3 and subsequently analysed in the laboratories of the CULS Prague. Stand samples were taken in September 2015 for yield evaluation.

Water infiltration into the soil, surface water runoff and additional characteristics were investigated in the experimental field trial variants in Nesperská Lhota. The measurement was carried out on loamy Cambisol June 24, 2015. Each variation was measured 3 times in season 2015.The average content of Ct at the experimental plot: 2.15%. The experimental land is on a hillside with a uniform slope, average slope is 4.9°. The rainfall intensity was 90 mm h^{-1}.

Figure 1. Measurements by rainfall simulator.

The measurement was made in four variants of the field trial, which was already established in 2009. The options differ in different tillage on maize.

Variants of trial:

Variation 1 – no till

After the harvest in the summer of 2014 the straw was crushed and left in the land, while the land was left without tillage. In the spring maize was directly sown into the land without tillage.

Variation 2 – reduced tillage with spring pre-sowing tillage

In the autumn of 2014 the crown stubble cultivator took place (depth 0.08 m). During the winter, the soil was left with a surface covered by plant residues. In the spring, before maize seeding, there was a loosening of the soil by tines cultivator to a depth of 0.08 meters.

Variation 3 – conventional tillage

In the autumn of 2014, part of the land was ploughed into the middle depth (0.20 to 0.22 meters), while tractor during ploughing rode down the contours. The soil was left over in the winter in a rough furrow. In the spring sowing soil preparation took place (skid and spike gate) and maize sowings. Coverage of the surface soil by organic material at planting time was almost zero.

Variation 4 – conventional tillage and inter-row crop

At the beginning of autumn stubble disc tiller was carried (0.08 m depth). After the germination of second growth ploughing perpendicular was done to the contours. During the winter, the soil was left in a rough furrow. In the spring sowing soil preparation was conducted by seedbed cultivator with two levelling bars and harrows followed by sowing oats. 14 days after sowing oats were sown maize.

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.

Table 1. Physical properties of soil

Variation	Depth [m]	Porosity [%]	Bulk density [g cm^{-3}]
1	0.05–0.1	40.37	1.48
	0.1–0.15	44.32	1.47
	0.15–0.2	42.90	1.51
2	0.05–0.1	40.01	1.52
	0.1–0.15	41.59	1.50
	0.15–0.2	45.80	1.54
3	0.05–0.1	37.50	1.62
	0.1–0.15	39.48	1.57
	0.15–0.2	40.84	1.53
4	0.05–0.1	40.21	1.49
	0.1–0.15	40.62	1.53
	0.15–0.2	39.78	1.56

Surface runoff, infiltration rate during rainfall simulator measurement and other parameters are shown in the graphs in Figs 2 to 5.

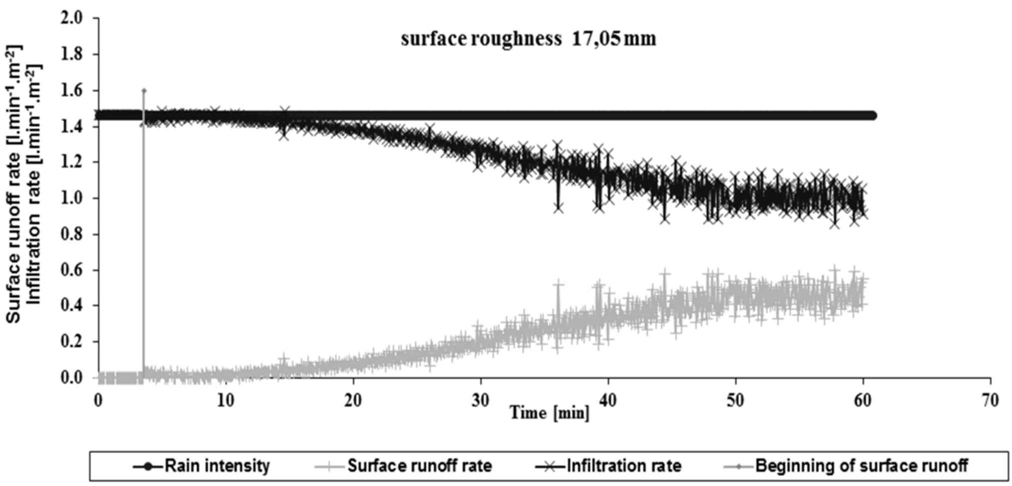

Figure 2. Process of observed values during rain simulation – Variation 1.

In the variant 1 (Fig. 2) at the onset the surface runoff was recorded 3.57 minutes after the beginning of intense rainfall simulation. Until the 15th minute the surface runoff was almost zero – the soil was able to infiltrate nearly all water. Subsequently infiltration gradually began to be reduced and at the end measurement stabilized.

Variation 2 was characterized by latest possible start of surface runoff from all four variants of the experiment. Then it was followed by a gradual increase of surface runoff, which was settled just before the end. This fact can be attributed to the spring loosening of soil to the depth of 0.08 meters. This variant showed excellent rate infiltration, but only until the loosening surface layer of soil was saturated with water.

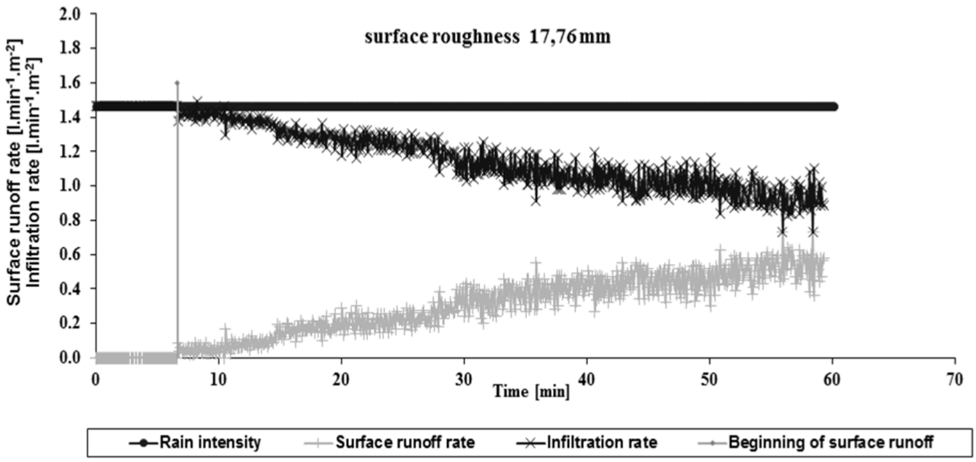

Figure 3. Process of observed values during rain simulation – Variation 2.

Variant 3 was characterized by the second earliest onset of surface runoff. This was followed by a sharp increase in short-term of surface runoff. The speed of surface runoff exceeded the values after 2 minutes of rain simulation. It conversely decreased rate of infiltration.

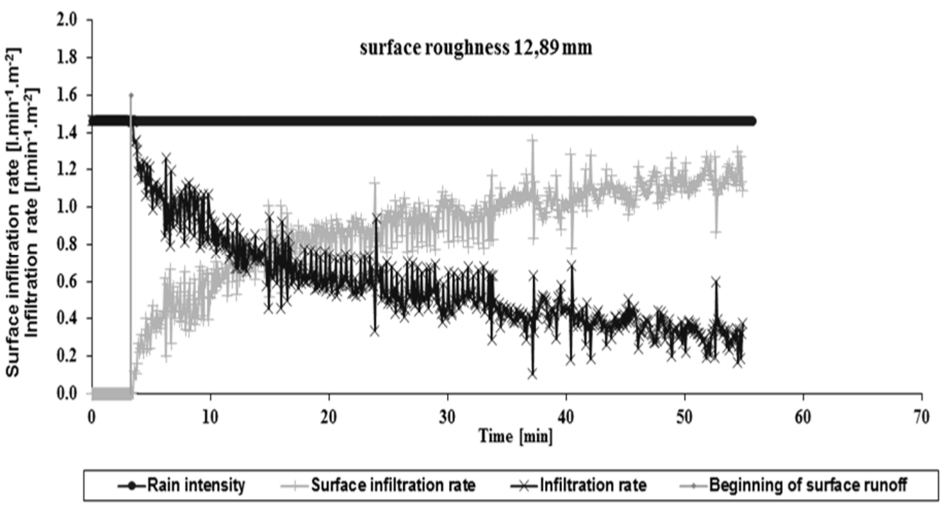

Figure 4. Process of observed values during rain simulation – Variation 3.

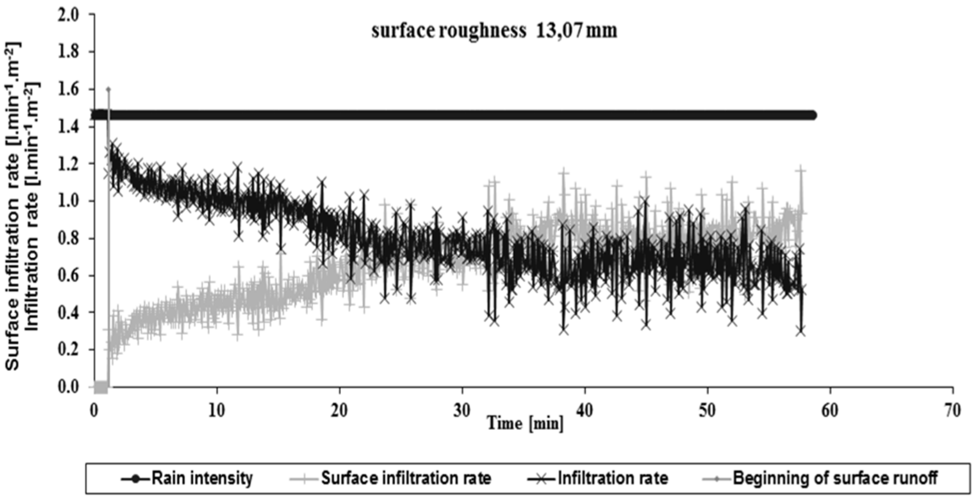

Figure 5. Process of observed values during rain simulation – Variation 4.

The time to onset of surface runoff was the shortest of all variants in the variant 4. This was caused by inter-row crops, which were filled by oats. Most area was covered by the crop. Though the time to onset of surface runoff was short, it did not manifest any significant way to the next rate of surface runoff.

The rain from the preceding measurements could also influence the conditions for the infiltration of water into the soil. The rain influenced the creation of soil crust at variant 3. The crust on the soil surface may significantly worsen the conditions for water infiltration into the soil.

The predicted reason for the low rate of infiltration is in this variant of the experiment the fact that there is a considerable deterioration of the conditions of water absorption during the following months, although just after ploughing, the soil contains macropores which facilitate infiltration of rainwater.

The measured results showed that there is a great influence of soil conservation technologies on cultivation of maize. The lowest cumulative runoff was in variant 1, which incorporated the amount of 13 kg. After that it was followed by variant 2 (autumn and spring plate preparation loosening) to 17.03 kg.

The classic tillage through plough had the largest cumulative runoff. It was 51, 35 kg. The variant 4 is to be seen as a demonstrable effect covered by organic matter. Nevertheless, given that the treated plot ploughing, it had a large influence on coverage of organic material.

Quick ability of water infiltration into the soil has a great influence on the supply of plants with water and runoff. During the intensive rainfall it leads to rapid saturation of the soil and the resulting susceptibility to flooding.

During maize cultivation on light soils land variant 3 (conventional tillage with ploughing) was most threatened by excessive surface runoff water.

Consequently in the cultivation of maize the soil should not be left without soil organic matter, thereby reducing the amount of outflowing precipitation.

The best emerged was variant 1 (no drill) for the reduced technologies which maintained the lowest value of surface runoff compared to variant 2 (disc loosening).

When comparing the measured values with the results of authors, who have dealt with the quantification of erosion processes in the application of different tillage practices in the production technology, positive protective effect of plant biomass in the soil surface and the surface layer of soil was confirmed (Truman et al., 2005; Terzoudi et al, 2007; Zhang et al., 2014; Mloza-Banda et al., 2016). Even under the conditions of the field the experiment showed that the cultivation of corn using conventional tillage technology with tillage is risky, alternative technology of maize cultivation without tillage significantly showed less erosion with the erosion events.

This experiment was designed as a multiannual. The maize yield has been also evaluated during the experiment. The five-year yield comparison reached the highest point in variation 3 (conventional technology). Variation 4 has reached only 62 percent of revenues compared to variation 3. Variation 1 has reached 81 percent of the yield, compared with variation 3. Variation 2 has reached 93 percent of the yield, compared to variaton 3

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 3 was most threatened by excessive run-off (conventional tillage with ploughing), which confirmed the risk of erosion on maize 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 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. Conditions in the Czech Republic are characterized by high average slope of the land. It is reported that approximately half of the land in the Czech Republic is threatened by water erosion.

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REFERENCES

Janeček, M. 2005. Protection of agricultural land from erosion. ISV publishing, Praha, 195 p. (in Czech).

Javůrek, M., Vach, M. & Mikanová, O. 2010. Long-term trends in the production of winter wheat in the context of soil properties under different tillage type Luvisol. *Úroda* **12**, 483–486 (in Czech).

Kovaříček, P., Šindelář, R., Hůla, J. & Honzík, I., 2008. Measurement of water infiltration in soil using the rain simulation method. *Research in Agricultural Engineering* **54**, 123–129.

Klik, A., Kaitana, R. & Badraoui, M. 2002. Desertification hazard in a mountainous ecosystem in the High Atlas region, Marocco. In. *12th ISCO Conference,* Beijing. 636–644.

Morgan, R.P.C. 2005. *Soil Erosion and Conservation.* Blackwell Publishing, London, 304 p.

Mloza-Banda, H.R, Makwiza, C.N., Mloza-Banda, M.L. 2016. Soil properties after conversion to conservation agriculture from ridge tillage in Southern Malawi. *Journal of Arid Environments* **127**, 7–16.

Novák, P., Kovaříče, P., Maše, J. & Hůl, J. 2011. Measurement of soil resistance to water erosion in three ways of establishing the maize crop. In: *10th international scientific conference engineering for rural development 26.05.2011*. LLU Jelgava, 51–54.

Novák, P., Mašek J. & Hůla J. 2012. Methods of crop stand establishment in of resistance to water. In: *11th international scientific conference engineering for rural development 24.05.2012*. LLU Jelgava. 179–183.

Terzoudi, Chr.B., Gemtos, T.A. Danalatos, N.G., Argyrokastritis, I. 2007. Applicability of an empirical runoff estimation method in central Greece. *Soil & Tillage Research*. **92**, 198–212.

Truman, C.C., Shaw, J.N. & Reeve, D.W. 2005. Tillage efects on rainfall partitioning and sediment yield from an ultisol in central Alabama. J. *Soil Water Conservation* **60**, 89–98.

Zhang, G.H., Liu, G.B., Zhang, P.C. 2014. Influence of vegetation parameters on runoff and sediment characteristics in patterned Artemisia capillaris plots. *Journal of Arid Land* **6**, 352–360.

Seed passage speed through short vertical delivery tubes at precise seeding

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Abstract. The development trend of precision seed machines is the use of central seed hopper. Another requirement is to increase the driving speed during precise sowing up to 10–12 km h^{-1}. This involves increased demand for uniformity of the seeds movement between the dosing mechanism and seed coulters. Previous measurements of seed passage speed showed undesirable changes in distance of seed during passage by long delivery tubes. The research was therefore focused on the evaluation of flyby seed parameters in short vertical delivery tubes of inner diameter 10, 12 and 14 mm and a length of 0.50 m. The aim of the experiment was to evaluate the dependence of the seed passage speed of corn, winter wheat and oilseed rape on the air pressure in the supply hose from the fan to short vertical delivery tubes and to recommend appropriate settings of air pressure in the intake air to delivery tubes. Logarithmic function was chosen for the description of dependence of flyby speed of three crops seeds on air pressure in the vertical tubes. The speed of the seed at the end of seed tubes, established as necessary for high-speed seeding (10 m s^{-1}) was achieved in all three test seed tubes when the air pressure in the supply pipe 3.0 kPa. Air speed in the vertical delivery tubes was 3.15 to 4.2 times higher than the speed of the seeds. Based on the correlation index values from 0.90 to 0.96, the high quality of the regression model was found in all cases. It was found that the short vertical delivery tubes of internal diameter 10, 12 and 14 mm are useful for a new developed seeder. On the other hand, deviations of seed passage speed for winter wheat seeds occur at higher air speed. Higher internal diameter of downtube decreased significantly seed passage speed for maize seeds.

Key words: precise seeding, flyby speed of seeds, short vertical delivery tubes.

INTRODUCTION

Individual seed hoppers for every sowing unit are still used for precision sowing machines. Seeds fall from a low height from the metering unit directly into a furrow which is produced by furrow opener. Recently, producers of seeders and precision seeders are focused on the development of machines with the application of a central hopper for seeds. The metering units for precise sowing are located above the furrow opener. Pneumatic transport of the seeds in the seed tubes is an important requirement for correct operation of machines for accurate sowing which is called high-speed seeding (precise sowing with ground speeds from 10 to 12 km h^{-1}). The seeds must be transported by the air stream in the tube at regular distances. There is also a requirement that the minimum differences would be in speed between the individual seeds for various crops. Previous measurements of seed passage speed showed undesirable changes in distance of seed during passage by long delivery tubes. According to Cui & Grace (2006), further work is needed to improve understanding of multiphase biomass pneumatic conveying and to assist in the development of biomass energy and conversion processes. Pneumatic conveying, in which particles are transported or suspended by gas (air) in vertical and horizontal conveying systems, has found wide industrial applications. Other information for studying of pneumatic conveying are in the works of Russo (2011) and Jech et al. (2011).

The physical characteristics of seeds can strongly influence their movements in the agricultural machine as well as in the air. The knowledge of the physical characteristics of particles is essential for the constructors and operators. In this respect the size, size distribution, shape, mass, bulk density, true density, coefficient of friction and aerodynamic resistance of grains are great importance (Polyak & Csizmazia, 2010).

The aim of measuring of the vertical seed flyby in delivery tubes was to determine the effect of different air pressure in the supply hose on the speed of crops seed in three short vertical downtube with different inner diameters.

MATERIALS AND METHODS

Vertical delivery tubes 0.50 m length were connected to the outlet of a fan used in FARMET Excelent seed seeders. The fan was driven by Rexroth hydrogenerator with a fluent change the rotation frequency of the fan rotor – Bosch Rexroth type ABKAG-60AL09-A10VSO-28/160M058F652. Changing the speed of the fan rotor was used to adjust the air pressure in the supply hose from the fan to vertical delivery tubes.

To measure the airstream speed in delivery tubes were used two devices: a TESTO pressure probe, 0638.1445 model connected to a TESTO 445 device with internal memory. Pressure probes were connected to Pitot tubes to measure differential pressure and airstream speed in the axis of delivery tubes (Flandro et al., 2012). Pitot tubes were installed in delivery tubes at a distance of 0.05 m in front of the end of vertical delivery tubes.

The airstream speed in vertical delivery tubes of 10, 12 and 14 mm in inside diameter and of the lengths 0.50 m was measured at a pressure in the supply hose from the fan to delivery tubes in steps of 0.5 kPa, in the range from 0.5 to 4.0 kPa (Table 1).
To measure seed passage speed BALLUFF optical sensors, BLG 30C-005-S4 model, connected to a datalogger, were used. Optical sensors were from each other at a distance of 0.10 m. The bottom optical sensor was placed at a distance of 0.05 m from the ends of the tube. The speed of seed passage was calculated from the measured time segments. Each measurement at a increasing air pressure in steps of 0.5 kPa were done in ten replications. Information about crops are in Table 2. Seed passage speed of these three crops was measured: corn, winter wheat and winter oilseed rape. Besides the size these seeds differ in shape – oilseed rape is rounded, wheat and maize have three different dimensions.

The reason for the selection of seed tubes with an inner diameter 10, 12 and 14 mm were the results of previous measurements of seed flyby in tubes with internal diameter 16 mm. Basic data about the selected seed crops are presented in Table 2.
The results of measurements were processed using Statistica 12 (StatSoft, Inc., Tulsa, Oklahoma) program.

Table 1. Air velocity in the vertical delivery downtubes with different air pressure in the supply tube

Air pressure in supply tube [kPa]	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0
The rotation speed of the fan rotor [1 min^{-1}]	1,305	1,824	2,150	2,543	2,815	3,066	3,305	3,500
Air velocity on delivery tube inner diameter 10 mm (m s^{-1})	18.15	24.37	25.53	27.70	28.48	34.97	*	*
Air velocity on delivery tube inner diameter 12 mm (m s^{-1})	17.94	23.40	29.04	34.82	38.51	43.31	47.72	*
Air velocity on delivery tube inner diameter 14 mm (m s^{-1})	17.32	23.37	30.21	30.55	31.49	44.83	48.97	*

* – out of the measuring range.

Table 2. Crops, varieties and thousand seeds weight

Crop	Variety name	Thousand seeds weight (g)
Corn (*Zea mays* L.)	CE 220 H	312.5
Winter wheat (*Triticum aestivum* L.)	Darwin	45.6
Winter rape (*Brassica napus* L. *var. napus*)	Hornet	5.6

RESULTS AND DISCUSSION

The graph in Fig. 1 shows the flyby speed of maize seed in vertical downtube with internal diameter 10, 12 and 14 mm at increasing air pressure in the supply tube. Logarithmic function was used for the description of dependence of flyby speed of corn seeds on air pressure in the vertical tubes.

The highest flyby speed of seed was always observed at the highest pressure setting, a 4 kPa. For maize seed with a decreasing inner diameter seed pipes speed flyby of seed corn grew. The differences are increased with increasing pressure within the air supply tube. For corn seed flyby speed of seed grew with a decreasing of inner diameter of delivery tube. During the seeder work it is appropriate to maintain the rotor speed of the fan at a level close to 3,000 1 min^{-1}. This value corresponds to the pressure of 3 kPa in the supply tube from the fan to delivery tubes. When air pressure exceeds 3 kPa flyby speed of seed exceeds 10 m s^{-1}, which is sufficient for reliable transport of maize seed in the short vertical tubes. Delivery tubes with inside diameter 10 and 12 mm have proved to be suitable for corn seed.

The graph in Fig. 2 shows the flyby speed of winter wheat seed in vertical downtube with internal diameter 10, 12 and 14 mm at increasing air pressure in the supply tube. Logarithmic function was also used for the description of dependence of flyby speed of winter wheat seeds on air pressure in the vertical tubes. When the air pressure in the supply hose from the fan to delivery tubes is between 1 to 3 kPa there were not statistical significant differences between the values of flyby speed. Only two values of flyby speed for highest air pressure and inner diameter of tube 12 mm showed differences.

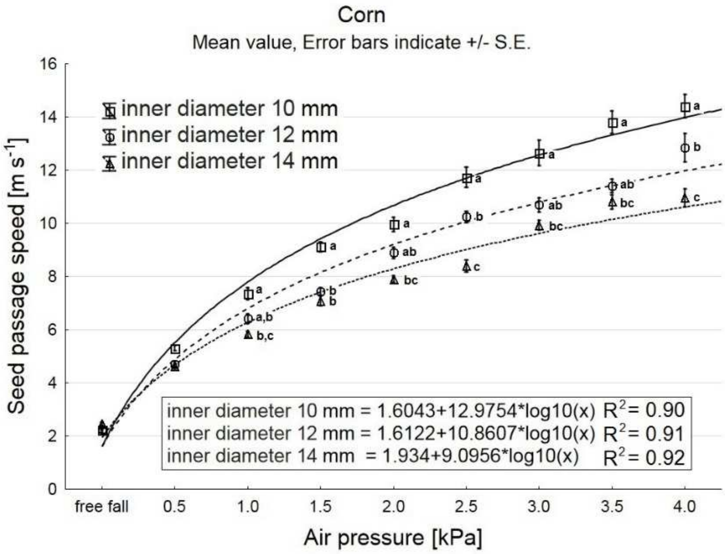

Figure 1. The flyby speed of maize seed in vertical downtube with internal diameter 10, 12 and 14 mm at increasing air pressure in the supply tube. Significant differences are indicated by different letters (a, b, c).

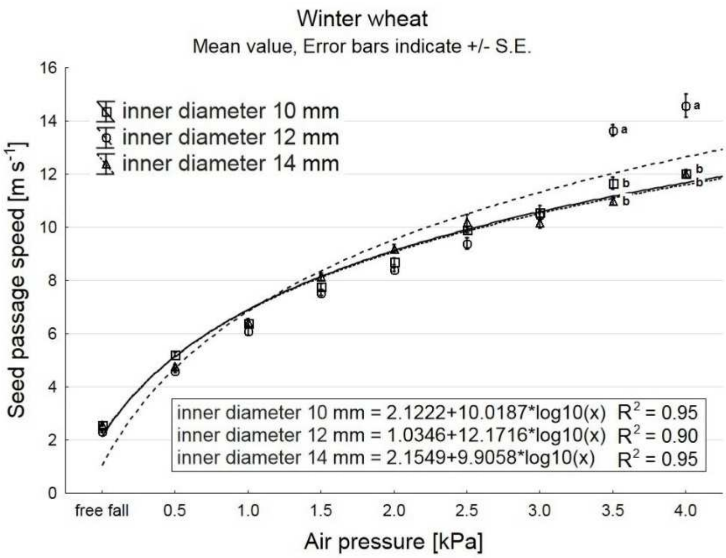

Figure 2. The flyby speed of winter wheat seed in vertical downtube with internal diameter 10, 12 and 14 mm at increasing air pressure in the supply tube. Significant differences are indicated by different letters (a, b).

There were not found statistically significant differences in the flyby speed of oilseed rape seeds (graph in Fig. 3) for delivery tube with an inner diameter of 10 and 14 mm and pressure in the range 2–4 kPa. Statistically significant differences showed values for tube with inner diameter 12 mm.

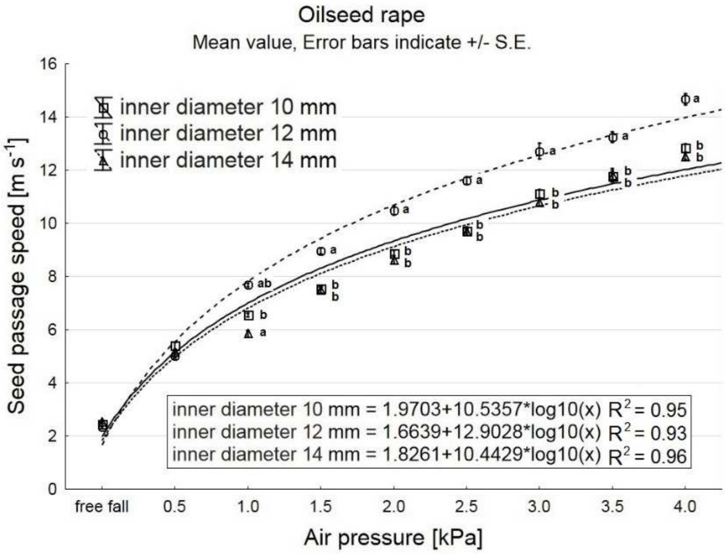

Figure 3. The flyby speed of oilseed rape seed in vertical downtube with internal diameter 10, 12 and 14 mm at increasing air pressure in the supply tube. Significant differences are indicated by different letters (a, b).

Comparison of values of flyby speed between the different seeds and inner diameter of delivery offers graphs in Figs 4, 5 and 6.

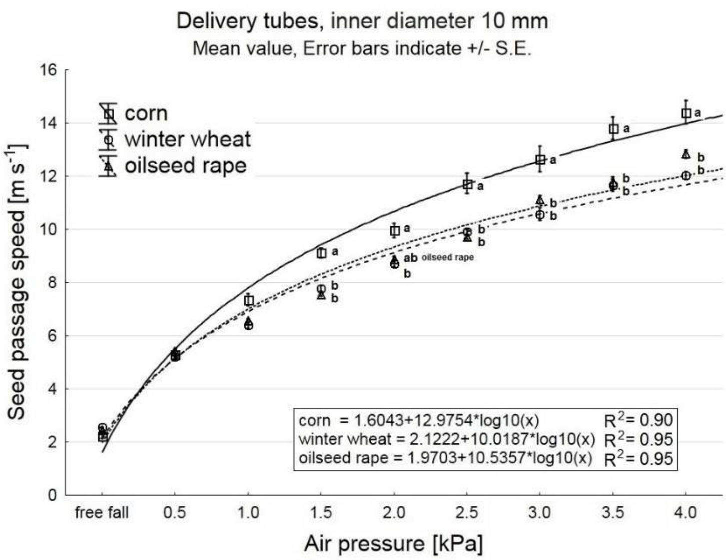

Figure 4. The flyby speed of seeds in vertical downtube with internal diameter 10 mm at increasing air pressure in the supply tube. Significant differences are indicated by different letters (a, b).

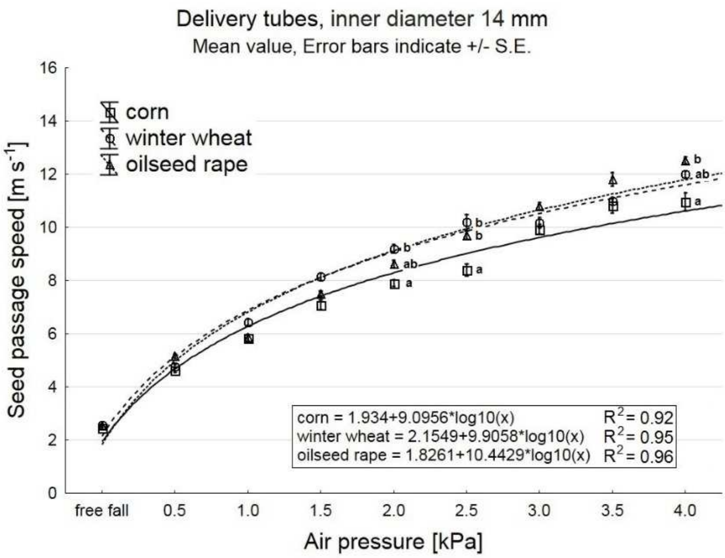

Figure 5. The flyby speed of seeds in vertical downtube with internal diameter 14 mm at increasing air pressure in the supply tube. Significant differences are indicated by different letters (a, b).

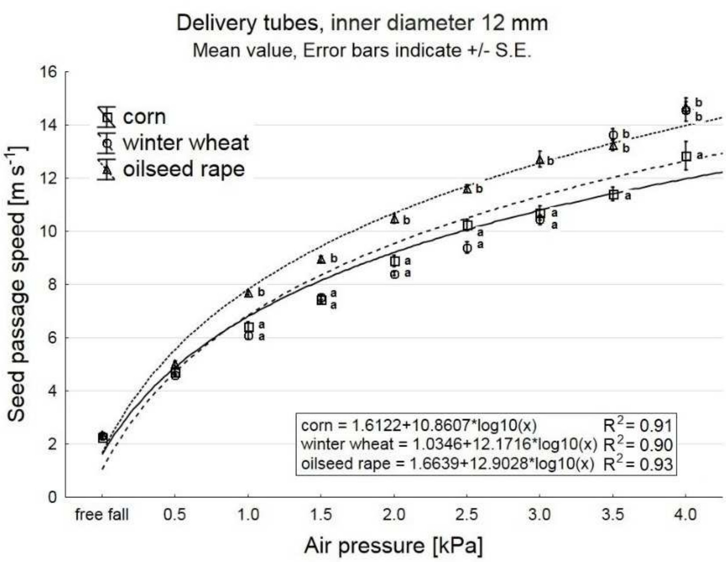

Figure 6. The flyby speed of seeds in vertical downtube with internal diameter 12 mm at increasing air pressure in the supply tube. Significant differences are indicated by different letters (a, b).

The graph at Fig. 4 shows that there are not significant differences in the flyby speed for inner diameter 10 mm for the seeds of rape and winter wheat. Maize seed showed a higher speed for values of air pressure higher than 1.5 kPa. Similar character of speed flyby was observed for wheat and oilseed rape with an internal diameter of tube 14 mm – see the graph on Fig. 5. Speed flyby of corn seed was found lower than for the wheat and rape seeds at an air pressure of 3 kPa. Other differences in the speed flyby for three crops were found in case of tube with an inner diameter of 12 mm – Fig. 6. Similar values of flyby speed of seeds were observed for maize and oilseed rape. Seeds of oilseed rape has significantly higher flyby speed.

There were not statistical differences for free fall. The values were between 2.21 to 2.57 m s^{-1}. This low flyby speed of seed in vertical delivery tube is not suitable for high-speed seeding. Based on the requirement for the seeding speed higher than 10 m s^{-1} and for better fixation of seeds in a row, the higher flyby speed of the seeds in the delivery tubes is necessary. The minimum required flyby speed of seed was achieved with the pressure 3.0 kPa in the supply tube. The flyby speed of seeds has not been measured if the air pressure in the supply tube was higher than 4 kPa, because of the risk of seeds damage was assumed. Ghafori et al. (2011) states that mechanical damage of seeds increased linearly as the air velocity increased.

The problem of high speed precision seeding is in the fact that the seeds of wheat and maize have three different dimensions: length, width and thickness. This causes irregularity in movement of these seeds during their aerial drift. There are applied the rules of aerodynamics (Caughey, 2011).

The results are in accordance with the requirements of high seeding performance in compliance with the required seeding (Kruse et al., 2008). High-speed precision seeding is a perspective to the verification of new ways of stand establishment of crops, which are used in soil conservation technologies (Götz & Bernhard, 2010).

CONCLUSIONS

After the experience with larger inner diameter delivery tube it has proved as necessary to verify the flyby seeds of selected crops seeds in vertical delivery tubes with smaller inner diameter. Air pressure in the supply tube was chosen as an indicator for setting of the seeder for pneumatic transport of seed in the delivery tubes. The air pressure is easily adjustable and easy to check by the driver and operator of the seeder.

Previous experiment with the flyby of the seeds in vertical delivery tube has shown that the risk of blockage delivery tube increases when delivery tube with inner diameter less than 10 mm was used.

For delivery tubes with internal diameter of 16 mm or more were found that the irregular movement of the seed increased and accuracy of seeding decreased. The results presented in this paper demonstrate the applicability of the short vertical delivery tubes with internal diameter of 10 to 14 mm for a new machine for precision seeding.

REFERENCES

Caughey, D.A. 2011. *Introduction to aircraft stability and control course*. Notes for M&AE 5070. New York, Cornell University Ithaca, 154 pp.

Cui, H. & Grace, J.R. 2006. Pneumatic conveying of biomass particles: a review. *China Particuology,* **4**(3–4), 183–188.

Ghafori, H., Hemmat, A., Borghaee, A.M. & Minaei, S. 2011. Physical properties and conveying characteristics of corn and barley seeds using a suction-type pneumatic conveying system. *African Journal of Agricultural Research* **27**(6), 5972–5977.

Götz, S. & Bernhard, H. 2010. Production comparison of new sowing methods and normal seed of silage maize. *Landtechnik* **2**, 107–110. (in German).
Flandro, G.A., McMahon, H.M. & Roach, R.L. 2012. *Basic aerodynamics*. Cambridge: University Press. 419 pp.
Jech, J., Angelovičová, M., Angelovič, M., Berkášek, K., Honzík, I., Kvíz, Z., Mareček J., Krnáčová, E., Polák, P., Poničan, J., Rybka, A., Ružbarský, J., Sloboba, A., Sosnowski, S., Sypula, M. & Žitňák, M. 2011. *Machines for plant production* **3**. Praha, Profi Press, 368 pp. (in Slovak).
Kruse, M., Hackländer, J., Humpisch, G., Lamprecht, H., Pippel, G. & Schwanz, H. 2008. *Seeds and seeding manual*. Agrimedia GmbH, 214 pp. (in German).
Polyak, N.I. & Csizmazia, Z. 2010. Measuring the Terminal Velocity of Particles with an Elutriator, Using Image Analysis. In: *CIGR Workshop on Image Analysis in Agriculture*, 26–27. August 2010, Budapest.
Russo, G.P. 2011. *Aerodynamic measurements*. Cambridge, Woodhead Publishing, 257 pp.

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New design of roller separation line and its effect on the separation of hop matter

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Abstract. This article deals with the roller conveyor which constitutes a part of a machine line to separate the hops harvested from low trellises. Various parameters affecting the right operation of this roller conveyor are examined. In the last season a model of roller conveyor designed and constructed for this purpose was subject to experimental verification with the objective of integrating it in the actual line. Dependency of hop matter falling through on the gap size between rollers was examined. They were standard, commonly used rollers.

In 2015 rollers with a different diameter and different profile of metal welded collars were designed and produced. The new construction allows for reducing the gap between rollers up to 20 mm. As compared to the former solution including rollers of 60 mm in diameter, this one constitutes a difference of 28 mm.

The measurements in the season of 2015 were conducted using these new rollers and there were two parameters to examine. They were the gap size between rollers and rotation frequency of the rollers. The measurements were carried out using a hop matter sample taken from low trellises. The dependency of the hop matter falling through was being examined for 3 gaps (28, 24 and 20 mm) between rollers and for three rotation frequencies of the rollers. The measurements revealed that with a setting resulting in the smallest possible gap between rollers (20 mm) by up to 15% more leaves can be separated, compared to the rollers of 80 mm in diameter, and by approx. 60% more leaves compared to the former solution including the rollers of 60 mm in diameter. Furthermore it was found that a change in rotation frequency of the gaps does not affect the separation of leaves in any significant way.

Key words: hops, separating machine, roller conveyor.

INTRODUCTION

Hops are currently used mainly as one of the basic ingredients in beer production. Ninety-eight percent of world hop production is grown for this purpose (Carter et al., 2007). Other purposes of use are not recorded in world statistics. However, their importance is well-known in pharmaceutics (Vrzalová & Fric, 1994). For instance, flavonoids contained in hop cones appear promising as antioxidants and antivirals, especially against the HIV virus (Wang et al., 2004).

Extraordinary climatic and soil conditions contribute to the exceptional aroma characteristic of Czech hop varieties. Saaz semi-early red-bine hop is still the worldwide most recognised aroma hops (EAGRI, 2014).

One of the key problems in Czech hop production is the problematic labour hiring for the most demanding operations which include e.g. hanging and sticking of hop wires and vine training. On these grounds, some growers tend to switch for hop growing on low trellises which do not require these operations. In the new growing system the hop bines spontaneously climb (wind) up a special plastic net, an essential part of a low hop-field structure (Štranc et al., 2010; Štranc et al., 2012).

Most of traditional hop varieties cannot be grown on low trellises, as these reach only 40 to 60% of the yield achieved on classic constructions (Seigner et al., 2008). New 'dwarf' varieties bred for low trellises should, according to breeders and economic experts, achieve at least 80% of the yield from the varieties grown on classic trellises (Darby, 1999).

In the Czech Republic, low trellis hop production is at the experimental stage and the current low-trellis hop-fields cover less than 50 ha (EAGRI, 2014).

This cultivation technology requires different machinery. Low trellis hops are harvested by a mobile harvester, pulled by tractor. The hop matter brought by the mobile harvester is then subject to separation in the machine separating line which is specifically adjusted contrary to the classical machine picking line. The separation is aimed at ensuring that hop cones are separated from stems and leaves (Jech et al., 2011).

This article deals with the part of a hop sorting line that is located after the secondary picker, namely with a roller conveyor with infinitely adjustable pitch of its individual rollers. This feature is important in terms of separating hop cones from stems and leaves. This roller conveyor serves as a roller screen. The main function of a roller conveyor is to separate hop matter into small-sized fraction formed by hop cones, leaves and fragments of size smaller than the size of the gap between separate rollers, and into coarse fraction composed of stems, clumps, large leaves that do not fall in between rollers (Neubauer et al., 1989).

A proper operation of a roller conveyor is affected by several parameters. They are the profile of the rollers and the gap between separate rollers. To be able to determine the precise significance of these parameters, in 2014 a model of roller conveyor was constructed, which is a scale copy of a real roller conveyor (Krupička & Rybka, 2014).

In the 2014 harvest season a set of measurements were conducted in the laboratory of the Department of Agricultural Machines, FE, CULS in Prague that addressed the dependency of the hop matter falling through on the gap size between rollers. Original rollers of 60 mm in diameter were used for the purpose of these measurements.

The objective of this research was to design and implement a new construction of the rollers which would allow for achieving better separation of leaves and small-sized impurities. Previous measurements conducted in the 2014 harvest season proved that the smaller the gap between rollers is, the more leaves get separated (Krupička & Rybka, 2015).

An original constructional solution of a roller conveyor with rollers of 60 mm in diameter enabled to set the smallest possible gap of 48 mm. When the rollers diameter was enlarged by means of pipes made of mirelon, the gap size decreased to 28 mm. Thanks to the newly designed rollers this gap became even smaller.

MATERIALS AND METHODS

Roller conveyor model

The model (Fig. 1) is a scale copy of the roller conveyor used in the sorting line to separate hops grown on low trellises. The model has a total of 9 rollers of a standard 60 mm diameter. The rollers are 600 mm long. The first roller is fixed to the frame, while the remaining 8 rollers allow for changing their pitch, thus modifying the gap between them. The space under the rollers was divided by means of KAPA boards, to be able to determine the amount of the hop matter fallen in between the separate rollers. Hop feeding was provided by a belt conveyor 600 mm wide and 1,000 mm long.

Figure 1. Model of a roller conveyor.

The throughput of the model is 450 kg h^{-1} of hop matter and is derived from the throughput of a real 2 m wide roller conveyor. This throughput corresponds to the peripheral speed of the conveyor belt of 0.27 m s^{-1} and the rotation frequency of the conveyor rollers of 0.67 s^{-1}. These values were set by means of frequency converters. Also the vertical distance of the belt conveyor from the roller conveyor corresponds to the real one.

Figure 2. Laboratory roller conveyor with rollers fitted with welded collars with toothed profile.

For the purposes of the measurement new rollers were used, of 89 mm in diameter and with toothed profile of the metal welded collars (Fig. 2). On the tube is 14 metal welded collars. They are spaced apart 39 mm. A metal welded collar has 30 teeth and the outer diameter is 125 mm. Due to the enlarged tube diameter and the height of collar 17.5 mm it is possible to set the gap between rollers to 20 mm. This profile of metal welded collars more effectively catches leaves and small-sized twigs and shifts them further on.

Measurement methodology

The 2015 harvest season measurements used again the hop variety Sládek, harvested from low trellises. To prevent the hops from changing their characteristics during the separation, the fresh hop matter was brought from the hop grower every single measurement day.

The hop matter sample was selected so that the percentage representation of individual components (hop cones, leaves) remained unchanged. A sample weighing 450 g (Fig. 3) corresponds to the throughput of the model roller conveyor, which is 450 kg h^{-1}. The sample contained 16 g of cones and 282 g of leaves. The average hop cone size was determined out of a sample comprising 100 pieces. The average value of the hop cone length was 28 mm the average value of the cone diameter was 16 mm.

Figure 3. A hop matter sample evenly spread over the conveyor belt.

The measurement was conducted in such a way that the hop matter sample was mingled and evenly spread over the conveyor belt. The sample layer was approx. 40 mm high. Then the roller drive was switched on, followed by the belt conveyor drive. The hop matter was being continuously separated on the roller conveyor and thanks to KAPA boards, installed under each roller, was falling through into 7 containers. The individual components of the hop matter that fell in between rollers were weight accurate to 1 g.

For the season of 2015 several measurements were prepared. This article deals with a measurement conducted with the rollers of 89 mm in diameter. With these rollers three gaps were possible to measure. Namely, they were gaps of 28, 24 and 20 mm.

With all the gap sizes between rollers the dependency of hop matter falling through on the rotation frequency of the rollers was also examined. The basic rotation frequency of the rollers was 0.67 s^{-1}, then 0.8 $s^{-1}$and 0.94 s^{-1}.

RESULTS AND DISCUSSION

Comparison of three different gaps between rollers of equal diameter and basic rotation frequency

The graph in Fig. 4 depicts the measured data with rollers of 89 mm in diameter and toothed profile of their metal welded collars. With the rollers measurements were carried out for a total of three gap sizes between rollers, namely 20, 24 and 28 mm. The graph clearly shows the dependency of the hop matter falling through for each gap (20, 24 and 28 mm). When the gap is set to 20 mm, only 17% of all the matter falls through the first gap, which is by approx. 13% less compared to the gap of 28 mm.

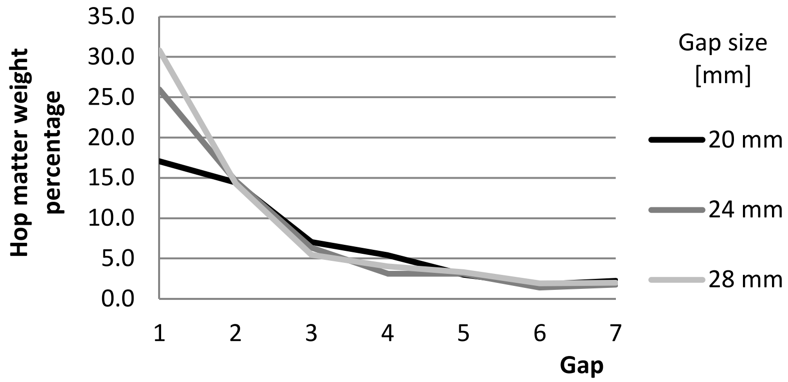

Figure 4. Weight percentage of the hop matter fallen through the separate gaps for rollers of 89 mm in diameter and rotation frequency of 0.67 s^{-1}.

A detailed view of the amount of the cones and leaves fallen through the individual gaps is illustrated in the following two graphs (Fig. 5 and 6).

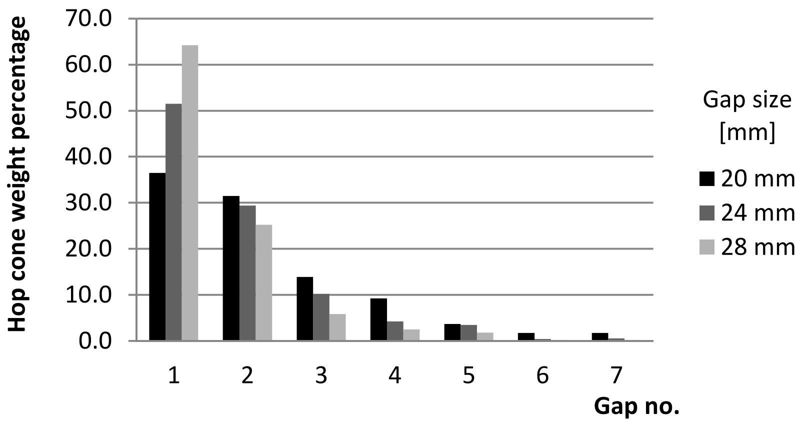

Figure 5. Weight percentage of the hop cones fallen through the separate gaps for rollers of 89 mm in diameter and rotation frequency of 0.67 s^{-1}.

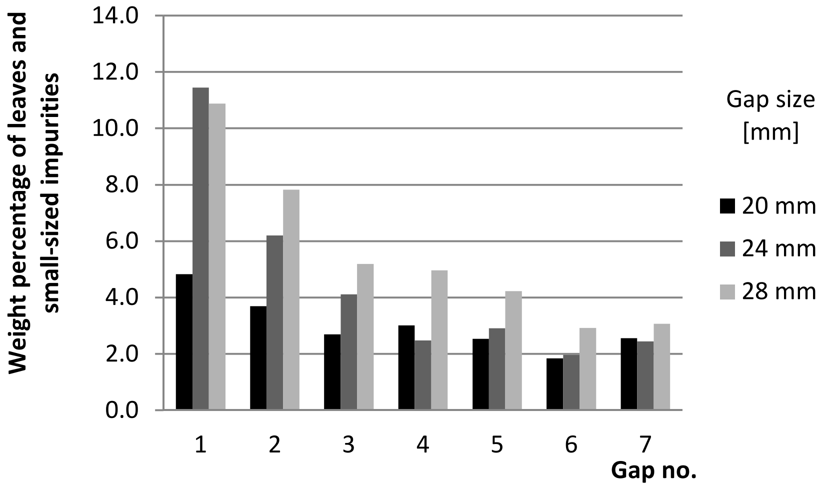

Figure 6. Weight percentage of the leaves and small-sized impurities fallen through the separate gaps for rollers of 89 mm in diameter and rotation frequency of 0.67 s^{-1}.

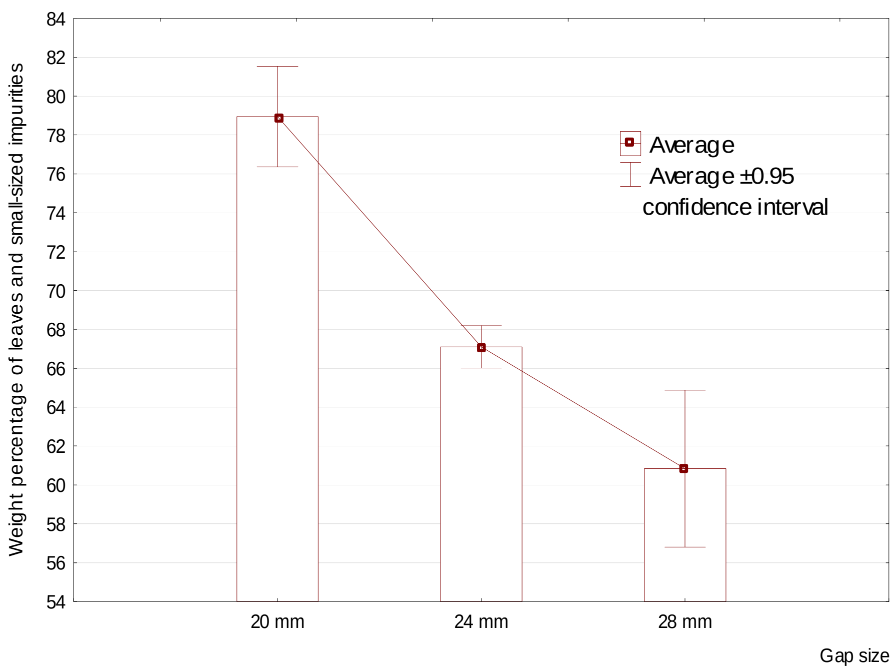

Figure 7. Weight percentage of leaves and small-sized impurities in the waste with the rollers of 89 mm in diameter and rotation frequency of 0.67 s^{-1}.

As regards the leaves and cones in the waste, the best results in terms of leaf separation were measured with the gap of 20 mm (Fig. 7). Less than 79% of all leaves were carried into the waste. With the gap set to 20 mm, by 18% more leaves were separated in comparison to the gap set to 28 mm. Another graph illustrates how many hop cones were carried into the waste. With the gap set to 20 mm the amount was 1.6% of cones, whereas with the other two gaps almost no cones ended up in the waste (Fig. 8).

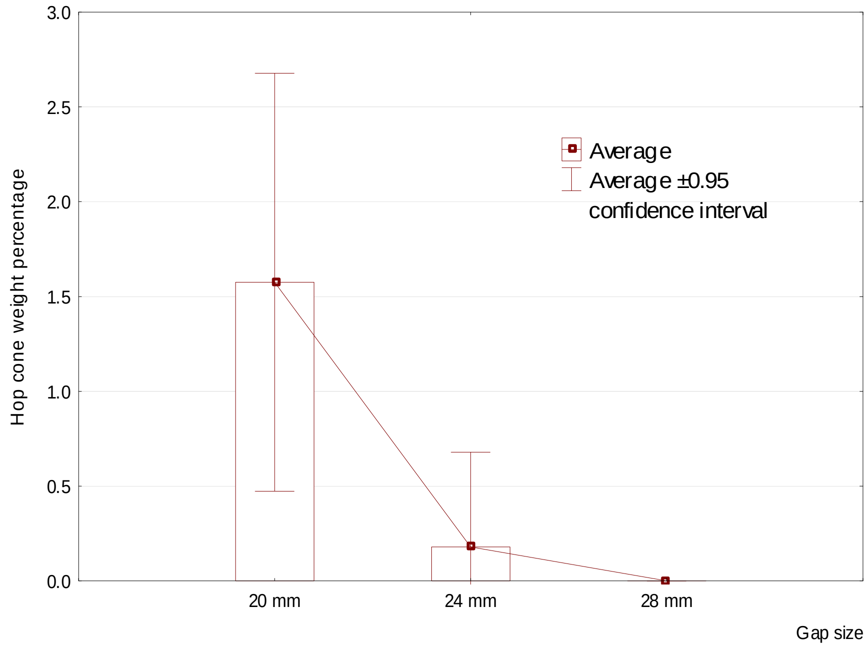

Figure 8. Weight percentage of hop cones in the waste with the rollers of 89 mm in diameter and rotation frequency of 0.67 s^{-1}.

Dependency of hop matter falling through on the gap size and rotation frequency of the rollers

The processed measured data revealed that the rotation frequency of rollers proved to have no significant effect on separation of leaves. Our assumption that increasing rotation frequency of the rollers would cause a higher percentage of leaves and small-sized impurities to leave for the waste, was not confirmed. The following graphs in pictures 9, 10 and 11 illustrate the weight percentage of leaves and small-sized impurities in the waste for individual gaps and three rotation frequencies of rollers. Apparently, no dependency can be derived from the measured data. A slight difference can be observed between the individual rotation frequencies with the gap between rollers of 28 mm and 24 mm. With the gap of 20 mm there is almost no difference.

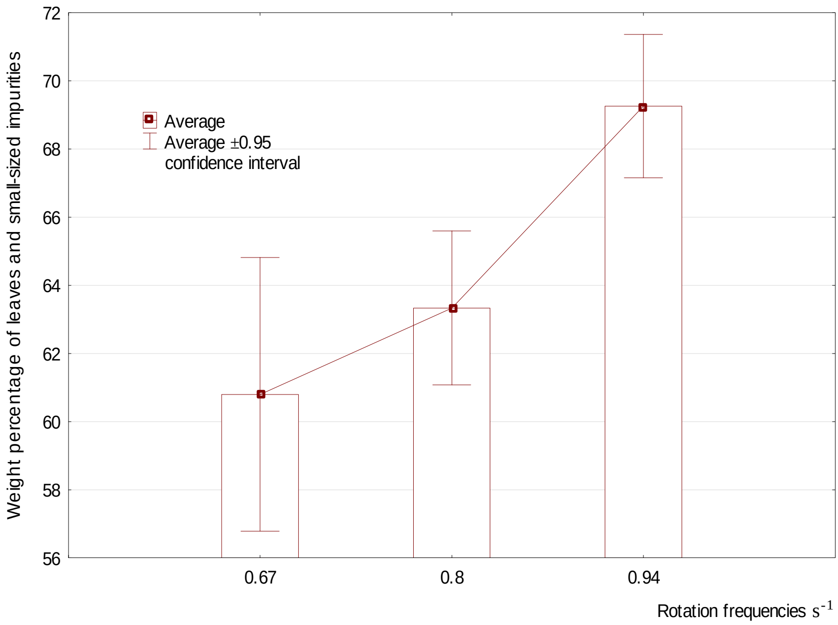

Figure 9. Weight percentage of leaves and small-sized impurities in the waste with the rollers of 89 mm in diameter, gap of 28 mm and three rotation frequencies.

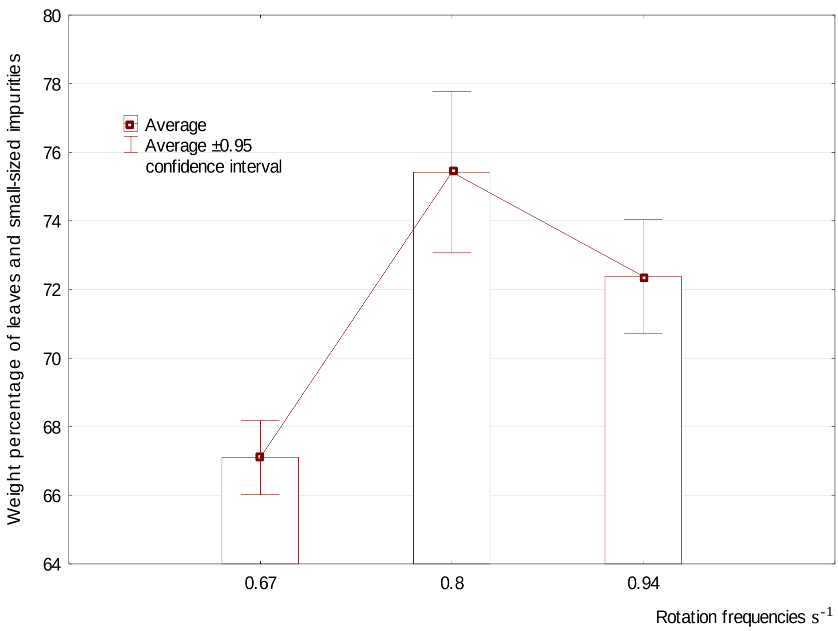

Figure 10. Weight percentage of leaves and small-sized impurities in the waste with the rollers of 89 mm in diameter, gap of 24 mm and three rotation frequencies.

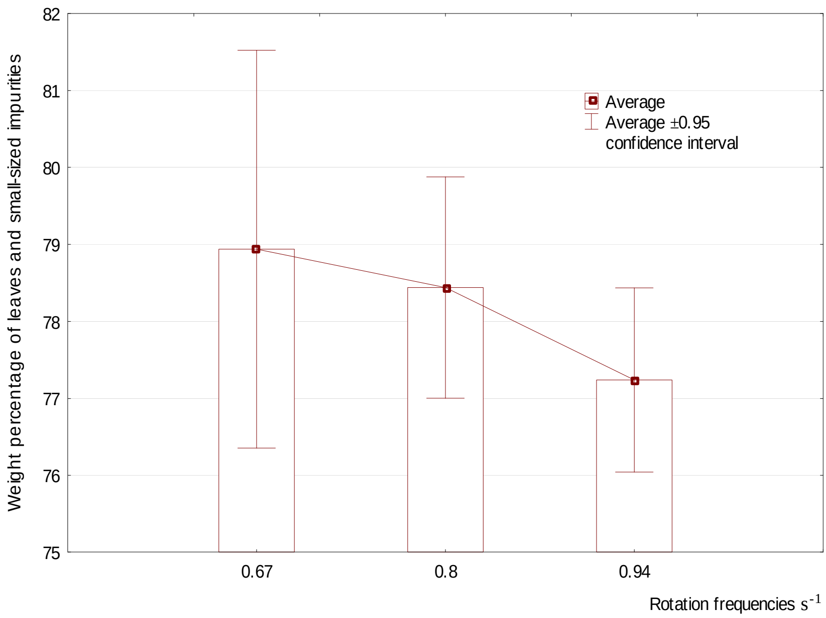

Figure 11. Weight percentage of leaves and small-sized impurities in the waste with the rollers of 89 mm in diameter, gap of 20 mm and three rotation frequencies.

CONCLUSION

In the course of the 2014 harvest season measurements it was found that neither the roller diameter nor the gap size between them have any effect on the separation of medium-length and long stems, which were separated perfectly in all cases. For this reason the measurements in 2015 were conducted using a hop matter sample which comprised only hop cones and leaves. The amount of these components had been precisely defined.

The measurements confirmed that decreasing gap between rollers results in separation of more leaves and small-sized impurities. At the same time, however, it increases the proportion of hop cones in the waste. In terms of the separation of leaves the best variant proved to be the variant with a gap of 20 mm, which was the smallest possible gap between rollers. With this gap setting, less than 79% of all leaves were carried into the waste. At the same time, however, 1.6% of hop cones was found in the waste.

When comparing these new rollers with a gap set to 20 mm with former rollers of 60 mm in diameter and the smallest possible gap of 48 mm, the difference in separated leaves makes approx. 60%.

No statistically significant differences were found when comparing different rotation frequencies of the rollers. For this reason any following measurements will be carried out with the basic rotation frequency of 0.67 s^{-1}.

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REFERENCES

Carter, P., Oelke, E., Kaminski, A., Hanson, C., Combs, S., Doll, J., Worf, G. & Oplinger. E. 2007. *Alternative field crops manual—hop*. [online] Last revision 1.8.2011). [cit. 12.1.2016]. Available from <http://corn.agronomy.wisc.edu/Crops/Hop.aspx>

Darby, P. 1999. *Economic yield potential of dwarf hop varieties. In: New Procedures in Hop Growing, Proceedings of International Symposium*, Hull, Bavaria, Federal Ministry of Food, Agriculture and Forestry, Germany

EAGRI. 2014 *Situation and Outlook Report of Hops* [online]. Last revision december 2015 [cit. 12.1.2016]. Available from: http://eagri.cz/public/web/file/433497/SVZ_Chmel_2014.PDF (in Czech)

Jech, J., Artim, J., Angelovičová, M., Angelovič, M., Bernášek, K., Honzík, I., Kvíz, Z., Mareček, J., Krnáčová, E., Polák, P., Poničan, J., Rybka, A., Ružbarský, J., Sloboda, A., Sosnowski, S., Sypula, M. & Žitňák, M., 2011. *Machines for crop production 3: machinery and equipment for post-harvest treatment of plant material*, Prague, Profi Press s.r.o., 368 p. ISBN 978-80-86726-41-0 (in Slovak).

Krupička, M. & Rybka, A. 2014. *Parameters affecting the separation small fraction of the roller track machine lines for the separation of hops*, XVI. International Conference of Young 2014, 9–10.9 2014, Czech university of life sciences Prague, Faculty of Engineering, 91–96 pp. ISBN 978-80-213-2476-3 (in Czech).

Krupička, M. & Rybka, A., 2015. Dependency of hop material fall through on the size of gaps between rollers of the roller conveyor in separating machine. *Agronomy Research* **13**(1), 101–108.

Neubauer, K., Friedman, M., Jech, J., Páltik, J. & Ptáček, F. 1989. *Machines for crop production*. SZN Praha, 716 s. ISBN 80-209-0075-6 (in Czech).

Seigner, E. & Lutz, A., Oberhollenzer, K., Seidenbergr, R., Seefelder, S., Felsenstein, F. 2008. *Breeding of hop varieties for the future*. Second International Humulus Symposium, Ghent, Belgium. ISHS *Acta Horticulturae* **848**, 49–58.

Štranc, P., Štranc, J., Holý, K., Štranc, D. & Sklenička, P., 2012. *Growing conventional varieties of hops in low trellis*, Praha: FAPPZ, ČZU v Praze a Zemědělská společnost při ČZU v Praze, ISBN 978-80-87111-33-8 (in Czech).

Štranc, P., Štranc, J., Štranc, D., Holopírek, F., Podsedník, J., Zídek, J., Alt, A. & Vent, L. 2010. *The benefits of the technology of low trellis* [online]. The last revision in 19.3.2010 [cit. 25.1.2015]. Available from: http://zemedelec.cz/prinos-technologie-nizkych-konstrukci/ (in Czech).

Vrzalová, J. & Fric, V., 1994. *Crop production – IV*. Prague: CULS Prague, FAPPZ, 80 p. ISBN 80-213-0155-4 (in Czech).

Wang, Q., Ding, Z.-H., Liu, J.-K. & Zheng, Y.-T. 2004. Xanthohumol, a novel anti-HIV-1 agent purified from hops Humulus lupulus. *Antiviral Res*. **64**, 189–194.

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Integrating ergonomics principles and workplace health protection and promotion to improve safety and health at work - evidence from Estonia

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Abstract. Previous scientific literature indicates that organisations manage workplace health promotion (WHP) in different ways. Despite conceptual and empirical justification, researchers have not consistently included concepts of WHP in ergonomics and safety studies.
The objective of the study is to explore workplace health protection and promotion activities available in Estonian organisations and to assess how ergonomic principles are integrated with workplace health protection and promotion within an organisation.
The current study adopted a multi-method approach. The WHP activities were evaluated using the questionnaire of 36 items administrated to all members (organisations) of the Estonian Human Resource Management Association. A qualitative approach includes eight case studies (organisations, with the best practices of WHP and ergonomic interventions), semi-structured interviews with human resource personnel.
The data reveal key issues in WHP management in Estonian organisations. A statistical analysis of WHP questionnaires shows many organisations with outstanding programs and positive employers' perceptions towards WHP. However, qualitative data indicate some important aspects of WHP and drawing attention to contextual variables in the development of safety management systems and improving the integration of ergonomics programs with WHP. The main contribution of the study is providing the conceptual clarification on incorporated WHP, how it complements a safety management system and showing its possible effect on employees' health, safety behaviour and on knowledge exchange. It is essential for the established WHP program to have a fully integrated part of safety management system in the organisation and employees' health and healthy behaviour must be recognised, acknowledged and be managed.

Key words: health protection, healthy workplace, ergonomics, health behaviour, health promotion.

INTRODUCTION

According to scientific literature, creating a healthy work- place is important. (McDonald et al., 2000; Zwetsloot et al., 2010; Yi, 2011; Schröer et al., 2014) Organisations deal with workplace health in different ways (Larsson, 2015). Many employers implement workplace health promotion (WHP) programs for their employees in order to improve their health, work ability and work productivity (Dul & Neumann, 2009; Zwetsloot et al., 2010; Rongen, et al., 2013). Holmqvist (2009) claims that WHP not only aims to improve health and well-being of employees; it can also contribute to generating sustainable and responsible organisations. Musculoskeletal and mental health are mainly associated with the physical and psychosocial conditions of work, as well as with individual so-called lifestyle or health behaviours. An integrated approach to occupational health and safety (OHS) and ergonomics (as a macroergonomic approach) as well as WHP should include attention to the work environment, work organisation and health behaviour in order to maintain employees' health, safety and wellbeing (Goldgruber & Ahrens, 2010). When an organisation deals with OHS proactively or/and establishes a voluntary OHS management system, it is generally complemented by WHP practices that focus not only on occupational risk reduction and safety, but also on positive factors in the work environment (e.g. employees' involvement in health and safety activities and decision making regarding OHS). (Zink, 2005) Additionally, OHS is one of the most important topics of ergonomics. Occupational ergonomics intends to improve human interaction with equipment and environments through the optimised design of job and work system. Haslam (2002) suggests that ergonomics can usefully draw upon behaviour change models developed by those concerned with health promotion in the community. Additionally, Punnet with colleagues (2009) demonstrated that macroergonomics provides a framework to improve both physical and organisational features of work, and to empower individual employees.

According to WHO (1986), health promotion can be defined as health as a resource for everyday life and the workplace as an important setting for health promotion. The most common European definition of WHP is 'the combined effort of employees, employers and the community to improve the health and well-being of people at work' (European Network for Workplace Health Promotion, 2007) Health promotion in the workplace as part of employees' well-being means that an environment is created there for valuing health and it allows healthy living. Well-being is often related to the concepts of quality of life and happiness (Stockols, et al., *cit*. Larsson, 2015) and in work settings, well-being has often been relabelled as job satisfaction, positive affect, work engagement and intrinsic motivation (Soler, et al., 2010 *cit*. Larsson, 2015). Torp et al. (2011) who analysed WHP studies regarding their use of settings approaches to the same analysis strategy as described above. Additionally, employees' good physical, mental and social health and their ability provide greater capacity for work, which is why many organisations consider health promotion as part of the organisational culture (Taylor, 2011) and motivation system components.

This article examines health promotion from the perspective of social cognitive theory. Social Cognitive Theory (SCT) started as the Social Learning Theory (SLT) in the 1960s. The social cognitive approach, rooted in an agentic model of health promotion, focuses on the demand side (Bandura, 2004). SCT has been widely used in health promotion models, since the theory promotes effective self-management of health habits that keep people healthy as well as in safety culture research. This theory is also a basis for the organisational (safety) culture reciprocal model developed by Cooper (2000) and lately supplemented by Järvis (2013) with knowledge management dimensions; it is used as the framework for the current study used to identify the activities associated with the assessment of organisational (safety) culture, health and safety as well as management of health knowledge within the organisation (Fig. 1). Workplace health is determined by many factors at the individual (person), organisational and environmental level (Zwetsloot, et al., 2010, Polanyi, et al., 2000) and, therefore, it is essential to address all these factors for effective managing of workplace health.

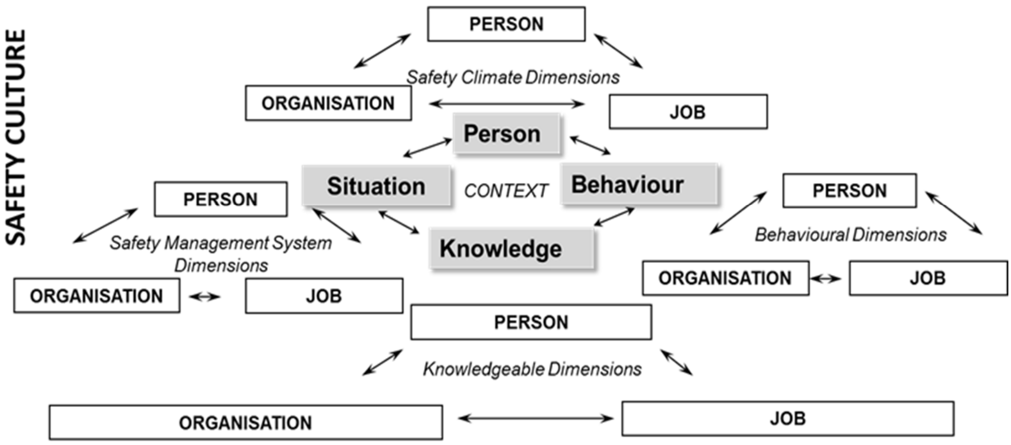

Figure 1. Reciprocal safety culture model (Järvis, 2013; Järvis et al., 2014).

Additionally, SCT presents several determinants that include knowledge of health risks and benefits of different health practices, perceived self-efficacy that one can exercise control over one's health habits, outcome expectations about the expected costs and benefits for different health habits, the health goals people set for themselves and the concrete plans and strategies for realising them, and the perceived facilitators and social and structural impediments to the changes they seek.

Health promotion can be also seen as behaviour promotion that focuses not only on 'health' concepts, but also on such psychosocial concepts as 'attitude', 'activity', 'function', and 'behaviour' (Holmqvist, 2009). This includes sets of techniques of gathering information about employees' health and behaviour as well as of programs for promotion of employees' health and wellness, changing employees' lifestyles and behaviour according to organisation norms and values. There are many human resource management programs used in order to change employees' behaviour and decrease health-related risks, which focus not only on employees' physical and mental aspects relevant to their job, but also on their individual life, including employees' social life, eating, drinking, smoking, sleeping habits, fitness (Conrad, 1987; Holmqvist, 2009). Holmqvist (2009) suggests that health promotion can be also explained and seen as social control by shaping employees' attitudes and behaviour. Additionally, there is a need to distinguish between health-programs that are intended to prevent sickness and health, and the others – to promote employees health through managing their individual behaviour (Holmqvist, 2009). It is interesting that the concept of WHP is viewed differently in Europe and in the United States (US) and Europe. For instance, in the US, the WHP generally addresses the employees' health behaviour and wellness and WHP programs include healthy eating, physical activities, smoking cessation and stress management. At the same time, in Europe, the WHP focuses also on leadership, organisation of work, physical and psychosocial work environment (Zwetsloot et al., 2010), European Network for Workplace Health Promotion, 2007) and employees' participation (Larsson, 2015).

Despite the growing interest in health and productivity in the economic benefits of workplace health management (De Greef et al., 2004; Loepkke et al., 2008), only a few studies (Sorensen, et al., 2005; Punnet et al., 2009; Larsson, 2015) have been focused on occupational health and safety intervention and have reported how WHP is managed. Kirsten (2010) claims that the number of organisations that have implemented a proactive and integrated approach to workplace health is still limited and therefore, more in-depth empirical knowledge of how workplace health promotion (WHP) is managed and integrated are needed (Larsson, 2015). Despite conceptual and empirical justification, researchers have not consistently included concepts of WHP in ergonomics and safety studies. Additionally, there is need to explore how various organisational actors, and in particular senior managers and human resource managers, describe WHP management with specific attention to the understanding of WHP as a broad approach, including its relation to general management of the organisation (Larsson, 2015).

In the light of the above arguments, in the present study we explore workplace programs available in Estonian organisations that combine OHS – especially ergonomics – with WHP, focusing on employees perceptions and emphasising the contribution of work organisation.

The objective of the study is to explore workplace health protection and promotion activities available in Estonian organisations and to assess how ergonomic principles are integrated with workplace health protection and promotion within an organisation.

MATERIALS AND METHODS

The majority of previous studies on WHP have explored individual-directed interventions or the implementation of management standards for work-related stress as well as the implementation of the WHP approach only in large organisations (Mellor et al., 2011; Mellor & Webster, 2013; Larsson, 2015). Larsson with colleagues stated that there is a need to investigate organisational actors (particular senior managers) and WHP management with specific attention how it is integrated into the general management system within an organisation. Based on the considerations above, we share Larsson's (2015) view and define WHP as a comprehensive integrated approach combining work organisation, work environment, personal practices and resources, and health behaviour in order to maintain employees' health, safety and well-being.

Data were collected during the period of December 2015-January 2016 from a questionnaire, semi-structured interviews with HR personnel and relevant documentation analysis (i.e. risk assessment, action plan related to WHP, proactive hazard control and prevention, recommendations from occupational health physicians, training plan, relevant strategy and policy, national authorities' annual report, databases etc.), which complement and verify the data collected during the interviews.

The workplace health promotion (WHP) activities were evaluated using a questionnaire of 36 items administrated to all (n = 336) members (organisations) of the Estonian Human Resource Management Association. in order to measure management health and safety priority, commitment, and competence; health promotion incentive; safety communication, training and learning, ergonomics support and local initiative in improving workplace health and safety. Altogether 56 organisations fulfilled the questionnaire and participated in the study. The majority of the respondents were from organisations operating in the private sector (68%) and from large organisations (68%) located near the capital of Estonia. The analyses have been prepared using SPSS Statistics 22.0.

To assess how ergonomic principles, workplace health protection and promotion are integrated into the OHS programs in Estonian organisations eight semi-structured face-to-face interviews with HR personnel were conducted. The sample was formed from organisations with the best practices of WHP and ergonomic interventions according to the results from Estonian Competition 'Best Work-Related Practices', based on an evaluation by Labour Inspectorate. A simple random sample was selected from those organisations based on the following criteria: best practice in WHP and ergonomics, different sizes and operational fields. In the qualitative part, the focus was on the interview guide incorporating a series of relevant themes to be covered during the interview to help direct the conversation. The objective of the interview was to build up a picture that would take into account not only how WHP is organised, implemented, maintained and integrated with ergonomic principles, but also how health promotion goals and practices are realised practically as an organisational value, how managers and employees value their safety and health, if health management is valued and supported by top management and how HR personnel viewed their role in the improvement of safety culture. The interviews were conducted in Estonian language. Each interview lasted for one hour on average and was carefully recorded, fully transcribed and analysed. We used conventional content analysis. Data analysis started with reading all data repeatedly to achieve impression and obtain a sense of the whole. Then, we read data word by word to derive codes by first highlighting the exact words from the text that appear to capture key thoughts or concepts. Every effort was made to protect privacy, confidentiality, and anonymity of individuals and organisations participating in this study.

RESULTS AND DISCUSSION

The data reveal key issues in occupational health and safety interventions and workplace health promotion (WHP) programs in Estonian organisations. The results will be presented as follows: first, the main results from the questionnaire covering different workplace intervention programs that combine WHP and ergonomics are described; second, the main findings from the interviews with human resource (HR) managers from organisations with the best WHP practices are presented.

Workplace health promotion programs and activities available in Estonian organisations

Results from the current study reveal that 80.4% of the organisations (questionnaire study) and all eight organisations (interviewing) offer health and safety promoting activities for their employees more than is required by relevant law.

Ergonomic support activities are integrated into the overall system of WHP. In practice, the management of WHP was reported as closely linked to fitness programs, which focus on providing physical exercise and other healthy lifestyle activities for employees (e.g bicycle parking, sports clubs, hiking, training etc). According to the survey only two people of 56 participants answered the question 'What are the options of fitness support in your organisation?' that in their organisation physical activities are not supported and four people answered that they are not using listed options. Additionally, these results are in a line with previous research carried out by Estonian National Institute of Health Development in 2014, where the most common form of WHP activities was physical exercise.

The rest of the answers were divided (the percentage represents the percentage of 56 respondents) as shown by the table (Table 1) below.

Table 1. Responses to the question 'Which opportunities are offered to employees in your organisation to support physical activities?'

Opportunities to support physical activities	The number of responses	% of responses
Enabling bicycle parking	37	66.1
Cooperation with sports clubs and other sports providers	30	53.6
The exercise and sports participation in the series are supported	28	50
Support will be given a one-off exercise and sports participation in events	27	48.2
The thematic information in the internal web and an information stand	22	39.3
Organising motion event	21	37.5
Thematic training courses, supervised training organisation	15	26.8
Fitness facilities accessible for employees	14	25.0
Organisation of trainings in the workplace	10	17.9
Support will purchase training equipment (sports equipment, shirts, suits, shoes, etc.)	10	17.9
Exercise and sports events advertising intermediation	10	17.9
The organisation its own fitness club	6	10.7
Mobility consultancy	6	10.7
Participation in campaigns and trainings	6	10.7
Movement advisor (-consultant) service	2	3.6
Purchase of thematic publications, literature and information materials	2	3.6
Other	10	17.9

Several of the listed activities as fitness facilities accessible for the workplace organisation of trainings in the workplace, the organisation its own fitness club and movement advisor are related to the ergonomics.

In addition to the list of survey respondents had received replies to the note more health enhancing activities offered by organisations. The list (Tables 1, 2) includes a number of activities supporting ergonomics that allows us to say that ergonomics is part of the health promotion.

Table 2. Responses to the question 'What are the other offered opportunities to support health in your organisation'

Offered opportunities to support health	Frequency	% from 56
Health services available (massage, gymnastics, swimming pool service, etc.)	32	57.1
Property to vaccination	24	42.9
Donor days	18	32.1
Health-related training courses and seminars	12	21.4
Regular series (Health-Month, Health Week, etc.)	12	21.4
Body composition measurements (eg, the percentage of fat)	10	17.9
Health information and training, and consulting on specific issues, among other things, to prevent injuries	8	14.3
Bone density measurements	1	1.8
Not for use in listed options	8	14.3
Other	0	0

The spectrum of health promotion activities is very diverse in organisations that participated in the interviews. Out of the activities which are represented in all of the organisations best practice has been gained from common summer days, where intentionally added elements are related to health promotion. In all the interviewed organisations sports activities (like fitness facilities, cooperating with sports clubs) are supported. Areas, directly related to ergonomics, of operation as well as employer's support differ. In three of the organisations surveyed, the ergonomics is particularly important. Partners who provide suitable furniture are included, seat balls are purchased, which contribute to the acquisition of ergonomic tools. In two organisations, there are mobilised climbing walls, where employees are able to stretch during rest period.

Key issues in WHP management in Estonian organisations

Leadership and management support to WHP

The study found a correlation between the results, which showed a statistically significant level $\alpha = 0.01$ between variable 'available physical activities for employees' and 'what support is provided to WHP by management'. Ratings were given on a scale from 1 (very low) up to 10 (high).

Based on the results of the questionnaire study, a strong relationship was found between management's commitment and support provided to health promotion in the organisation (questions 41–51) and support for the fitness program and physical activities offered for employees. The correlation relationship ($r = 0.477$) is of medium-strength and positive. Based on the results, it can be argued that the wider the variety of opportunities for their physical exercising and fitness programs offered to the employees by the organisation, the higher assessment scores were given by respondents to management support and commitment to WHP.

There is also a positive medium-strength ($r = 0.494$) correlation relationship between the answers to the questions '*Does your organisation carry out activities to promote employees' health?*' and '*What is management's support for health promotion in your organisation?*' The more activities are implemented within an organisation (different employees' survey / health checks etc.), the higher scores were gained in the assessment of management involvement and activities.

Almost half of the questionnaire respondents (48%) reported that WHP is the organisation's policy and there are policy documents supporting WHP. The reason why organisations started to deal with employees' WHP is clear – in order to ensure employees' health, wellbeing and safety; and the idea was initiated by senior managers (35%) and more than half of the respondents (55%) stated that employers wishes and recommendations are generally accepted. There is a significant difference between organisations in the public sector and in the private sector regarding an initiator of the WHP (12% in the public sector and 45% in private companies initiator are made by senior managers). Respondents stated that management's support is valued and perceived and it created above average in all organisations (Fig. 2). The maximum management contribution was perceived by 14.3% of the respondents.

However, the support of senior managers of private companies is more obvious than that in the public sector.

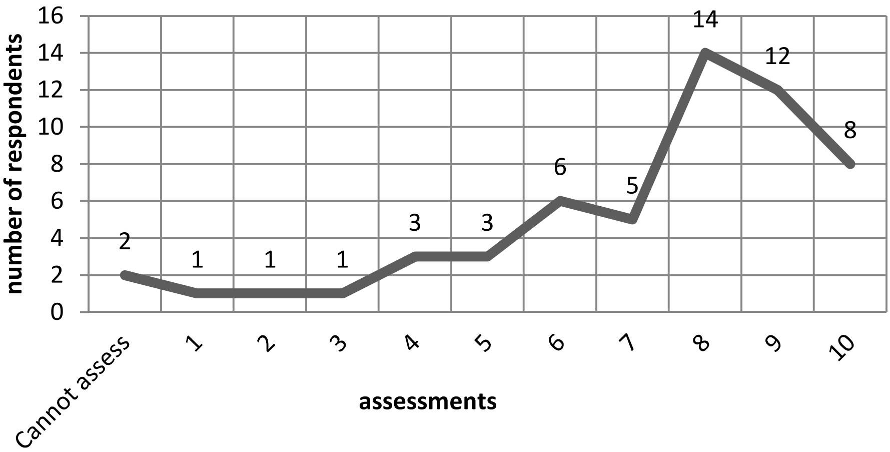

Figure 2. Responses to the question 'Please, assess the management's support for health promotion in your organisation'. (Assessments were given in Likert scale, where 1 = very small and 10 = very high).

In the investigated organisations WHP activities were related to the general management system. Most of the interviewees stated that they could not provide specific documents but the fact why dealing with health promotion already supports the management and is based on organisation's goals. It is confirmed in the interviewees' answers:

'…The documentation does not have a direct association to health promotion but there are certain amounts in the budget considered.'

'…We have a flat structure. Everybody including senior management is involved in ideas.'

'…A lot is related to the management's expectations and values. If management does not value you cannot do anything.'

Results of our study support that good leadership and employer's commitment to health and safety are essential for development of health promoting leadership, what based on organisational goals and management trends (Eriksson et al., 2011).

Based on the result from the current study, we can conclude that human resource personnel are responsible for the WHP programs and coordinate relevant activities in Estonian organisations (Fig. 3).

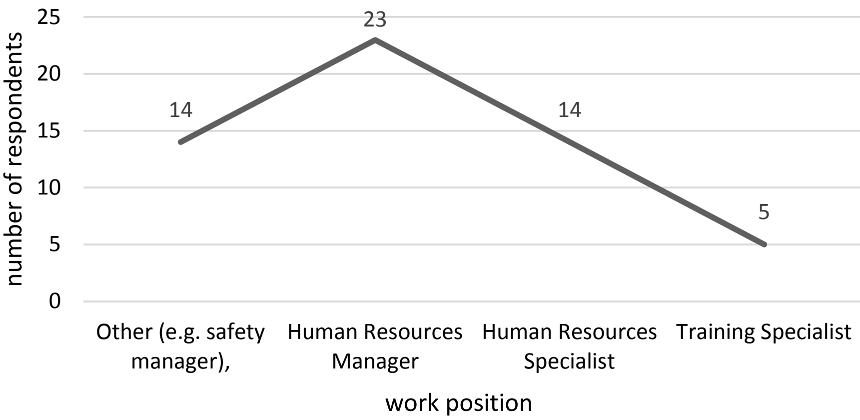

Figure 3. Responses to the question: 'Who is dealing and responsible for WHP programs and activities?'

These findings are confirmed by the results from the quality study in the organisations with 'Best Workplace Practices' award. In all eight interviewed organisations, WHP programs and related activities are also coordinated by human resource (HR) managers and HR personnel. Additionally, safety manager /work environment specialist and middle managers as well as employees' representatives are also involved in the implementation of WHP measures. One HR manager commented:

'*…A healthy mind in a healthy body! Therefore, HR personnel feel constant pressure to offer some WHP and safety activities for employees and to encourage them to participate in WHP programs provided by the employer…*'

Even though the health safety issue may not be the full responsibility of HR, it is a common practice in Estonian organisations (especially in SMEs) that a safety manager belongs to the HR department or the HR manager fulfils additional tasks as a safety manager and deals with health and safety issues. Larsson (2015) declared that in general, middle managers and the head of the department deal with WHP and are involved in inspiring individual employees to participate in WHP programs.

The current research revealed several important barriers to the uptake of health promotion: lack of financial resources (43%), lack of personnel interested in health promotion (this is the main problem in the public organisations); lack of time and knowledge about health management and possible outcomes; lack of willingness among personnel to participate in some health promotion activities. These results are similar to those reported by Armstrong with colleagues (2007). In addition, the well-known reasons are: lack of resources and expertise, lack of skills and knowledge and lack of evaluation data, mutual mistrust between lack of evaluation data (Armstrong et al., 2007).

Health and safety behaviour, employees' participation and management of health knowledge within the organisation

Based on the theory and previous studies, we can claim that attitude, behaviour and health knowledge (both employee and management) have a significant impact on health promotion within the organisation (Taylor, 2011).

It is important for the management of health and safety, how senior managers understand, perceive and expand the term 'health promotion'. Different research sources define WHP from different points of view and this will depend on the attitudes and values. Interpretations of the term 'health promotion' varied during the interviews, but the idea and the goal of WHP were common, integrating both ergonomics and general occupational health and safety in order to ensure employees' health and safety. One of the HR managers stated:

'... Health promotion also includes ergonomic interventions, for example, new job methods and equipment …'

Based on our results, it is possible to clams that investigated organisations are aware of the main values that contribute to health promotion and protection at the workplace. For those organisations, OSH means more than just focusing on formal issues required by the relevant legislation. The main focus on physical and psychological wellbeing of the employees, preventing them from harm by paying attention to behavioural aspects, and social and cultural processes within an organisation.

Most of the activities were provided both during and after working hours and these activities were seen from a social perspective in order to ensure better communication, job satisfaction and social climate within an organisation. WHP is commonly seen as an important factor how an employer can contribute both to the employees' individual health and well-being. Health and safety as a value and the top management commitment to healthy workplace and health behaviour are the key factors for an effective WHP program as well as employees' involvement to participate in WHP activities (61%). Those results are in accordance with the opinion of researchers (Holmqvist, 2009; Lapina et al., 2014; Torp & Vinje, 2014; Larsson, 2015), who have also reported that WHP is as corporate social control of employees' behaviour and a part of social responsibility of an organisation.

Involvement and activities will become possible only when people themselves value their health. Based on the results of the survey can be argued that the staff of the health promotion and the profession itself value their health. The majority of respondents 96.5% (Table 3) consider their health very important and 28.6% consider it of average importance.

Health promotion essentially depends on the employees' and management knowledge of health risks and benefits of different health practices. Perceived self-efficacy that one can exercise control over one's health habits, outcome expectations about the expected costs and benefits for different health habits, the health goals people set for themselves and the concrete plans and strategies for realising them, and the perceived facilitators and social and structural impediments to the changes they seek.

In best practices it is clearly seen that the employees are involved in the awareness-raising process.

Table 3. Responses to the question: 'How important is your health to you?'

	Frequency	Percent	Valid Percent	Cumulative Percent
On average, an important – sometimes I remember, then I will do something	16	28.6	28.6	28.6
Very important – I mean, I keep and handle	38	67.9	67.9	96.5
Other (Health is important. No special tricks and efforts do not do.)	1	1.8	1.8	98.3
Missing	1	1.8	1.8	100.0
Total	56	100.0	100.0	

Organisations employing best practices health promotion is part of the culture of the organisation. Thus, four of the eight in the same terms stated outright that

'…*Health promotion is linked to the organisation's culture'*

'…*When asked why it made these activities, the reply was that they fit the organisation'*

'…*So historically. It is this that is suitable for the organisation's activities'*

Also, in Schaefer's study worksite health promotion ranges from keeping the employees health (38.2%) to worksite health promotion as part of the business culture (9.1%). 81.1% of the companies considered their activity in worksite health promotion to be successful. Those companies that did not implement any activities for worksite health promotion, as a prime reason, state that they have not thought about it as yet (44.0%). (Schaefer et al., 2015)

In most of the organisations who had the best practices, health promotion has an important part in the process of socialisation of the staff.

'…*Synergy and flap are important'*

'…*The goal is the reduction of labour turnover. In addition to the normal, to do something different'*

When asked what is being done to ensure health promotion as a continuous process, all of the interviewees answered (though different wording but similar in spirit) that health does not consist of single projects and it is not done through a campaign. Monitored through satisfaction surveys, employee surveys and feedback, which is important, and according to that the health-related activities will be developed.

'…*Health promotion is an ongoing process'*

'…*Nothing will be done only after the campaign'*

Based on the interviews it could be argued that it is very important how employees feel about their own health.

'…*if employees do not care about their own health they can't be involved in health promotion'*

Substantial part of the activities that had been done was training and counselling as well as the support of knowledge sharing.

Views on what could constitute 'regularly informing' staff about OSH differed, from providing information on an intranet to directly notifying staff via email or at meetings. In order to be effective, WHP programs should address organisational conditions in addition to individual behaviours. It means that employees' involvement in decision making about work processes and employees' empowering, promotion learning, reward appropriately and attendees to interpersonal relationships are crucial for successful and effective health promotion and protection programs including ergonomic principles. Punnet et al. (2009) claim that an effective occupational ergonomics program must address organisational features such as incentive pay, decision latitude, task design, quality of supervision, work scheduling, understaffing, division of labour among employees and between people and machines.

Based on the research conducted by the HR staff of Estonia, it can be argued that WHP management with specific attention to the understanding of WHP as a broad approach. When an organisation deals with OHS proactively or/and establishes a voluntary OHS management system, it is generally complemented by WHP practices, focusing on not only occupational risk reduction and safety, but also on positive factors in the work environment (e.g. employees' involvement in health and safety activities).

CONCLUSIONS

A healthy and vital workforce is an asset to any organisation. Workplace health management and health promotion become increasingly relevant for organisations. This paper explores WHP programs available in Estonian organisations, how WHP is managed in eight organisations. The results from the statistical analysis of WHP questionnaires show that many organisations have outstanding programs and positive employers' perceptions and attitudes towards health promotion. The results demonstrate that WHP programs vary depending on the health risk profile, position and organisational culture. These programs include general health-related initiatives that intend to promote and increase physical exercise and improve eating habits, reduce smoking, and manage stress. However, the management of WHP was dominated by fitness programs (physical exercise), healthy habits focusing on individual health behaviour. At the same time, factors related to work organisation, work environment and, in particular, to ergonomics, were found to receive less attention. However, qualitative data indicate some important aspects of health promotion and drawing attention to contextual variables in the development of safety management systems and improving the integration of ergonomic principles with workplace health protection and promotion. In this study we described WHP programs in Estonian organisations. Based on the results of the study, it can be argued that ergonomics is not generally seen as separately stated activities, but it is a part of the health promotion and protection in the investigated organisations. An employer can establish conditions and provide opportunities as well as resources for WHP and ergonomics interventions, which can help an employee to stay healthy and, thus, ensure quality of life, well-being, and the work ability of employees. This study demonstrated that WHP is successful in those organisations where health promotion and ergonomic interventions are management topics and integrated into the safety management system. WHP also has an important role in an organisation's motivation programs, enhances work efficiency, and affects the labour flow and safety behaviour. These results indicate the need for further research in order to explore best practices of incorporation of WHP into safety management system as part of general management system. The study explores WHP programs in Estonian organisations in order to highlight the possibilities of integration them with ergonomic principles as well as safety management systems from the personnel manager's point of view. The study shows that possible barriers for the implementation of health promotion programs are as follows: lack of management support and commitment and lack of relevant knowledge. The main contribution of the study is providing the conceptual clarification on incorporated health promotion and how it complements an occupational safety management system and showing its possible effect on employees' health and safety behaviour and on knowledge exchange.

We emphasise the importance of work organisation and health and safety interventions in maintaining employees' health, safety and wellbeing. It is essential for the established workplace health promotion program to have a fully integrated part of safety management system in the organisation and employees' health and healthy behaviour must be recognised, acknowledged and be managed.

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REFERENCES

Armstrong, R., Water, E., Crockett, B. & Keleher, H. 2007. The nature of evidence resources and knowledge translation for health promotion practioners. *Health Promotion International* **22**(3), 254–260.

Bandura, A. 2004. Health promotion by social cognitive means. *Health Education and Behavior* **2**, 143–164.

Boudreau, J. & Ramstad, P. 2009. HR's evolution. *HR Monthly,* April, 34.

Conrad, P. 1987. Wellness in the Work Place: Potentials and Pitfalls of Work-Site Health Promotion. *The Milbank Quarterly* **65**(2), 225–275.

Cooper, M. 2000. Towards a model of safety culture. *Safety Science* **36**, 111–136.

De Greef, M., & Van den Broek, K. 2004. *Quality of the working environment and productivity: Research findings and case studies.* Working Paper, European Agency for Safety and HealthWork: Luxembourg.

Dowling, P. & Roots, A. 2009. Beyond HR: The new science of human capital. *Research and Practice in Human Resource Management*, July, 268.

Dul, J., & Neumann, W.P. 2009. Ergonomics contributions to company strategies. *Applied Ergonomics* **40**(4), 745–752.

Eriksson, A., Axelsson, R., & Axelsson, S.B. 2011. Health promoting leadership - Different views of the concept. *Work*.

European Network for Workplace Health Promotion. The 1065 Luxembourg Declaration on Workplace Health Promotion in the European Union. European Network for Workplace. Health Promotion; 2007 *http://www.enwhp.org/fileadmin/rs-okumente/dateien/Luxem 1069 bourg Declaration.pdf.* Accessed 7.2.2016

Goldgruber, J. & Ahrens, D. 2010. Effectiveness of workplace health promotion and primary prevention interventions: A review. *Journal of Public Health*.

Haslam, R.A. 2002. Targeting ergonomics interventions—learning from health promotion. *Applied Ergonomics* **33**(3), 241–249.

Holmqvist, M. 2009. Corporate social responsibility as corporate social control: The case of work-site health promotion. *Scandinavian Journal of Management* **25**, 68–72.

Järvis, M., Virovere, A. & Tint, P. 2014. Managers' Perceptions of Organizational Safety: Implication for the Development of Safety Culture. *Scientific Journal of Riga Technical University, Safety of Technogenic Environment* **5**, 18–28.

Järvis, M. 2013. *Assessment of the Contribution of Safety Knowledge to Sustainable Safety Management Systems in Estonian SMEs*. Doctoral thesis, Tallinn University of Technology: Tallinn University of Technology Press. pp 230.

Kirsten, W. 2010. Making the link between health and productivity at the workplace – a global perspective. *Industrial Health* 1036 **48**(3), 251–225.

Lapina, I., Maurane, G. & Starineca, O., 2014. Human Resource management models: aspects of knowledge management and corporate social responsibility. *Social and Behavioural Science* **110**, 577–586.

Larsson, R. 2015. Managing Workplace Health Promotion in Municipal Organizations. *Mälardalen University Press Dissertations*. No 172. School of Health, Care and Social Welfare, pp 78.

Loeppke, R., Nicholson, S., Taitel, M., Sweeney, M., Haufle, V & Kessler, R.C. 2008. The Impact of an Integrated Population Health Enhancement and Disease Management Program on Employee Health Risk, Health Conditions, and Productivity. *Population Health Management* **11**(6), 287–296.

McDonald, N., Corrigan, S., Daly, C. & Cromie, S. 2000. Safety management systems and safety culture in aircraft maintenance organisations. *In Safety Science* **34**, 151–176. Elsevier Sci Ltd.

Mellor, N., Mackay, C., Packham, C., Jones, R., Palferman, D., Wester, S & Kelly, P. 2011. – 'Management standards' and work-related stress in Great Britain: Progress on their implementation. *Safety Science* **49**(7), 1040–1046.

Mellor, N. & Webster, J. 2013. Enablers and challenges in implementing a comprehensive workplace health and well-being approach. *International Journal Workplace Health Management* **6**(2), 129–142.

Polanyi, M.F., Frank, J.W., Shannon, H.S., Sullivan, T.J. & Lavis, J.N. 2000. Promoting the determinants of good health in the workplace. In: Poland BD, Green LW, Rootman I, editors. Settings for health promotion: Linking theory and practice. Thousand Oaks: Sage Publications; pp. 138–160.

Punnet, L., Cherniack, M., Henning, R., Morse, T. & Faghri, P. 2009. The CPH-NEW Research Team. Conceptual Framework for Integrating Workplace Health Promotion and Occupational Ergonomics Programs. *Public health Reports* **124**, 16–24.

Rongen, A., Robroek, S.J.W., van Lenthe, F.J. & Burdorf, A. 2013. Workplace Health Promotion. A Meta-Analysis of Effectiveness. *American Journal of Preventive Medicine* **44**(4), 406–415.

Sanjib Kumar Das. 2014. Integrating Ergonomics tools in Physical Therapy for Musculoskeletal Risk Assessment and Rehabilitation- A Review. *IJESR* **2**, Issue 10.

Schaefer, E., Drexler, H. & Kiesel, J. 2015. Workplace Health Promotion in Small, Medium-Sized and Large Enterprises of the Health-Care Sector - Frequency, Reasons for the Company Management to Take Action and Barriers to Implementation. *Das Gesundheitswesen*. February.

Schröer, S., Haupt, J., & Pieper, C. 2014. Evidence-based lifestyle interventions in the workplace-an overview. *Occupational Medicine* **64**(1), 8–12.

Sorensen, G., Barbeau, E., Stoddard, A.M., Hunt, M.K., Kaphingst, K. & Wallace, L. 2005. Promoting behavior change among working-class, multi-ethnic workers: results of the healthy directions—small business study. *American Journal Public Health* **95**, 1389–1395.

Zink, K.J. 2005. Stakeholder orientation and corporate social responsibility as a precondition for sustainability. *Total Quality Management* **16**(8–9), 1041–1052.

Zwetsloot, G.I.J.M., Scheppingen, A.R. Van, Dijkman, A.J., Heinrich, J., & Besten, H. Den. 2010. The organizational benefits of investing in workplace health. *International Journal of Workplace Health Management* **3**(2), 143–159.

Taylor, T. 2011. *Occupational Safety and Health culture assessment - A review of main approaches and selected tools*. European Agency for Safety and Health at Work.

Torp, S. & Vinije, H.E. 2014. Is workplace health promotion research in the Nordic countries really on the right track? *Scandinavian Journal of Public Healt*h **42**, 74–81.

Torp, S., Eklund, L. & Thorpenberg, S. 2011. Research on workplace health promotion in the Nordic countries – a literature review, 1986–2008. *Global Health Promotion* **18**, 15–22.
Wilson, P. 2009. No direction. *HR Monthly*, May, pp. 20–3.
Workplace Health Promotion of Large and Medium-sized Businesses: The Relationship between and Predictors of Activities in two German states. Accessed 13.1.2016.

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Productivity of Vimek 404 T5 harvester and Vimek 610 forwarder in early thinning

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Abstract. The scope of the study was to evaluate productivity of small size forest machines in early thinning, as well as to identify opportunities to use this technology to Latvia. The study was implemented in Sweden using Vimek 404 T5 harvester and Vimek 610 forwarder. The machines were driven by experienced operators; harvesting and forwarding methods were adopted to the operators' experience. Time studies were done by team of researchers from Latvian State forest Research Institute 'Silava'. The study demonstrated that Vimek 404 T5 harvester has considerable advantages in compare to conventional forest machinery to produce limited number of assortments like biofuel or mixture of pulpwood and biofuel in early thinning. Annual capacity of a single harvester working in one shift is 800 ha or 25,000 m^3; however, application of the machine is limited – it might not work efficiently in commercial thinning in Latvia due to large number of assortments required by customers, and it has limited possibilities of utilization during seasonal restrictions of forest operations. Productivity of Vimek 610 forwarder is comparable with conventional middle size forwarders; however, it becomes less beneficial with increase of forwarding distance. Prime cost of biomass, including harvesting, forwarding and road transport to a 50 km distance is 14.3 EUR m^{-3}. Hourly cost of Vimek 404 T5 and 610 is similar – 26–28 EUR h^{-1}.

Key words: Vimek 404 T5, Vimek 610, early thinning, productivity.

INTRODUCTION

Demand for woody biomass as renewable material, including small dimension logs, as well as biomass is expected to rise in future. It can be supplied both by increasing planted areas of fast-growing trees and their hybrids (Jansons et al., 2014; 2013) and by more efficient extraction of wood in forest thinning operations (Lazdiņš & Thor, 2009). To increase the output of biomass from small size tree harvesting operations, specialized forest machinery including small harvesters and forwarders is of crucial importance (Spinelli et al., 2010; Spinelli & Magagnotti, 2010).

Vimek 404 T5 harvester is one of the smallest serially produced forest harvesters having at least twice smaller price than conventional 'small-size' harvesters like John Deere 1070 or Ponsse Beaver, which are currently the most common machines in forest thinning in Latvia (Būmanis & Lazdiņš, 2012). Another benefit of the Vimek harvester is low fuel consumption and maintenance costs (Lundberg, 2013a; Vimek 2013).

Vimek 404 T5 harvester is equipped Keto Forst felling head (newer models are equipped with Keto Forst Silver felling head), which is suitable for processing of small trees using accumulating function. A weight of the felling head is 300 kg and it can process trees with diameter of up to 30 cm. Control system (produced by Motomit) of the felling head is automated and it is compatible with the StanForD-standard and can be used in Joint stock company 'Latvia state forests'. It is possible to equip the felling head with stump treatment spreader. The harvester can be also equipped with other small size felling heads or guillotine heads to adopt the machine for specific operations. Ellipsoidal cutting bar improves performance of the machine in early thinning and cleaning of undergrowth (Lundberg, 2013a).

A drawback of the small felling head is ability to delimb trees in one direction only; respectively, if the operation should be repeated, an operator has to put the tree down, turn the felling head by 180 °, grip the tree again and repeat delimbing or to move tree back through feed rollers with open delimbing knifes to repeat delimbing. Both options require additional time (Lazdiņš et al., 2015).

Harvester is equipped with CAT C2.2T engine (44 kW, Kubota V2003T in earlier versions). Width of the machine is 1.8 m or 2.15 (with wider tires suitable for low baring soils), length – 3.35 m, clearance – 40 cm. Reach lenght of the MOWI 2046 crane is 4.6 m. Weight of the machine is 4400 kg. Fuel consumption is only 4 L per hour. A serial production of the machine was started nearly 15 years ago, in 2001 (Vimek 2013).

There are few offers of Vimek harvesters in the second hand market, price of the second hand machines varies from 110,000 to 145,000 EUR, which is close to a price of new machines. There are no Vimek harvesters operating in forest in Baltic states (Demonstrē ‘Vimek 610 BioCombi’).

The Vimek 610 forwarder is not unique in it's class, however, it's one of the few machines of this kind produced serially. The forwarder is equipped with the same engine as harvester, front tires of the forwarder are slightly bigger and rear tires are smaller than of the harvester. Clearance of the machine is 40 cm; length 6.8 m; loading area 1.65 m^2; height – 1.97 m; load capacity – 5,000 kg, own weight – 4,700 kg; a reach length of MOWI P25 crane is 5.2 m at maximum capacity of 330 kg (Lundberg, 2013b).

The forwarder grip is supplied with 'tilt' function, which is necessary to transport trees by crane in vertical position securing significantly smaller damages to the remaining trees. Rear axle has mechanically driven drum between tires securing better performance on slopes and low bearing capacity soils (Lundberg, 2013b).

There is only one operating Vimek 606 forwarder in Latvia, availability of the machines in the second hand market is limited. Price of the second hand machines is 75,000 to 91,000 EUR depending from conditions. Price of new machines is about 110,000 EUR.

The regulations in Latvia formally do not permit use of small machinery like Vimek 404 harvester and Vimek 610 forwarder in thinning due to limitations of area of strip-roads. According to the Latvian legislation it may not exceed 20% of the stand area. The small-size machinery makes up to 2.5 m wide strip-roads (technological corridor) every 10 meters (using the maximum extension of the crane). In practice operators do not use the maximum extension of the crane and the distance between the corridors is even smaller. In Sweden, the strip-roads made by small-size harvesters and forwarders are not considered as corridors because no trees of the dominant species should be extracted to make these reads, i.e. the limitation of 20% of the stand area is not applied on small machines. According to Swedish regulations the part of a stand under the narrow strip-roads is considered as properly tended and not as a corridor.

The scope of the study was to obtain information on productivity of the Vimek harvester and forwarder in a conventional conditions, where the operators can apply the work methods they are used to, and to identify the potential issues and their solutions if the machines are utilized in Latvia; particularly, in relation to bucking orders and limitations of area of the strip-roads.

MATERIALS AND METHODS

Researchers from the LSFRI Silava took part in time studies of Vimek 404T6 harvester and Vimek 610 forwarder in Sweden in the beginning of 2015 (the last week of February). The trial was organized by the Vimek company with support of Urban Lundström, sales manager of the company, who consulted Latvian researchers during the trials and shared experience about the use of the small-size machinery in Sweden. The issues relating to forestry and quality requirements in Sweden were explained by the manager of the logging company providing machines for the trials.

The operators participating in the trials were experienced with the type of operation (early thinning), but less experienced with the machines – they used to work before with John Deere 1070 harvester and John Deere 810 forwarder.

The work time was accounted using shock- and humidity-resistant field computer Allegro CX with time tracking software SDI. During hauling the driving speed of the forwarder was determined using GPS measurements within the SDI software.

The time studies did not include accounting of fuel consumption, and the average figures provided by the manufacturer's were used. The work time of the harvester was matched with accounting of the engine hours, i.e. the time study was stopped when the engine was switched off and resumed when the engine was started again.

The time study of thinning was done during one shift per day. The duration of a shift was 8–12 hours. The consumption of work time was determined per every crane cycle recording at the same time the average diameter of the gripped trees (at the cutting height visually) and quantity of trees processed per crane cycle. The work time elements are shown in Table 1). Volume of every load forwarded to roadside were estimated by the operator.

Produced biomass was calculated using biomass expansion factors specified for Sweden and validated by the harvester accounting system (Marklund, 1988).

The air temperature during the tests was 3–8 °C during daytime and -2–0 °C during night-time. On 23 February there were small precipitations (10 mm per day). During other days the weather conditions were optimal and did not affect the productivity.

The study was implemented in 2 spruce stands typical for delayed pre-commercial thinning in Sweden according to the machine operators. The stands were surveyed before and after the operations, including assessment of thinning quality and the stand parameters (diameter and height of trees in circular sample plots). Circular sample plots of 50 m^2 area were equally distributed across the thinned area and at least 100 trees per ha were measured (species, diameter and height of about 10% of trees) in the sample plots. Damages of remaining trees were accounted across the whole stands after harvesting and forwarding to separate impact of both machines.

Table 1. Work time elements in harvesting and forwarding

Harvesting		Forwarding	
Category	Explanation	Category	Explanation
Informative fields	work cycle number	Informative fields	various notes
	average diameter of gripped trees d1.3, mm	Productive work time	driving to stand
	qty. of gripped trees		reaching logs when loading
	felled half-trunks		gripping logs when loading
	various notes		loading logs in the bunk
Productive work time	reaching tree		arranging logs in bunk
	time for gripping tree		driving during loading
	cutting tree		putting logs and slash into strip-road
	drawing the trunk and placing in the assortment stack		driving out of stand
	clearing the undergrowth		reaching log when unloading
	bucking the tree		
	time consumed to enter the stand		unloading logs – from gripping till releasing in the yard
	time consumed to exit the stand		gripping logs when unloading
	other non-standard operations		moving when unloading
Non-productive time	activities not related to work		other work-related operations
		Non-productive time	activities not related to work

RESULTS AND DISCUSSION

The average tree diameter in Stand 1 increased from 9.7 cm to 10.3 and in Stand 2 – from 10.9 cm to12.1 cm due to thinning (Tables 2, 3), the remaining basal area decreased to 17 and 23 m^2 ha^{-1}, respectively. According to the measurement data the felled volume in Stand 1 was 73m^3 ha^{-1} and in Stand 2–89 m^3 ha^{-1} (Table 4).

Table 2. Stand characteristics before thinning

Stand	Number of trees per ha^{-1}	Diameter, cm	Height, m	Growing stock, m^3 ha^{-1}	Basal area, m^2 ha^{-1}
1	3,625	9.7	10.6	188	27
2	3,500	10.9	13.6	295	33

Table 3. Characterisation of the stands after thinning

Stand	Number of trees ha^{-1}	Average tree diameter, cm	Average tree height, m	Trunk volume, m^3 ha^{-1}	Basal area, m^2 ha^{-1}
1	2,025	10.3	10.9	115	17
2	2,000	12.1	14.3	206	23

Table 4. Parameters of extracted trees

Stand	Number of trees ha^{-1}	Trunk volume, m^3 ha^{-1}	Basal area, m^2 ha^{-1}
1	1,600	73	10
2	1,500	89	10

The number of trees remaining in the stands after thinning is comparatively high (both, according the Swedish and Latvian standards). Recommended thinning intensity in the experimental stands would be to extract 500 trees ha^{-1} more so that remaining number of trees is 1,500 trees ha^{-1} in both stands.

Most of the trees in the stands after the thinning are 9–12 cm thick; the proportion of the trees with diameter below 8.1 cm after the thinning does not exceed 10% (Fig. 1). The largest reduction during thinning took place in diameter group 5–8 cm.

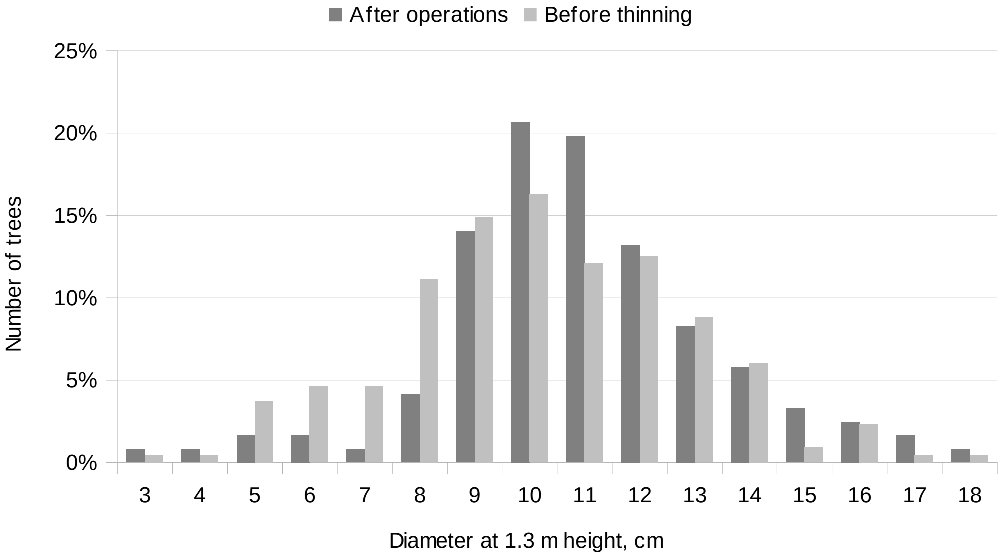

Figure 1. Distribution of the numbers of trees by diameter classes.

The time studies of the harvester and forwarder continued 3 days; the forwarder started to operate with delay of 2 days. The most of the work time was used to delimbing and bucking operations (Fig. 2); driving in and out from the stand, as well as the work cycles that did not resulted in produced logs took 9% of the work time (the time when the engine was on). Bucking, delimbing and driving in stand altogether consumed 66% of the productive time.

Trees with diameter above 8 cm dominated in extracted stock (Fig. 3). Their proportion in the number of the felled trees was 79 % and their volume was 85 % of the produced roundwood and biofuel. Operator avoided to cut trees with diameter below 8 cm; however, considering the high initial density, it was impossible to fully avoid cutting of small trees.

The diameter distribution of the extracted trees significantly differs from similar tests in Latvia (Lazdiņš et al., 2013; Lazdiņš et al., 2014; Liepiņš et al., 2015), where the most of the trees extracted in early thinning have diameter below 8 cm. The reasons for the difference are influence of the undergrowth, which is extracted to improve visibility and accessibility, and considerably higher number of types of the assortments to be produced in thinning in Latvia. Swedish experience (reduction of the number of assortments) can provide solution for this problem, however productivity and economic consequences of the optimisation of the assortments' structure should be evaluated in further studies. Another Swedish experience to expand to Latvia is getting switching to variable length of logs (2.2–5.5 m for pulpwood or biofuel logs).

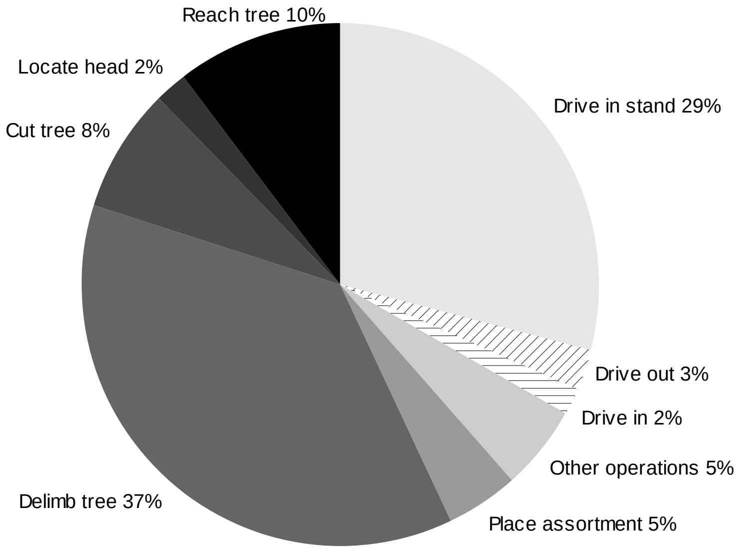

Figure 2. Distribution of work time elements in the total duration.

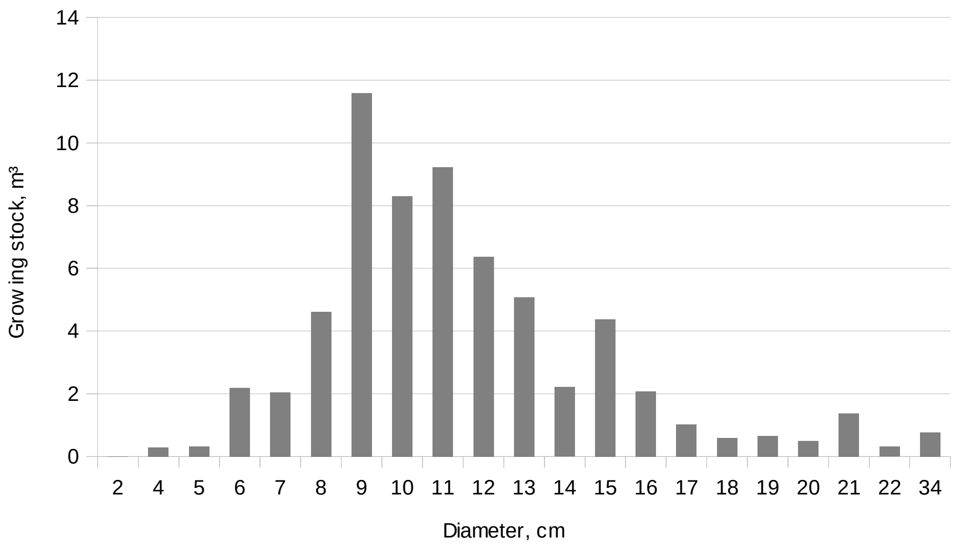

Figure 3. Distribution of the number of felled trees by diameter.

On average, in 5.3 m^3 of roundwood and biofuel was produced during 1 productive work hour (Table 5). The efficient work time (work cycles resulting with logs) was 94 % of the planned work time. Productivity increase with growth of diameter of extracted trees (Fig. 4); but number of threes processed per productive hour decreases with increase of the diameter, reaching 124 trees per productive hour at 8 cm diameter (Fig. 5).

Table 5. Summary of productivity figures of harvesting

Stand	Productivity, m^3 per productive work hour	Productivity, m^3 per planned work hour
1	5.494	5.287
2	4.783	4.638
On average	5.312	5.122

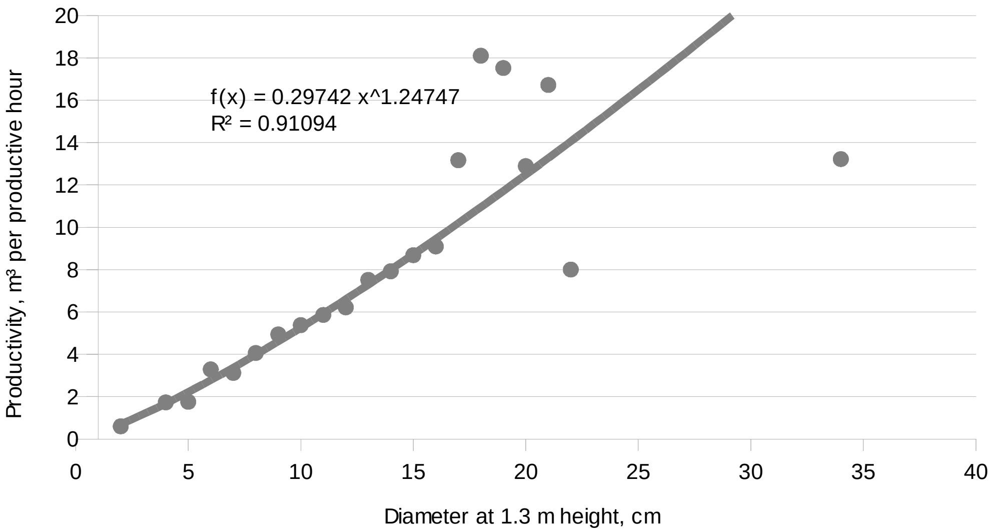

Figure 4. Harvesting productivity (m^3 per direct work hour) depending from diameter of tree.

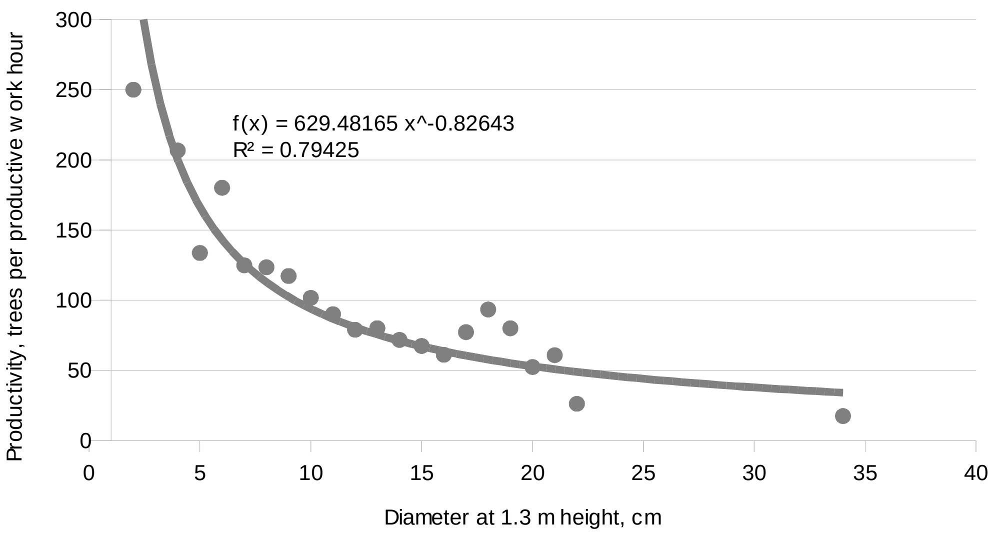

Figure 5. Harvesting productivity (trees per direct work hour) depending from diameter of tree.

Productivity of forwarding is shown in Table 6, structure of work elements – in Fig. 6. Loading and unloading time is comparable results obtained in Latvia in trials in similar conditions with heavier machines like John Deere 810D. Driving speed of the Vimek forwarder is considerably smaller (Lupiķis et al., 2014).

Table 6. Summary of forwarding productivity

Productivity of loading in, m^3 per productive work hour	Productivity of loading out, m^3 per productive work hour	Productive time from total time	Average driving speed, m min^{-1}
17.9	56.1	99%	22.7

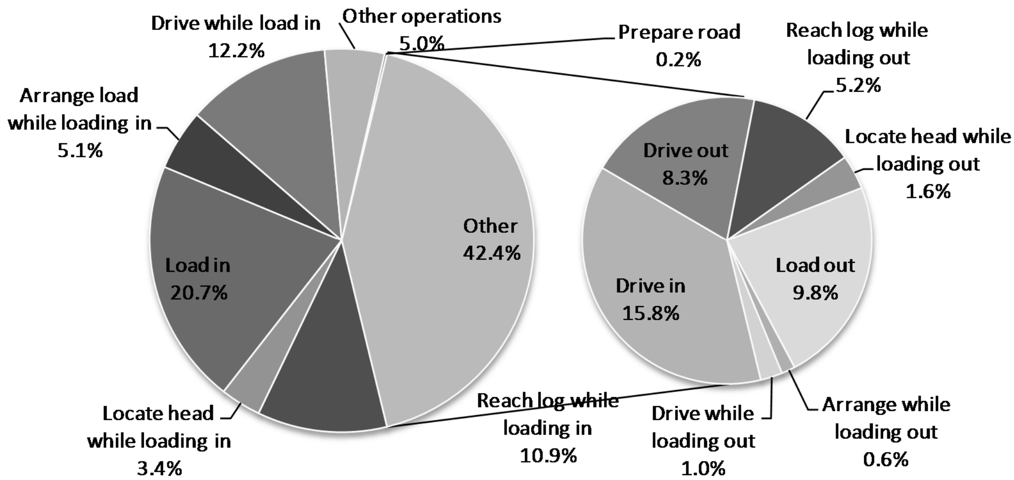

Figure 6. Structure of work elements in forwarding.

Productive time consumption per load, excluding driving, in trials was 23 min. including 17 min. for loading and 5 min. for unloading, average load was 5 m^3.

CONCLUSIONS

1. The productivity figures of harvesting obtained in early thinning in Sweden are at least twice better than the results of similar trials in Latvia. High productivity is result of better work methods (time spent to cut undergrowth trees is negligible); simple structure of roundwood and biofuel assortments in Sweden (not more than 3 types of logs are produced in early thinning, variable length of logs is accepted, all the types of logs are piled in one stack in a stand); optimal choice of work method that makes it possible to make a free network of strip-roads adjusting the pathway of harvester to the actual structure of stand.

2. Damages to the remaining trees and soil in the trials in Sweden were far below the thresholds according to Latvian regulations. The forwarder operator had no problems hauling even 5 m long logs following the path of the harvester. It is important to use this combination of machines in early thinning and not the Vimek harvester and a larger

forwarder or vice versa, as the benefits come from the use of the combination of particular harvester and forwarder.

3. The revenues from the sale of timber from thinning using Vimek machine set cover the production costs if the diameter of average cut tree is at least 6 cm if biofuel is delivered as partially delimbed small logs and at least 5 cm if wood chips are delivered to customer. The work conditions are optimal in stands where the diameter average cut tree is 8-10 cm. In stands with larger trees, in particular in fertile forest types, the productivity is hindered by the increasing time consumption for delimbing.

4. The harvester's measurement system makes it possible to account the timber according to the requirements of Joint stock company 'Latvia state forests'; consequently, there are no organisational obstacles to using this set of machines in thinning and other logging works in the state forests.

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REFERENCES

Būmanis, K. & Lazdiņš, A. 2012. *Pārskats par tehnoloģiju un tehnikas pieejamību enerģētiskās koksnes sagatavošanai un piegādei no galvenās cirtes, kopšanas cirtēm un meža infrastruktūras apauguma* (Report No. 2012/26-IP on availability of technologies for biomass production and deliveries from regenerative felling, thinning and ditch cleaning operations). LSFRI Silava, Salaspils, 65 pp. (in Latvian).

Mežaks R. 2015. Demonstrē 'Vimek 610 BioCombi' (Demonstration of 'Vimek 610 BioCombi'). *Meža avīze* **235**, p. 11. (in Latvian).

Jansons, A., Sisenis, L., Neimane, U. & Rieksts-Riekstins, J. 2013. Biomass production of young lodgepole pine (*Pinus contorta* var. latifolia) stands in Latvia. *iForest – Biogeosciences and Forestry* **6**, 10–14.

Jansons, A., Zurkova, S., Lazdina, D. & Zeps, M. 2014. Productivity of poplar hybrid (*Populus balsamifera* x *P. laurifolia*) in Latvia. *Agronomy Research* **12**, 469–478.

Lazdiņš, A., Kalēja, S., Gruduls, K. & Bārdulis, A. 2013. Theoretical evaluation of wood for bioenergy resources in pre-commercial thinning in Latvia. In: *Annual 19th International Scientific Conference Research for Rural Development Proceedings* **2**, Jelgava, Latvia, pp. 42–49.

Lazdiņš, A., Kalēja, S. & Zimelis, A. 2014. Results of evaluation of Bracke C16.b working methods in coniferous and mixed stands. In: *Proceedings of the Nordic Baltic Conference OSCAR14. Presented at the Nordic Baltic Conference OSCAR14 Solutions for Sustainable Forestry Operations,* Skogforsk, Knivsta, Sweden, pp. 106–109.

Lazdiņš, A. & Thor, M. 2009. Bioenergy from pre-commercial thinning, forest infrastructure and undergrowth – resources, productivity and costs, in: *Annual 15th International Scientific Conference Research for Rural Development Proceedings*. Jelgava, Latvia, pp. 147–154.

Lazdiņš, A., Zimelis, A., Prindulis, U. & Kalēja, S. 2015. *Vimek harvestera 404 T5 un pievedējtraktora 610 ražīgums jaunaudžu kopšanā Zviedrijā* (Report No. 2015/09, Productivity of Vimek 404 T5 harvester and Vimek 610 forwarder in early thinning in Sweden). LSFRI Silava, Salaspils, 37 pp. (in Latvian).

Liepiņš, K., Lazdiņš, A., Liepiņš, J. & Prindulis, U. 2015. Productivity and Cost-Effectiveness of Mechanized and Motor-Manual Harvesting of Grey Alder (*Alnus incana* (L.) Moench): A Case Study in Latvia. *Small-scale Forestry* **14**, 493–506.

Lundberg, F. 2013a. 404T5 – upgraded member of the dream team. *Vimek magasin 7*. Available at: https://www.yumpu.com/en/document/view/48542151/vimek-404t5-baltic-fcs. Accessed at: 11.05.2015.
Lundberg, F. 2013b. Vimek 610 enters pro class. *Vimek magasin 6*. Available at: https://www.yumpu.com/en/document/view/47254072/vimek-610. Accessed at: 11.05.2015.
Lupiķis, A., Sarkanābols, T. & Lazdiņš, A. 2014. Comparison of soil compaction using tracked and wheeled machines in early thinning. In: *Proceedings of the Nordic Baltic Conference OSCAR14. Presented at the Nordic Baltic Conference OSCAR14 Solutions for Sustainable Forestry Operations*, Skogforsk, Knivsta, Sweden, pp. 11–13.
Marklund, L.G. 1988. *Biomassafunktioner för tall, gran och björk i Sverige*. Sveriges lantbruksuniversitet, Institutionen för skogstaxering, 73 pp. (in Swedish).
Spinelli, R. & Magagnotti, N., 2010. Performance and cost of a new mini-forwarder for use in thinning operations. *Journal of Forest Research* **15**, 358–364.
Spinelli, R., Magagnotti, N. & Nati, C. 2010. Benchmarking the impact of traditional small-scale logging systems used in Mediterranean forestry. Forest *Ecology and Management* **260**, 1997–2001.
Vimek. 2013. VIMEK 404 T. Available at: http://www.forsttechnik-koch.de/papers/404-eng.pdf. Accessed at: 11.05.2015.

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Segmented capacitance sensor and first tests of inverse problem solution

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Abstract. The segmented capacitance sensor (SCS) is developed for the purpose of material throughput measurement. SCS can be used in precise agriculture (e.g. yield maps creation) or for controlling of mass flow in stationary lines. This sensor is a compromise between simple capacitance throughput sensor which has been developed at the Department of Agricultural Machines Faculty of Engineering of Czech University of Life Sciences Prague and electrical capacitance tomography sensor. The SCS consists of the bottom plate (bottom electrode) and several upper electrodes which are placed parallel above the bottom plate. The upper electrodes are sometimes called segments of an upper plate. The bottom plate is undivided and it is assumed that it will be stored under measured material. During the measurement process the electric capacitance between one upper electrode and the bottom plate is measured every time. The sensor should be able to determine the distribution of material between upper electrodes and the bottom plate. This paper presents the algorithm of inverse problem solution. The algorithm was tested in two phases. The testing during the first phase was done via mathematical model which was presented in previous papers. Results show that the presented algorithm can be used for the inverse problem solution. For the purpose of the second testing phase a simple SCS was made. Electrical capacitances were measured by precise LCR meter. In the second testing phase, the inverse problem algorithm was tested using the actually measured data.

Key words: finite element method, inverse problem, electrical capacitance tomography, electrical field.

INTRODUCTION

Material throughput measurement sensors are a very useful tool, both in the field of precision agriculture and other areas. This is noted by authors such as Kumhála et al. (2013) or Jadhav et al. (2014). Stafford et al. (1996), Savoie et al. (2002) and also Kumhála et al. (2009; 2010; 2013) have developed and tested different capacitance sensors for the material throughput measurement of plant material. The authors presented the advantages as: non-contact measurement, simple mounting on the machine, simplicity of the sensor, and low cost. The mentioned papers also confirmed the perspective of capacitance throughput sensors.

Kumhála et al. (2009) described the filling theory of the capacitance throughput sensor. It is very important that the capacitance of a sensor depends on the distribution of material between its plates. Nevertheless, the simple capacitance throughput sensors cannot provide information about material distribution. This fact can produce significant errors. The problem can be resolved with an electrical capacitance tomography (ECT). ECT is based on multiple capacitance measurement of the sensing area. Usually ECT sensors are composed of 8–14 electrodes. This means that 28–120 independent capacitance measurements are obtained. The problem is that capacitance changes are very small and they have to be measured in a large range. For example Yang (2010) presents values of capacitance change between 0.1 fF to 0.1 pF. This author also suggests that measurement accuracy should be about 0.01 fF and better. It is evident that ECT sensors are very complicated devices and for some applications (e.g. throughput measurement) a simpler device can be used. An interesting possibility can be the segmented capacitance sensor (SCS). The idea of SCS has already been described in several papers e.g. Kumhála et al. (2012), Lev et al. (2013a; 2015). The SCS consists of the bottom plate (bottom electrode) and several upper electrodes that are placed parallel above the bottom plate. The upper electrodes are sometimes called segments of an upper plate. The number of measuring upper electrodes corresponds with the number of obtained signals. This is a fundamental difference from ECT sensors, which usually produce many more output signals. It is thus necessary to use a different approach towards the solution of the inverse problem.

Yang & Peng (2003) have compared the known methods of solving the inverse problem for ECT. This process the mentioned authors call 'image reconstruction'. The authors highlight a method based on the Landweber iteration that displays qualitatively the best results. This method was tested also on SCS by Lev et al. (2012). However, it has been shown that the SCS provides too few output signals for the use of this algorithm. It has also emerged that it is possible to determine relatively well the horizontal position of the sample in the imaging region, but the determination of the vertical position is very difficult. This is probably due to the spatial arrangement of SCS.

Algorithms used by ECT assume a completely random distribution of the material in the imaging area. However, in many applications it can be assumed that the examined material forms only the layer, which could be replaced by a polygonal line specifying the boundary between the material and the air. This paper tests the method of inverse problem solution based on this approach.

MATERIALS AND METHODS

For the purpose of the experiment there was assembled a testing SCS. The sensor had 8 measuring upper electrodes that were evenly spaced in the upper part of the frame. The distance between upper electrodes and the bottom plate was 100 mm, the sensing area was 360 mm in width and 400 mm in depth. Each measuring electrode was 40 mm wide and 400 mm long. Gaps between the upper electrodes were 5 mm. Dimensions of the bottom electrode were 360 mm in width and 400 mm in length. The frame of the sensor was made from phenolic paper sheet plate (Hp 2061). The thickness of the side walls was 20 mm and the thickness of the other parts was 10 mm. All electrodes (measuring upper electrodes and bottom plate) were made from material called cuprexit that was 1 mm thick. This material is used for printed circuit board (the laminate covered with a thin layer of copper).

For the measurement of electrical capacitance there was used precision LCR meter GW Instek LCR 8110G. Electrical capacitance was measured in each measuring procedure between an upper electrode and the bottom plate. Measuring upper electrodes that were not actually used for the measurements were connected to the earth wire. The frequency of the measuring circuit was set to 100 kHz.

Inverse problem algorithm

Plugging the measuring device creates in the scanned region of SCS a relative electric field. Providing the wavelength is significantly higher than the sensor dimensions the field can be described in 3D by the Laplace equation:

$$\nabla \cdot (\varepsilon_0 \varepsilon_r \nabla \varphi) = 0 \qquad (1)$$

where: ε_0 – vacuum permittivity ($\varepsilon_0 = 8.85.10^{-12}$ $\mathrm{Fm^{-1}}$); ε_r – relative permittivity (-); φ – electric potential (V).

The electric capacitance between the measuring electrode and a bottom plate is calculated by use of equation:

$$C = -\frac{1}{U}\int_{\Gamma} \varepsilon_0 \varepsilon_r \nabla \varphi \cdot \mathrm{d}\Gamma \qquad (2)$$

where: C – electric capacitance between the measuring electrode and a bottom plate (F); U – voltage between measuring electrode and a bottom plate (V); Γ – area of the bottom plate ($\mathrm{m^2}$); $\mathrm{d}\Gamma$ – normal vector to the infinitesimal segment of the bottom plate.

The mathematical 2D model developed on the bases of Eq. (1) has been in the past already verified several times (Lev et al., 2013a; 2013b; 2015). For the SCS inverse problem solution this mathematical model must be first created. In this paper, the finite element method was used employing the Agros2D 3.2 program. In this paper, the ordered n-tuple of real numbers $a_1, a_2,\dots, a_n$ we will call (in sense of linear algebra) an n-component real vector a (vector a for short), $a = (a_1, a_2,\dots, a_n)$. Further calculations follow the rules for algebraic vectors in vector space V_n. The input of the inverse problem algorithm is the vector of normalized capacitance changes. For each component it holds:

$$c_{ni} = (c_i - c_{0i})/(c_{maxi} - c_{0i}) \qquad (3)$$

where: c_{ni} – the i-th component of the vector of normalized capacitance changes; c_i – electric capacitance between the i-th measuring upper electrode and a bottom plate; c_{0i} – electric capacitance between the i-th measuring upper electrode and a bottom plate when the sensor is empty; c_{maxi} – electric capacitance between the i-th measuring upper electrode and a bottom plate when the sensor is filled to its maximum (reference) capacity (i.e. the height of filling the SCS is 80 mm).

The algorithm aim is in finding a polygonal line, defined by points P_0 to P_9, such that it follows the actual material profile as close as possible. The end points P_0 and P_9 are during the evaluation process fixed at the edges of the sensing area. Points P_1 through P_8 are then located below centres of individual measuring upper electrodes. The problem thus reduces to finding the values of points P_1 through P_8, i.e. the vector p. The value of each point is always an integer number defined as a ratio of the point distance from the bottom plate and the dimension of one square element of the mesh. The side of the square is 5 mm in length. The mesh scale is based on the compromise between the speed and the accuracy of calculations.

To avoid adjusting or newly creating the analysis mesh whenever manipulating with the polygonal line, the space in the sensing area, corresponding the maximum filling of the sensor, is subdivided into a rectangular mesh. The searched profile then does not eventually correspond to the polygonal line. Instead it is represented by squares for which it holds that at least 50% of their area is found below the polygonal line. An example of such a situation is shown in Fig. 1. The continuous grey line represents the actual outline of the material profile, the polygonal line is plotted in black and the resulting searched profile is displayed again in grey colour.

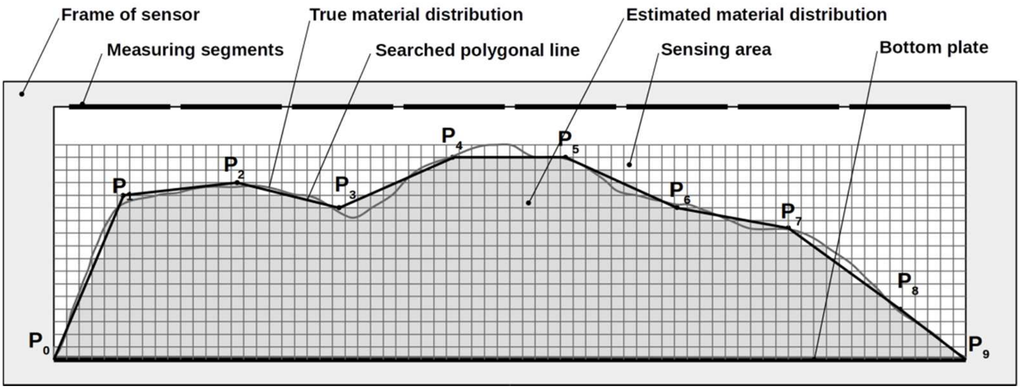

Figure 1. Cross-section of capacitance sensor. The actual distribution of the material, searched polygonal line and the estimated distribution of material are shown.

The following flowchart describes the algorithm:

1. Load vector of the normalized capacitance changes c_n, create vector p_j where index j represents the calculation step, choose the initial value of p_0 for j = 0.

2. Based on vector p_j define the distribution of material in the scanned region and for each of 8 measuring upper electrodes calculate with the help of Eq. (2) the electric capacitance between the measuring upper electrode and the bottom plate. Employing Eq. (3) calculated the normalized vector c_j (the values corresponding to an empty sensor and a sensor filled to its maximum capacity are also determined exploiting the mathematical model combined with Eq. (2)).

3. Calculate the coefficient ND_j defined as distance of vectors c_n and c_j

$$ND_j = \left\| c_n - c_j \right\| \tag{4}$$

4. Calculate the vector k, $k=(k_1,k_2,\ldots,k_i,\ldots)$,where

$$k_i = \frac{c_{ni} - c_{ji}}{\left| c_{ni} - c_{ji} \right|} \tag{5}$$

New vector p_{j+1}

$$p_{j+1} = f[p_j + k] \tag{6}$$

where f is a nonlinear function which defines individual coordinates of the vector:

$$\begin{aligned} x < 0 \quad &\Rightarrow f(x) = 0 \\ 0 \le x \le p_{max} \quad &\Rightarrow f(x) = x \\ x > p_{max} \quad &\Rightarrow f(x) = p_{max} \end{aligned} \tag{7}$$

where p_{max} is the maximum possible value of the vector coordinate. It corresponds to the height of the material outline in the scanned region having the sensor at its maximum capacity.

5. Check whether the new vector p_{j+1} (obtained through correction) has not already been used during the analysis. If not, the program returns with this new vector p_{j+1} to point 2 (index j is incremented by 1). Otherwise, the program continues.

6. Calculate the vector p_{j+1} again. First, determine the vector d_n where for each coordinate d_{ni} it holds

$$d_{ni} = \frac{c_{ni} - c_{ji}}{c_{ji}} \tag{8}$$

The vector p_j requires adjusting one component, which must correspond to the component in vector d_n with the largest absolute value and at the same time the following conditions must be satisfied

$$(d_{ni} < 0 \land p_{ji} > 0) \lor (d_{ni} > 0 \land p_{ji} < p_{max}) \tag{9}$$

The vector p_{j+1} is thus obtained from vector p_j such that the coordinate complying with the above described conditions is incremented by 1 if $d_{ni} > 0$ or reduced by 1 if $d_{ni} < 0$.

7. Perform operations described in point 2 with a new vector p_{j+1} and increment index j by 1.

8. Calculate the coefficient *NDj* using Eq. (4)

9. Compare the current and the previous coefficient *ND*. If $ND_j < ND_{j-1}$ continue with the next step 10. Otherwise, the searching process is terminated and the desired vector is identified with vector p_{j-1}.,

10. Based on vector cj determine a new vector pj+1 based on the procedure described in point 6. Then, return to point 7.

The experiment description

The inverse problem algorithm was tested on three different material profiles. As a material, timber prisms made from chipboard with a moisture content $MC_{w.b.}$ = 7.5% were used. A relative permittivity was set equal to $\varepsilon_r = 4$ (James, 1975). First, the values corresponding to an empty sensor were measured. Then, eight tested prisms were placed longitudinally into the centre of the scanned region. These prisms created an object that was used as a reference filling of SCS. This object was 80 mm high, 360 mm wide and 220 mm long. It was accepted that such a region is maximally filled and the associated measurement was used for normalizing other measurements. This reticular SCS is displayed in Fig. 2. Note the SCS cannot taken into account a different level of the filling in longitudinal direction. The depth of filling has to be constant all the time. Prisms from the same material were subsequently used to create three tested profiles. These are, including dimensions, shown in Fig. 3. Each measurement of electric capacitances was repeated three times.

Entirely identical scenario was simulated with the help of the Agros2D program. Distribution of the electric field corresponding to individual measurements was determined using the finite element method. The electric capacitance followed from Eq. (2). Initial value of vector p_0 was set to $p_0 = (8, 8, 8, 8, 8, 8, 8, 8)$. The inverse problem algorithm was also programmed in the environment of the Agros2D program. The programming language Python 2.7 and libraries NumPy 1.8.2 and Matplotlib 1.3.1 were exploited.

For the purposes of evaluating the results there was calculated the relative error of the calculated profile *RE*

$$RE = \frac{\|g_r - g\|}{\|g\|} \tag{10}$$

where g_r – vector of the contour of the calculated profile; g – vector of the contour of real profile.

The number of coordinates of vectors g_r and g equals the horizontal resolution of the sensing area. Each coordinate represents the height of the profile measured from the bottom plate. Another parameter that was used for the evaluation of the results was the relative error of profile area *REA*:

$$REA = \frac{a_r - a}{a} \tag{11}$$

where a_r – area of calculated profile (m^2); a – real area of profile (m^2).

Figure 2. Reference filling of SCS with the testing material.

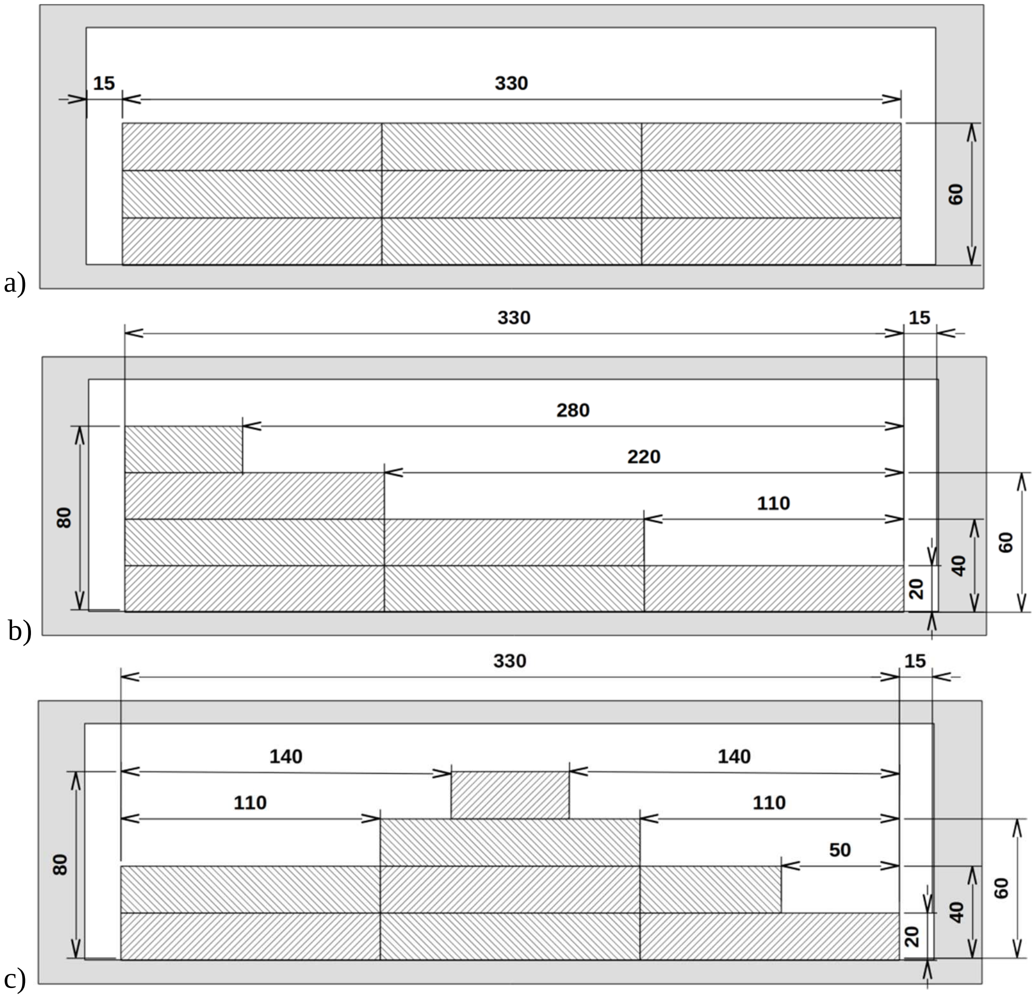

Figure 3. Profiles used for testing the inverse problem algorithm: a) – profile I, b) – profile II, c) – profile III.

RESULTS AND DISCUSSION

Results of the calculations are shown in Fig. 4. Figs 4 (a–c) represent the results based on real measurements. These results are therefore affected both by inaccuracies in the measurements and by the accuracy of the mathematical model that is used during the reconstruction. Figs 4 (d–f) represent the results calculated from simulations carried out in the program Agros2D. The effects mentioned in the text above could therefore not be applied here. So it can be assumed that the variations in Figs 4 (d–f) are due to the limits of the used algorithm.

From Fig. 4 it is apparent that the tested algorithm has problem to resolve the vertical walls of the test profiles. This behaviour is caused by using polyline which as a matter of principle cannot fulfil these requirements. However, the use of SCS is planned rather for particular materials and chipboard prisms were chosen mainly because of the simple and clear definition of test profiles.

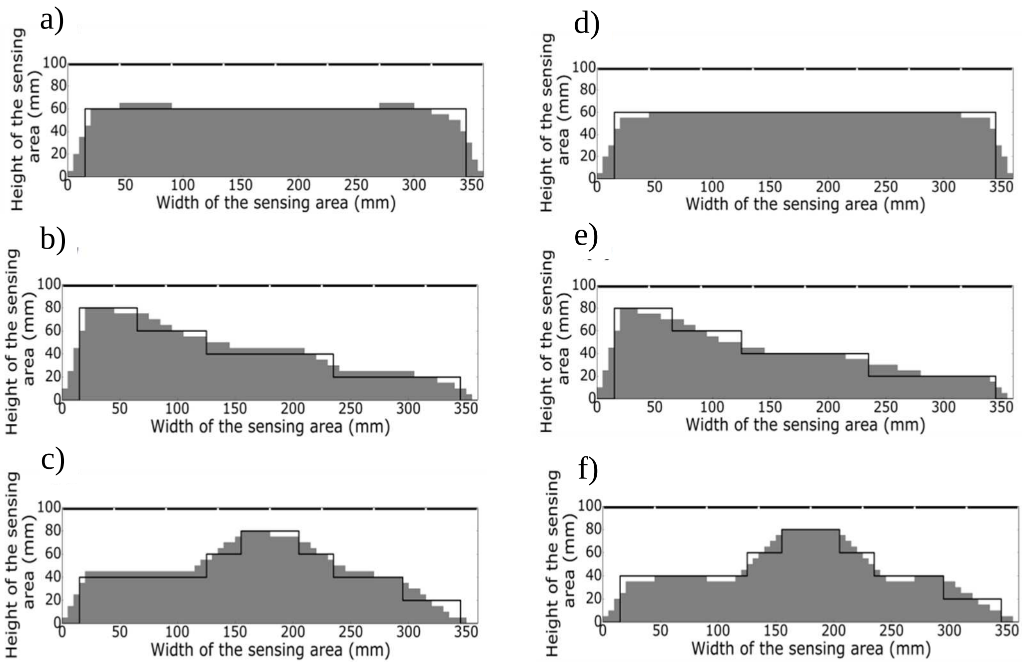

Figure 4. The calculated distribution of material in the SCS. Black curves show the actual distribution of test samples and the grey coloured area shows the calculated final layout. (a–c) represent the results based on real measurements, (d–f) represent the calculated results based on simulations carried out in the program Agros2D.

Table 1 contains calculated errors *RE* and *REA* for individual outcomes of the reconstruction algorithm. It can be said that in all three cases there was achieved a better result if the input data were obtained by simulation. This is an expected result. However, the differences posed against cases where the input data were actually measured, were not too large. It can therefore be concluded that the mathematical model used to describe the electric field in the sensing area of the SCS probably describes the actual behaviour of this electric field sufficiently.

Table 1. Comparison of results of the inverse problem algorithm. *RE* and *REA* error values are calculated by Eq. (10) and (11)

Variant	*RE* (-)	*REA* (-)
Profile I – measured input data	0.131	0.029
Profile I – calculated input data	0.119	0.008
Profile II – measured input data	0.193	0.081
Profile II – calculated input data	0.184	0.028
Profile III – measured input data	0.154	0.075
Profile III – calculated input data	0.135	0.005

RE error expresses the deviation between the actual and calculated shape of the profile. *RE* values in Table 1 range from 0.119 to 0.193. The lowest *RE* values were calculated for the profile I. It is probably due to the fact that it is a profile of the simplest shape. *REA* errors reflect the relative error of the profile area. This information may be useful if the SCS should be used for throughput measurement. According to Table 1 for cases where the input data were obtained by measurement, REA corresponds to the values 0.029 to 0.081, which is approximately 3–8%.

CONCLUSIONS

In this paper there was performed the first testing of algorithm for inverse problem solution at SCS. The results indicate that even for the relatively small number of output signals, it is possible to obtain valuable information on material distribution in the sensing area of the sensor. Further research is now needed to focus on the significant improving of the algorithm so that it can operate in real time.

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REFERENCES

Jadhav, U., Khot, L.R., Ehsani, R., Jagdale, V. & Schueller, J.K. 2014. Volumetric mass flow sensor for citrus mechanical harvesting machines. *Computers and Electronics in Agriculture* **101**, 93–101.

James, W.L. 1975. *Dielectric properties of wood and hardboard: variation with temperature, frequency, moisture content, and grain orientation.* Department of Agriculture, Forest Service, Forest Products Laboratory (U.S.), Madison, Wis, Res. Pap FPL 245, 32 pp.

Kumhála, F., Kavka, M. & Prošek, V. 2013. Capacitive throughput unit applied to stationary hop picking machine. *Computers and Electronics in Agriculture* **95**, 92–97.

Kumhála, F., Lev, J., Wohlmuthová, M. & Prošek, V. 2012. First tests with segmented capacitive throughput sensor. *Scientia Agriculturae Bohemica* **43**(1), 22–27.

Kumhála, F., Prošek, V. & Blahovec, J. 2009. Capacitive throughput sensor for sugarbeets and potatoes. *Biosystems Engineering* **102**(1), 36–43.

Kumhála, F., Prošek, V. & Kroulík, M. 2010. Capacitive sensor for chopped maize throughput measurement. *Computers and Electronics in Agriculture* **70**(1), 234–238.

Lev, J., Mayer, P., Wohlmuthová, M. & Prošek, V. 2013a. The mathematical model of experimental sensor for material distribution detecting on the conveyor. *Computing* **95**(suppl 1), 521–536.

Lev, J., Prošek, V., Wohlmuthová, M. & Kumhála, F. 2013b. The mathematical model of segmented capacitance sensor with grounded segments for determining of material distribution on the conveyor. *Agronomy Research* **11**(1), 73–80.

Lev, J., Prošek, V., Novák, P., Kumhála, F. & Wohlmuthová, M. 2015. Segmented Capacitance Sensor with Partially Released Inactive Segments. *Scientia Agriculturae Bohemica* **46**(3), 95 99.

Lev, J., Wohlmuthová, M. & Kumhála, F. 2012. Quality of material distribution imaging with segmental capacitive sensor using landweber's iterative algorithm. In: *Engineering for Rural Development 24.05.2012.* Latvia University of Agriculture, Jelgava, pp. 239–244.

Savoie, P., Lemire, P. & Thériault, R. 2002. Evaluation of five sensors to estimate mass-flow rate and moisture of grass in a forage harvester. *Applied Engineering in Agriculture* **18**(3), 389–397.

Stafford, J.V., Ambler, B., Lark, R.M. & Catt, J. 1996. Mapping and interpreting the yield variation in cereal crops. *Computers and Electronics in Agriculture* **14**, 101–119.

Yang, W.Q. & Peng L. 2003. Image reconstruction algorithms for electrical capacitance tomography. *Measurement Science and Technoogy* **14**, R1-R13.

Yang W.Q. 2010. Design of electrical capacitance tomography sensors. *Measurement Science and Technoogy* **21**(4), 1–13.

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Long-term effect of spruce bark ash fertilization on soil properties and tree biomass increment in a mixed scots pine-Norway spruce stand on drained organic soil

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Abstract. Ash contains all plant nutrients, except N, and is often used to facilitate forest growth and to prevent nutrient depletion potentially caused by harvesting. In this paper, we report effects of a large dose of spruce bark ash on soil properties and tree biomass increment in a mixed Scots pine-Norway spruce stand on drained organic soil in central Latvia, 12 years after ash application. Significant positive growth response after wood ash fertilization was recorded only for overstorey spruce. During the 12 years after fertilization the additional volume increment was 8.3 m^3 ha^{-1} or 0.7 m^3 ha^{-1} annually. The effect of wood ash application is long-term. Also 12 years after treatment fertilized overstorey spruces demonstrated 0.6 m^3 ha^{-1} additional annual volume increment compared to the controls. Additional diameter increment increased during the first 10 years after treatment but started to decrease in 2012. Results demonstrate that ash fertilization did not change N availability in the soil, and additional growth can be explained with improved supply of P, Ca, Mg and other nutrients. Ash application did not significantly influence the chemical composition of the O layer.

Key words: Ash Fertilization, Biomass Increment, Scots Pine, Norway Spruce, Soil Properties, Drained Organic Soil.

INTRODUCTION

Ash fertilization has a twofold effect. Firstly, it facilitates the return of nutrients to the forest ecosystem and, secondly, it helps to utilize wood ash generated as a by-product of combustion, whether for heat or power generation. Wood ash contains the following chemical elements: P, K, Ca, Mg, Mn, Cr, Cd, Pb, Na, S, As etc. (Kuokkanen et al., 2009; Lazdiņš et al., 2014). Several of those elements are essential to plant growth, especially phosphorus and potassium. The use of wood ash causes significant changes in soil physical and chemical properties. After fertilization pH value in the upper soil layer increases, as well as concentration of nutrients available to plants (K, Ca, Mg, B, P) (Saarsalmi & Mälkönen, 2001; Moilanen et al., 2002; Saarsalmi et al., 2004; Mandre, 2006). The presence of heavy metals (Cg, Pb, Cr) may limit the use of wood ash as fertilizer. Concern for environmental risks is most often related to concentrations of cadmium that often exceed the level allowed for fertilizers in agriculture (Evald, 1998; Korpilahti et al., 1998; Obernberger & Biedermann, 1998; Perkiomäki, 2004). Pitman (2006), however, suggests that additions of wood ash from known sources should not increase heavy metal loadings above those currently recommended.

The impact of ash fertilization on stand productivity is highly variable (Pitman, 2006; Reid & Watmough, 2014). It seems to be dependent on the already available nutrients in the soil, site fertility and soil type. Positive and fast growth response is recorded on nutrient-poor organic soils (Silfverberg & Huikari, 1985; Silfverberg & Hotanen, 1989; Ferm et al., 1992; Hytönen & Kaunisto, 1999; Ernfors et al., 2010). The effect, however, depends on the availability of nitrogen – in oligotrophic mires where there is a lack of available N ash fertilization effect can be minor (Moilanen et al., 2004). On mineral soils, the addition of wood ash is often targeted to counteract nutrient depletion caused by whole-tree harvesting.

One of the most significant advantages of wood ash is the long-term impact on the trees, compared to mineral fertilizers (Moilanen et al., 2002; Saarsalmi et al., 2012). It has been suggested that one single application of wood ash at 10 t ha^{-1} could replace nutrient losses from whole-tree and intense biomass harvesting sites, provided that additional N is added to create balanced input (Vance, 1996). However, also application of much higher doses (20–100 t ha^{-1}) of wood ash has been reported (Moilanen et al., 2012). It may be expected that in case of a larger dose the effects on other ecosystem parameters, e.g., ground vegetation development, soil properties and groundwater quality, will be more explicit.

The aim of the study was to determine the changes in tree growth, soil properties, groundwater chemistry and ground vegetation after fertilizing a mixed Scots pine-Norway spruce stand on drained organic soil with a large dose (50 t ha^{-1}) of wood ash. This particular paper presents results on long-term growth response and soil properties.

MATERIALS AND METHODS

Study site and plots

The study was conducted in a research forest in the eastern part of Latvia. This forest was already equipped with groundwater wells, since long-term hydrological measurements have been carried out there since 1963. A mixed pine-spruce stand on a former transition mire (drained in 1960) was chosen for the study (56°42´48´´N, 25°50´95´´E, 95 m a.s.l.). The site type according to the national classification system is *Myrtillosa turf. mel.* (Zalitis & Jansons, 2013). The soil type according to the WRB soil classification system is Hemic Rheic Histosols (Dystric, Drainic). A large dose of wood ash (50 tons ha^{-1}) was deposited at the study site in 2002 as part of the EU-funded project 'Wood for Energy - a contribution to the development of sustainable forest management' (*WoodEnMan*). It was decided to apply a large dose (50 tons ha^{-1}) of wood ash while during this project also impact on groundwater chemical composition was analyzed. One of the hypotheses was that a large dose of fertilizer would impair groundwater quality. The impact on groundwater chemistry was found to be insignificant but these results are not included in the current paper. Nine circular sample plots were established around already existing groundwater wells. Sample plots were treated with 50 tons of ash per ha, leaving a 1 m, 2 m and 3 m buffer zone (1 m – A1, B1, C1; 2 m – A2, B2, C2; 3 m – A3, B3, C3) around the groundwater wells (Fig. 1).

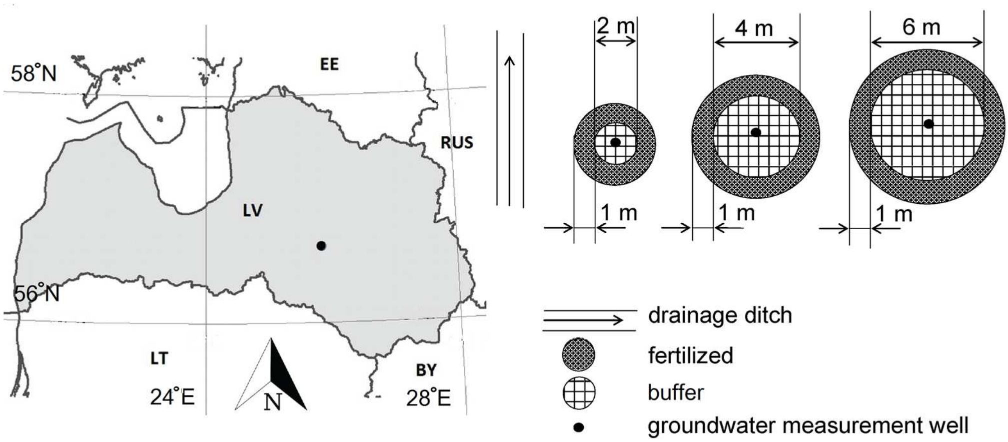

Figure 1. Study location and sample plot design.

Spruce bark bottom ash from sawmill *Vika Wood* was used for the project. The input of nutrients with ash was: P-PO_4^{3-} 21.5 g m^{-2}, K 54 g m^{-2}, Ca 282 g m^{-2}, Mg 382 g m^{-2}.The content of heavy metals and sulfate in the ash was not available.

Before the ash applicaton in the spring 2002 soil (0–15 cm depth) pH was 5.5; soil NH_4-N content was 14.9 mg 100 g^{-1}, soil PO_4-P content was 0.6 mg 100 g^{-1}, soil K content was 5.1 mg 100 g^{-1}, soil Ca content was 94.6 mg 100 g^{-1} and soil Mg content was 51.1 mg 100 g^{-1}.

Stand measurements

Tree diameter at breast height (DBH) was measured in the plots treated with ash and in control plots. Control plots were established 25 m away from groundwater wells on a transect parallel to the wells. In total, 18 circular plots were measured – 9 treated plots and 9 control plots. The sample plot size for tree measurement was 500 m^2 (R = 12.62 m). In this plot, all trees with DBH > 14 cm were measured. In the plot with R = 6.64 m from the center, also all trees with DBH > 6 cm were measured, and in the northeast segment of the inner circle, – also all trees with DBH >2 cm were measured. Tree species, DBH, height and storey was determined for all measured trees.

Tree increment

As the stand is uneven-aged, fertilizer impact was analyzed separately for overstorey pine, overstorey spruce and second storey spruce. Increment cores were taken from 10 trees in each treated plot (at least 3 overstorey pines, 3 overstorey spruces and 3 second storey spruces if this number of trees was found) and from 15 trees in each control plot (5 trees from each group, respectively). In total, 19 overstorey spruce, 29 second storey spruce and 32 pine increment cores were collected from the fertilized plots and 33, 34 and 68 increment cores from the control plots, respectively.

The volume increment for each tree was calculated according to the equation (Liepa, 1996):

$$Z_v^{vp} = 10^{-4} \cdot \lambda \cdot d^2 \cdot \left(\frac{0.4 \cdot i \cdot u \cdot (+4)}{d} + Z_{\mathrm{L}} \right) \quad (1)$$

where: λ – stem volume coefficient (0.306 for pine, 0.326 for spruce); d – stem diameter, cm; L – tree height, m; i – radial increment, mm; u – bark thickness coefficient (1.103 for pine, 1.046 for spruce); Z_L – height increment, m.

Height increment was calculated according to equation (Liepa, 1996):

$$Z_L = \frac{2iL(ad + b)}{cd + 100} \quad (2)$$

where: a, b, c – height increment coefficients (-0.0642, 6.356, 27.105 for pine, -0.0256, 1.693, 5.794 for spruce).

Changes in theoretical annual increment are defined as additional increment and it can be positive, negative or without changes. Additional increment is the result of treatments influencing tree growth. Additional volume increment was calculated according to equation (3) (Liepa, 1996). The method is based on the assumption that potential average tree increment after treatment can be calculated from trees on control plot with similar growing conditions and age. Annual increment for individual trees before treatment in control plots must correlate with average annual increment before treatment in treated plots.

$$Z_M^{kp} = 12732.4\psi \left(GH^{\alpha} D^{\beta \cdot lgH + \varphi - 2} - G_t H_t^{\alpha} D_t^{\beta \cdot lgH + \varphi - 2} \right) \quad (3)$$

where: ψ, α, β, φ – tree growth coefficients ($1.654 \cdot 10^{-4}$, 0.5658, 0.2592, 1.5969 for pine, $2.311 \cdot 10^{-4}$, 0.7819, 0.3418, 1.1881 for spruce); G, G_t – basal area of tree stand and its prognostic value, m^2 ha^{-1}; H, H_t – average height of tree stand and its prognostic value, m; D, D_t – average diameter of tree stand and its prognostic value, cm; t – time interval of disturbance (years after fertilization), years.

Prognostic value of stand basal area:

$$G_t = \frac{D_t^2 \cdot G}{D^2} \quad (4)$$

Prognostic value of average stand diameter:

$$D_t = D - 0.1 Z_D^{kp} \quad (5)$$

where: Z_D^{kp} – average stand diameter cumulative additional increment, cm. Calculated according to equation (Liepa, 1996):

$$Z_D^{kp} = 2u\left(\sum_j^t i_j - \sum_j^t i'_j\right) \quad (6)$$

where: i_j – average stand radial increment in year j, mm; i'_j – prognostic values of average stand radial increment, mm. alculated according to power regression equation:

$$i'_j = \eta \cdot \left(i'_{k;j}\right)^{\rho} \quad (7)$$

where: η, ρ – coefficients of regression equation; $i'_{k;j}$ – average radial increment from control trees after year disturbance for k trees in j year, mm.

Annual increment of control trees from control sample plots must correlate ($r > 0.50$) with annual increment in treated plots, otherwise it is not used in calculations.

Prognostic value of average stand height:

$$H_t = H - Z_H^{kp} \quad (8)$$

where: Z_H^{kp} – average stand height cumulative additional increment, m:

$$Z_H^{kp} = \frac{HZ_D^{kp}(aD + b)}{u(cD + 100)} \quad (9)$$

Differences in the average value of stand characteristics between treated and control plots were analyzed with Student's t-test for two independent samples. Significance of additional increment after ash treatment was checked with Student's t-test for paired samples. It was assumed that there was no additional increment in the absence of ash treatment. Control trees were used to construct the trend of theoretical tree increment values for a 12-years period following treatment and this was compared with the measured values in the treated plots. Two alternative hypotheses were considered:

H_0: Additional increment after treatment is equal to zero;

H_a: Additional increment after treatment is higher/less than zero.

Sampling and analyses of soil and organic O layer

Soil and soil organic O layer were sampled in each sample plot in 3 repetitions. Soils were sampled at 0–10 cm, 10–20 cm, 20–40 cm and 40–80 cm depth using a soil sampling probe with a steel cylinder of 100 cm^3 volume. At the same place, O layer monoliths (10 x 10 cm) were sampled from each subplot using a stainless steel square soil sampler.

Soil and soil organic O layer samples were prepared and analyzed in the Forest Environment Laboratory of LSFRI Silava according to ISO methodology. Soil and soil organic O layer samples were prepared for analyses according to the LVS ISO 11464 (2005) standard. A fine earth fraction of soil ($D < 2$ mm) was used for chemical analysis. The following parameters were determined in the soil and soil organic O layer samples: bulk density according to LVS ISO 11272:1998; potassium (K), calcium (Ca) and magnesium (Mg) extracted with concentrated nitric acid and determined by flame atomic emission or absorption spectroscopy; phosphorus (P) extracted with concentrated nitric acid and determined according to LVS 398 (2002); total nitrogen (N) content determined using a modified Kjeldahl method according to LVS ISO 11261 (2002); organic and total carbon (C) content determined using elementary analysis according to LVS ISO 10694 (2006); and soil acidity (pH $CaCl_2$ and pH H_2O) potentiometrically measured in the supernatant suspension of a 1:5 soil:liquid (v/v) mixture according to LVS ISO 10390 (2002). The content of heavy metals and sulphate was not analyzed.

Statistical analysis

Kruskal-Wallis one-way analysis of variance was used for statistical testing of additional increment. One of the samples was the mean annual increment in treated plots. The other was mean annual prognostic increment, calculated from control trees with equation (7) as described above. Error bars and confidence intervals presented in figures and tables are confidence intervals at 95% confidence level. All data analysis was conducted with R software.

RESULTS

Stand characteristics

Stand characteristics are summarized in Table 1. Mean diameter (D) and mean height (H) characterizes dominant tree species, while basal area, standing volume and number of trees characterizes all trees in the plot. No significant differences were detected between the mean stand characteristics of treated and control plots (Table 1). The largest mean height, basal area, standing volume and number of trees were found in plot A, both in the treated and control subplots, while the lowest mean diameter, height and standing volume of dominant tree species were found in plot C. Trees in the B and C sample plots had suffered from windthrow and fungal diseases to a greater extent than in the A sample plots, which could have affected mean stand characteristics.

Table 1. Stand characteristics in treated and control plots

	Plot	Mean Diameter, cm	Mean Height, m	Basal Area, m^2 ha^{-1}	Standing Volume, m^3 ha^{-1}	Number of Trees, per ha^{-1}
Treated	A	25.4 ± 1.3	23.9 ± 0.4	31.3 ± 5.7	335 ±47	1067 ±470
	B	25.7 ± 1.3	21.7 ± 0.3	24.8 ± 5.1	248 ± 57	640 ±68
	C	24.3 ± 1.3	19.6 ± 0.8	21.1 ± 4.0	198 ± 26	587 ±151
	mean	25.1 ± 0.8	21.8 ± 1.2	25.7 ± 3.8	260 ± 45	764 ± 207
Control	A	25.4 ± 0.6	23.3 ± 0.6	28.5 ± 5.1	311 ± 45	867 ±449
	B	27.7 ± 1.7	21.9 ± 1.2	22.6 ± 1.1	226 ± 21	593 ±69
	C	24.4 ± 4.2	19.7 ± 1.8	24.0 ± 3.6	221 ± 36	813 ±193
	mean	25.8 ± 1.6	21.6 ± 1.3	25.1 ± 2.5	252 ± 34	758 ± 164

Soil and soil organic O layer properties

Soil acidity, total nitrogen, organic carbon, phosphorus and base cation (K, Ca, Mg) content and stock in soil and soil organic O layer were analyzed in the study site. Mean soil pH (H_2O) varied from 4.0 ± 0.2 (0–10 cm, plot B) to 5.3 ± 0.1 (40–80 cm, plot C) in control plots and from 4.9 ± 0.6 (10–40 cm, plot A) to 5.9 ± 0.2 (40–80 cm, plot C) in the treated plots. Sample plots with ash treatment showed significantly (α = 0.05) higher soil mean, minimal and maximal pH values compared to control plots (Fig. 2). The largest differences (1.0 pH unit) were detected in the organic topsoil (0–10 cm): 5.2 ± 0.5 in the treated plots and 4.2 ± 0.2 in the control plots. Differences in the mean pH values between fertilized and control plots decreased with depth (0.6 and 0.4, at 10–20 and 20–80 cm depth, respectively). Also, the mean pH value of the soil organic O layer in the treated plots was significantly higher than in the control plots (5.0 ± 0.2 and 4.6 ± 0.1, respectively).

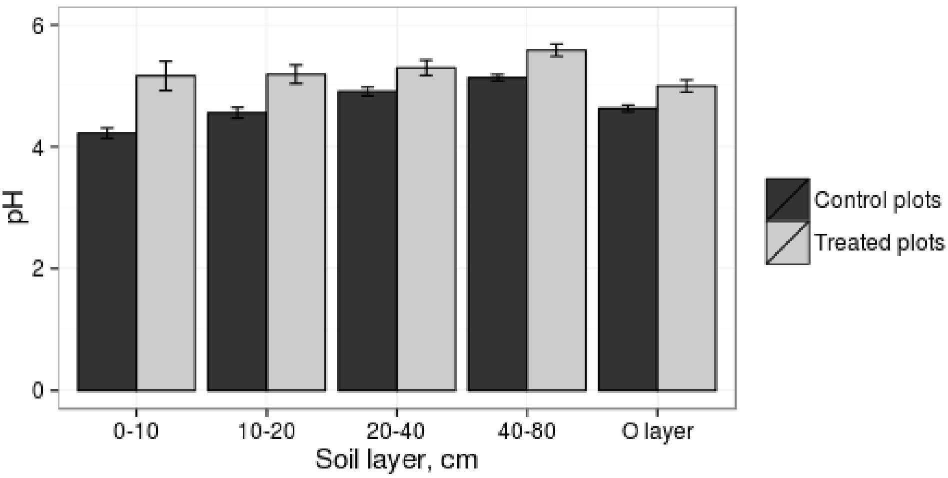

Figure 2. Mean pH (H_2O) in different soil layers.

The mean total N pool in the soil layers from 0–80 cm depth was 24.1 ± 1.7 t ha^{-1} in control plots and 23.5 ± 1.6 t ha^{-1} in treated plots. There was a trend toward a slight decrease in the total N pool in the upper soil layers (0-40 cm) of the fertilized plots but the differences were not statistically significant (Fig. 3). In addition, the N pool in the O layer was similar between treated and control plots (0.22 ± 0.2 and 0.21 ± 0.1 t ha^{-1}, respectively).

The mean total P pool in the soil layers from 0-80 cm depth was 0.63 ± 0.06 t ha^{-1} in control plots and 0.83 ± 0.13 t ha^{-1} in treated plots. The total P pool in the upper soil layer was significantly increased in the fertilized plots (Fig. 3). The mean P pool in the upper soil layer (0-10 cm) in the treated plots was 0.23 ± 0.09 t ha^{-1}, but in the control plots it was 0.11 ± 0.02 t ha^{-1} at the same depth. In the deeper layers, the P pool in the fertilized plots was still higher than in the control plots but the differences were not statistically significant. No significant differences were detected in the O layer.

The mean K pool in the soil layers from 0–80 cm depth was 0.22 ± 0.04 t ha^{-1} in control plots and 0.36 ± 0.05 t ha^{-1} in treated plots. The mean K pool in the sample plots with ash fertilization was higher than in the control plots at all analyzed depths, but statistically significant differences were only detected below 20 cm. According to results, K leaching into the deeper soil layers has taken place, while at the same time, better K supply in the upper soil layers is indicated.

Mean Ca pool in the soil layers from 0-80 cm depth was 17.2 ± 2.5 t ha^{-1} in control plots and 22.2 ± 3.7 t ha^{-1} in treated plots. Ca compounds in the fertilized plots were mainly found in the upper soil layer (0–10 cm), where the Ca pool was significantly higher than in control (Fig. 3). In the deeper soil layers in the fertilized plots, the Ca supply was slightly higher than in the control plots, but due to high variation, no statistically significant differences were detected. Below 40 cm depth, the Ca pools in the treated and control plots were similar. Consequently, most of the Ca supplied with the wood ash has accumulated in the upper soil layer. The Ca pool in the soil organic O layer was low and differences between treated plots and control were insignificant.

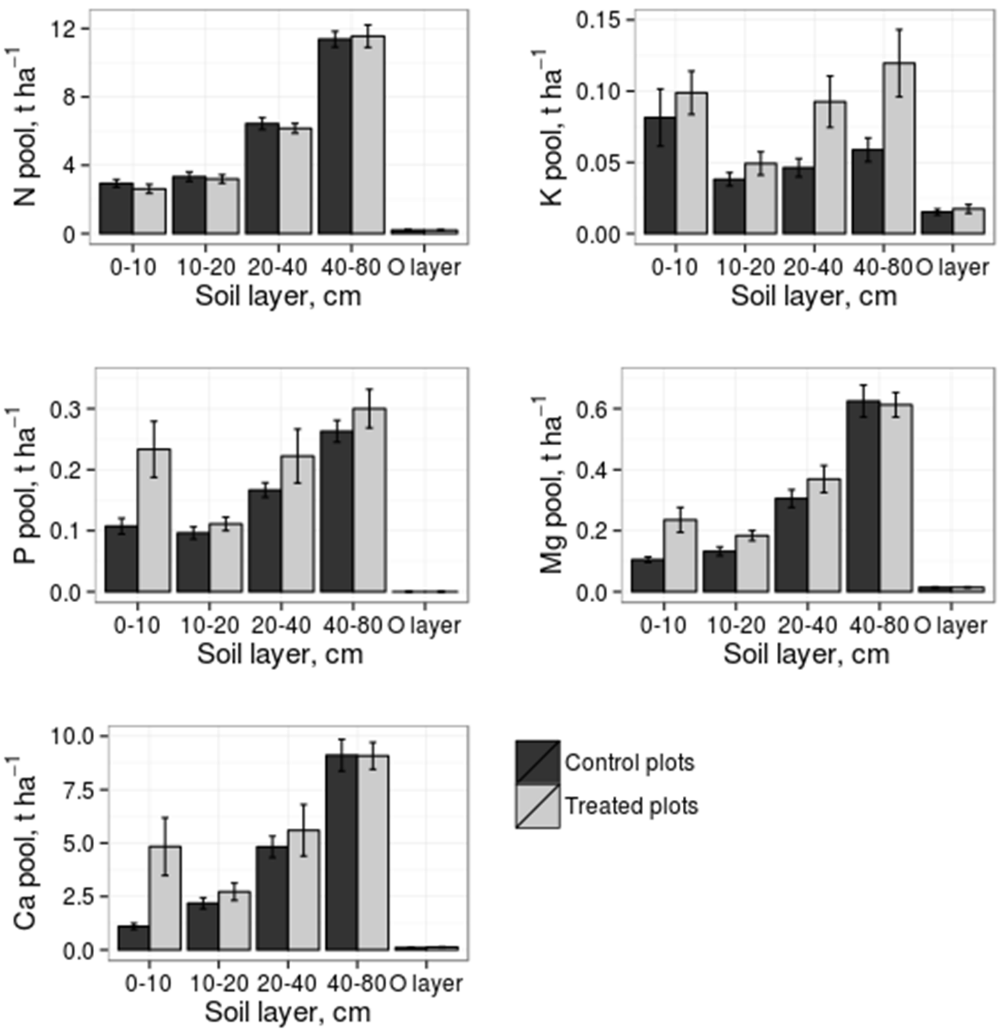

Figure 3. N, P, K, Ca and Mg pool in various soil depths and O layer.

The mean Mg pool in the soil layers from 0–80 cm depth was 1.17 ± 0.16 t ha^{-1} in the control plots and 1.40 ± 0.17 t ha^{-1} in the treated plots. The Mg pool in the soil was approximately 10 times lower than the Ca pool. A statistically significant difference between Mg pools in the treated and control plots was observed in the upper soil layer (0–10 cm). Down to 40 cm soil depth, the Mg pool in the fertilized plots was higher than in the control plots, but this difference was not statistically significant. Below 40 cm depth, no differences between Mg pools in the treated and control plots were detected (Fig. 3). In addition, similar to Ca, Mg has not leached deeper than the well-aerated upper soil layers, and is still available to the tree roots. No statistically significant differences between the soil organic O layer Mg pools in the fertilized and control plots were detected. The mean Mg pool in the soil organic O layer was 0.014 ± 0.002 t ha^{-1}.

The mean thickness of the soil organic O layer was 1.9 ± 0.2 cm in the control plots and 1.7 ± 0.1 cm in the treated plots. The mean bulk densities of the different soil layers in the control and treated plots are shown in Fig. 4. The mean bulk density of the soil organic O layer was 69.9 ± 6.5 kg m^{-3} in the control plots and 97.3 ± 10.0 kg m^{-3} in the treated plots. In half of the treated plots, soil organic O layer bulk density was higher than in the respective control plots. Differences in soil organic O layer thickness and bulk density can be explained by anthropogenic pressure, as different measurements are done regularly in the treated plots.

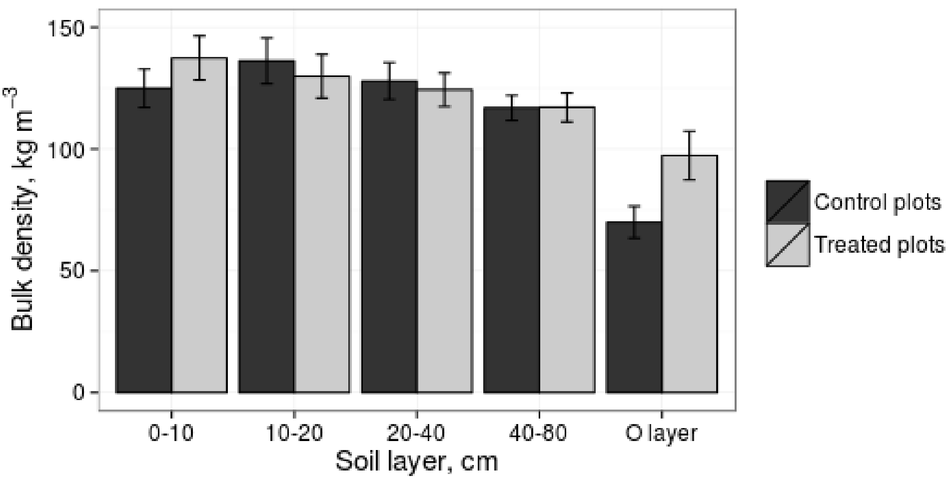

Figure 4. Bulk density of different soil layers.

Carbon stock in soil and biomass

The mean carbon stocks in different pools (living biomass and different layers of soil) in control and treated plots are shown in Table 2. In the study area, the largest carbon stock was located in the soil at 0-80 cm depth, with carbon stock ranging from 362 to 755 t ha^{-1} in this soil layer in different plots. A significant amount of carbon is stored in living tree biomass, ranging from 53.6 to 98.3 t ha^{-1}. The amount of carbon in the soil organic O layer does not exceed 12.6 tons ha^{-1}. No significant impact ($\alpha = 0.05$) of wood ash treatment on carbon stock in the different layers of soil and tree biomass carbon stocks was detected (Table 2). The measured differences were small and random.

Table 2. Carbon stock (t ha^{-1}) in living biomass and soils

Carbon pool	Control Plots			Treated Plots		
	A	B	C	A	B	C
Living biomass	84.7 ± 16.2	69.8 ± 4.3	76.3 ± 9.9	88.7 ± 13.4	75.1 ± 17.4	62.8 ± 9.0
Soil organic O layer	4.8 ± 0.3	6.3 ± 1.2	7.9 ± 0.8	7.1 ± 1.4	5.3 ± 1.2	9.4 ± 1.2
Soil, 0–10 cm	44.5 ± 4.5	86.0 ± 5.2	67.2 ± 4.5	51.1 ± 5.2	86.6 ± 7.4	64.1 ± 4.6
Soil, 10–20 cm	46.2 ± 2.6	104.2 ± 6.0	70.7 ± 4.6	43.4 ± 2.6	102.0 ± 1.7	62.9 ± 3.6
Soil, 20–40 cm	111.3 ± 7.2	191.2 ± 7.3	120.1 ± 10.6	105.8 ± 5.6	167.2 ± 8.4	130.0 ± 10.0
Soil, 40–80 cm	214.4 ± 8.0	312.4 ± 19.0	237.2 ± 20.4	220.5 ± 12.4	276.1 ± 14.5	288.1 ± 33.2
Soil, 0–80 cm	416.4 ± 9.8	693.8 ± 31.0	495.2 ± 58.2	420.7 ± 29.6	631.9 ± 23.5	545.1 ± 23.5

Tree increment

Increment cores were taken to analyze tree increment. With this method, it is possible to gather information about temporal changes in tree growth without time consuming, long-term observations. Analyzing growth only according to the tree ring width is not, however, the best approach, as the tree ring width naturally decreases with tree age. This parameter also does not allow the evaluation of economic gain. Volume increment is a better indicator for this purpose.

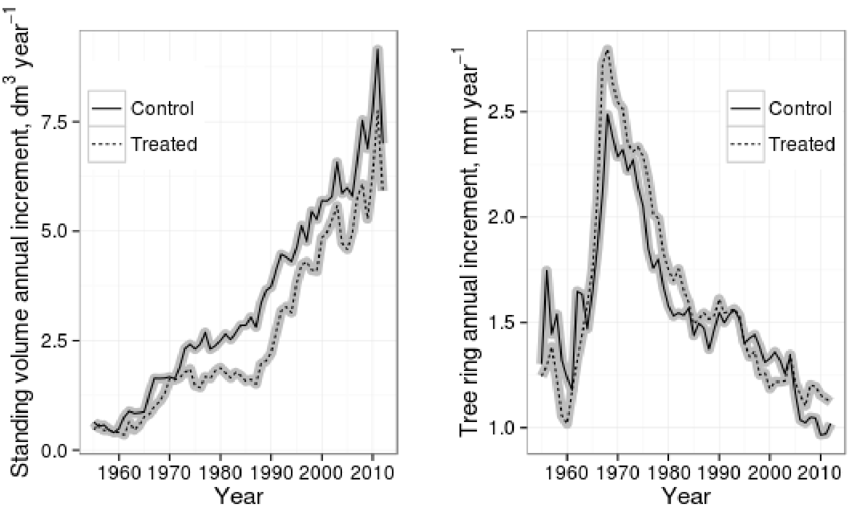

Figure 5. Mean standing volume and annual tree ring increment of pine and spruce combined in treated and control plots.

The most pronounced tree growth increase observed at the study site was noted in 1961, in the next year after drainage, indicating a very rapid response to the improved aeration and nutritional conditions. Since then, mean volume increment has displayed a steadily increasing trend, especially during the last 10 years. However, decreases in tree volume have also been observed in some growing seasons (Fig. 5). A strong correlation for annual tree ring and volume increment between ash-treated and control plots can be found before treatment ($r = 0.95$; $r = 0.91$), which is essential for calculations of additional increment.

Additional increment due to ash fertilization

Additional standing volume increment and additional diameter increment were evaluated to analyze the effect of ash fertilization on tree growth. Additional standing volume increment was calculated separately for pine overstorey, spruce overstorey and spruce second storey.

The effect of fertilization on the increment of pine and spruce was different (Table 3). After fertilization, the additional annual volume increments for spruce overstorey and spruce second storey were 0.68 m^3 ha^{-1} and 0.015 m^3 ha^{-1}, respectively. The additional volume increment for pine overstorey was negative, at -0.018 m^3 ha^{-1} per year. Only the additional volume increment for spruce overstorey was statistically significant ($p < 0.05$). The results suggest a positive response of spruce overstorey to fertilization, but no response in pine overstorey or spruce second storey.

Table 3. Additional standing volume increment and additional diameter increment

Parameter	Additional diameter Increment, mm		Additional standing volume Increment, m^3 ha^{-1}	
	12 years period	annual average	12 years period	annual average
Pinus sylvestris L. overstorey	-0.1	-0.01	-0.2	-0.02
Picea abies (L.) H. Karst overstorey	13.6	1.13	8.3	0.69
Picea abies (L.) H. Karst second storey	0.4	0.03	0.2	0.02
Mean of both species	13.8	1.15	8.2	0.68

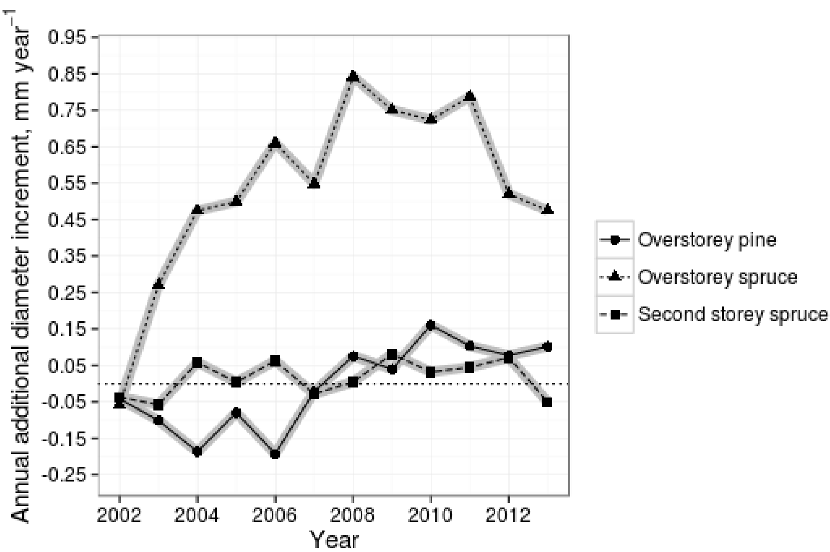

Figure 6. Mean annual additional diameter increment.

When temporal changes of the impact of wood ash application are analyzed, a small effect immediately after treatment (in 2002) can be seen (Fig. 6). Over time, the additional diameter increment of overstorey spruce increased, reaching its maximum in 2006–2011, or 5–10 years after ash application. Since 2012, the additional diameter increment has decreased. The additional diameter increment of pine tended to decrease during the first years following ash application, but then started to increase in 2007.

DISCUSSION

A large number of studies, especially those done in the Nordic countries, indicate that ashes can enhance the long-term productivity of some forested sites (Vance, 1996; Saarsalmi et al., 2001; Saarsalmi et al., 2004; Norström et al., 2012; Ingerslev et al., 2014). Dose rates of 10 t ha^{-1} have been suggested by Vance (1996) as being sufficient to replace all the nutrients lost by whole-tree harvesting. Our study assesses the long-term effect of spruce bark ash fertilization on organic soil properties and tree biomass increment in an area where 50 t ha^{-1} of ash were applied 12 years ago. According to literature, large doses of ash fertilizer may cause decline of woody shrubs and major changes to Bryophite and Lichen communities (Arvidsson et al., 2001; 2002; Jacobson & Gustaffson, 2001) and increase the likelihood of N leaching from sites with high N deposition (Högbom et al., 2001). Although no increase in cadmium or lead content of Vaccinuim species berries has been reported (Levula et al., 2000; Perkiömäki et al., 2003), in theory it may be possible, if a very high dose of fertilizer is applied.

Soil pH changes

Application of ash to the forest soil clearly has a liming effect (Jacobson et al., 2004; Ingerslev et al., 2014). Different long-term field trials indicate a sustained increase in pH in forest soil up to 30 years following ash application (Saarsalmi et al., 2012). In Denmark, studies by Ingerslev et al. (2014) indicate that the pH of the O-horizon increased significantly, by 0.9–1.7 pH units, at 2.5 years following wood ash application in a 44-year-old Norway spruce plantation with nutrient-poor soil. In Finland, 5–10 years after wood ash application (3 t ha^{-1} of loose wood ash) in coniferous stands (aged 31–75 yrs), the pH of the humus layer increased by approximately 1.0–1.7 pH units (Saarsalmi et al., 2004). Researchers in Finland resampled a Scots pine and Norway spruce site that had received an ash dose of 3 t ha^{-1} 16 years ago, and detected an increase in pH (0.6–1.0 pH units higher than control forest soils) for humic layers under canopies, with the effect most significant at the wetter sites (Saarsalmi et al., 2001). Our results confirm that the soil liming effect is maintained 12 years following spruce bark ash application, with the results indicating an increase of 1.0 pH units.

Nutrient pools in the soil

Results from investigations on the effects of wood ash application on soil are far from concordant, often due to differences in location, ash dose, site fertility and time span investigated (Norström et al., 2012). In general, however, addition of wood ash to organic forest soils has been shown to have a long-lasting effect. Due to increased pH, organic matter breakdown rates are accelerated and N is released for take-up by the trees (Pitman, 2006; Augusto et al., 2008; Ernfors et al., 2010). Similarly, our soil chemical analysis results show a slight decrease in the total N pool, in both the soil organic O layer and the upper soil layers (0–40 cm) in the plots given a spruce bark ash dose of 50 t ha^{-1} 12 years ago. In contrast to the N pool in the soil of the study plots, our results indicate statistically higher P, K, Ca and Mg pools in the treated plots, even 12 years after treatment, similar to previous studies (Eriksson, 1998; Saarsalmi et al., 2001; Arvidsson & Lundkvist, 2003; Jacobson, 2003; Jacobson et al., 2004; Saarsalmi et al., 2004). In the ash-treated plots, a significant amount of K has accumulated in the deeper soil layers. This reserve is not available to plants, as the groundwater level is, on average, 40–50 cm, and aerated soil and root depth is therefore limited to this depth. This leaching indicates that the trees have not been able to fully utilize the increase in K after ash fertilization. However, the K reserves remain there and may become available in favorable conditions, for example, in the event of groundwater level fluctuations. Naylor and Schmidt (1986) demonstrated that the availability of K was directly related to the amount added to the soil. The K dissolution rate and availability are dependent on soil pH (Naylor & Schmidt, 1986; Erich, 1991; Ohno, 1992).

Carbon stock

In long-term studies, wood ash has been shown to stimulate litter and cellulose decomposition and carbon mineralization (Moilanen et al., 2002; Perkiömäki & Fritze, 2002; Perkiömäki, 2004). It is noted that increasing the pH of soil may also result in carbon release due to increased microbial activity/growth and an increased decomposition rate of the humus layer (Kreutzer, 1995; Persson et al., 1995; Zimmermann & Frey, 2002; Corre et al., 2003). Furthermore, Rosenberg et al. (2010) found in Sweden that application of wood ash in high doses (6 Mg ha^{-1}) can deplete the organic C in soil and increase CO_2 evolution rates and heterotrophic respiration in the field, even 12 years after ash application at the N-rich Norway spruce site. Although our results show no differences in carbon stock between ash-treated plots and control plots, we could not assess the impact of ash fertilization on CO_2 emissions, as data about peat subsidence/growth rates are lacking for the study site. Even if we could measure peat subsidence/growth rates, peat stock is too high to detect any significant changes in carbon stock 12 years after fertilization. However, our results show a small but statistically insignificant increase ($p > 0.10$) on peat bulk density (0–10 cm), from 124.7 ± 12.9 in control plots to 137±14.1 ($\alpha = 0.10$) in ash-treated plots, indicating the possibility of increased peat decomposition rates.

Tree increment

According to the literature, the addition of loose ashes on drained peatlands usually increases forest growth (Moilanen et al., 2002; Moilanen et al., 2012; Saarsalmi et al., 2014). Insufficient supply of P and K is often regarded as one of the main factors limiting tree growth on drained peatlands in Finland, as no weathering of rock-forming minerals takes place in the peat (Magnusson & Hånell, 1996; Moilanen et al., 2005). The most pronounced positive response in tree stand to wood ash addition on peatlands is observed in nitrogen-rich sites, as wood ash contains all the major nutrients for plants, except N (Moilanen & Silfverberg, 2004; Saarsalmi et al., 2014). Ash application on mineral soils, however, is mainly aimed at counteracting soil acidification and returning the nutrients removed by harvesting, since on mineral soils tree growth is usually limited by the N that is evaporated during combustion. Therefore, a combination of ash and N fertilizer is often used to achieve the best results on mineral soils. However, even those results are variable. For example, Saarsalmi et al. (2004; 2006) reported that the combined addition of wood ash and N had no significant impact on the volume growth of 31- to 75-year-old conifer stands at 5 and 10 years after ash application. In addition, no significant treatment effect on the biomass growth of Scots pine was recorded in a study conducted in drained peatland sites in southern Sweden (Ernfors et al., 2010). However, in a study by Moilanen et al. (2002), Scots pine stem volume growth in a drained mire in the central part of Finland was substantially promoted for an extended period after treatment with 8 t ha^{-1} and 16 t ha^{-1} of wood ash.

Our results show that additional incremental growth as a result of ash fertilizer only occurred in overstorey spruce, with no significant impact on pine and second storey spruce increment. Tree age is a significant factor that may have influenced those trees' response to additional nutrient supply. Several trees are around 160 years old, and their reaction to changes to different factors is minor. Another likely explanation is the fact that study site is located in a confined aquifer discharge area. 86% of forests on wet and drained peat soils, and 60% of forests on wet and drained mineral soils in Latvia, are located in confined aquifer discharge areas, making it an essentially different situation from that in Fennoscandia (Indriksons & Zalitis, 2000; Zālītis, 2006; Zalitis & Indriksons, 2010). Discharge waters from the upper Devonian dolomite layers are rich in nutrients, and even in drained peatlands, where the peat layer is several meters deep and tree roots have no contact with the mineral soil, tree growth is very good, as nutrients are supplied by the sub-soil discharge waters. It is possible that in our study, the nutrient supply already is optimal for pine and additional fertilization does not have a significant impact. At the same time, spruce requires more nutrients than pine, and consequently shows a positive growth response to fertilizer. Second storey spruces suffer from unfavorable light conditions, and this could be the main factor limiting their growth. Considering the above, ash fertilization might be used to improve the growth of spruce stands on drained peat soils, while the effect may be minor in pine stands on drained peatland sites located in confined aquifer discharge areas.

The amount of ash applied, 50 t ha^{-1}, may be considered a very high dose. Even though even larger amount of peat ash (100 t ha^{-1}) has been applied in Finland (Moilanen, 2012), with no detrimental effects on the environment reported, wood ash is considered to have more pronounced effect than peat ash, both positive and negative. At our study site, no significant differences of N, P, K, Ca and Mg content in the groundwater in the year following fertilization were reported by Indriksons (2010). In 2012, ten years after ash application, the moss layer, significantly decreased in 2002, had fully recovered (Indriksons and Lazdina, unpublished data). However, the very high dose of the fertilizer potentially may have increased the content of heavy metals and sulfate in the soil and groundwater, and the lack of these data imposes limitations on the study. Heavy metal and sulfate content in the soil and groundwater should be analyzed next to be certain that the treatment has caused no negative long-term environmental consequences.

CONCLUSIONS

1. Significant positive growth response after wood ash fertilization was recorded for overstorey spruce only. For the 12 years following fertilization, the additional volume increment is 8.3 m^3 ha^{-1} or 0.7 m^3 ha^{-1} annually.

2. The effect of wood ash application is long-term. Twelve years after treatment, fertilized overstorey spruces demonstrate better growth than controls. Additional diameter increment increased during the first 10 years after treatment, but started to decrease in 2012.

3. In the fertilized plots, soil pH (H_2O) and the P pool were significantly higher than in the control plots (respective pH values: 5.2 ± 0.5 and 4.2 ± 0.2; respective P content: 0.23 ± 0.09 tons ha^{-1} and 0.11 ± 0.02 tons ha^{-1}).

4. The soil N pool is slightly higher in the control plots, but the differences are not significant. The results demonstrate that ash fertilization has not changed N availability in the soil, and a significant growth effect can be explained by the improved supply of P, Ca, Mg and other nutrients.

5. K has leached deeper into the soil and is mostly unavailable to plants at the present. However, with lowering of the groundwater level, it may become available.

6. Ca and Mg reserves are mostly concentrated in the upper soil layer (0–10 cm) and remain available to plants.

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REFERENCES

Arvidsson, H. & Lundkvist, H. 2003. Effects of crushed wood ash on soil chemistry in young Norway spruce stands. *Forest Ecology and Management* **176**(1), 121–132.

Arvidsson, H., Vestin, T. & Lundkvist, H. 2001 Ground and fi eld vegetation after recycling crushed wood ash to forest sites. *SkogForsk Report No.* **2**, The Forestry Research Institute of Sweden, Uppsala, 19–20.

Arvidsson, H., Vestin, T. & Lundkvist, H. 2002 Effects of crushed wood ash application on ground vegetation in young spruce stands. *Forest Ecology and Management* **161**, 75–78.

Augusto, L., Bakker, M.R. & Meredieu, C. 2008. Wood ash applications to temperate forest ecosystems – potential benefits and drawbacks. *Plant&Soil* **306**, 181–198.

Corre, M.D., Beese, F.O. & Brumme, R. 2003. Soil nitrogen cycle in high nitrogen deposition forest: changes under nitrogen saturation and liming. *Ecological Applications* **13**(2), 287–298.

Erich, M.S. 1991. Agronomic effectiveness of wood ash as a source of phosphorus and potassium. *Journal of Environmental Quality* **20**(3), 576–581.

Eriksson, H.M. 1998. Short-term effects of granulated wood ash on forest soil chemistry in SW and NE Sweden. *Scandinavian Journal of Forest Research* **2**, 43–55.

Ernfors, M., Sikström, U., Nilsson, M. & Klemedtsson, L. 2010. Effects of wood ash fertilization on forest floor greenhouse gas emissions and tree growth in nutrient poor drained peatland forests. *Science of the Total Environment* **408**, 4580–4590.

Evald, A. 1998. Ashes from straw and wood combustion and from wood gasification plants – possibilities of fractioned metal separation and ash utilization in Denmark. *Thermal Biomass Utilization* **3**, 77–88.

Ferm, A., Hokkanen, T., Moilanen, M. & Issakainen, J. Effects of wood bark ash on the growth and nutrition of a Scots pine afforestation in central Finland. *Plant and Soil* **147**, 305–316.

Hytönen, J. & Kaunisto, S. 1999. Effect of fertilization on the biomass production of coppiced mixed birch and willow stands on a cut-away peatland. *Biomass and Bioenergy* **17**, 455–469.

Högbom, L., Nohrstedt, H.-Ö. & Nordlund, S. 2001. Effects of wood-ash addition on soil-solution chemistry and soil N dynamics at a Picea abies (L) Karst site in southwest Sweden. *SkogForsk Report No.* **4**, 1–20.

Indriksons, A. & Zalitis, P. 2000. The impact of hydrotechnical drainage on the cycle of some biogenous elements in forest. *Baltic Forestry* **1**, 18–2.

Indriksons, A. 2010. Cycle of biogenous elements in drained forests. *Resume of the PhD paper.* Jelgava, 64 pp.

Ingerslev, M., Hansen, M., Pedersen, L.B. & Skov, S. 2014. Effects of wood chip ash fertilization on soil chemistry in a Norway spruce plantation on a nutrient-poor soil. *Forest Ecology and Management* **334**, 10–17.

Jacobson, S. 2003. Addition of stabilized wood ashes to Swedish coniferous stands on mineral soils – effects on stem growth and needle nutrient concentrations. *Silva Fennica* **37**(4), 437–450.

Jacobson, S. & Gustafsson, L. 2001. Effects on ground vegetation of the application of wood ash to a Swedish Scots pine stand. *Basic and Applied Ecology* **2**, 233–241.

Jacobson, S., Högbom, L., Ring, E. & Nohrstedt, H.O. 2004. Effects of wood ash dose and formulation on soil chemistry at two coniferous forest sites. *Water, Air and Soil Pollution* **158**(1), 113–125.

Korpilahti, A., Moilanen, M. & Finér, L. 1998. Biomass ash utilization in Finland. *Thermal Biomass Utilization* **3**, 43–54.

Kreutzer, K. 1995. Effects of forest liming on soil processes. *Plant and Soil*. **168–169**(1), 447–470.

Kuokkanen, M., Pöykiö, R., Kuokkanen, T. & Nurmesniemi, H. 2009. Wood ash – a potential forest fertilizer. In: *Proceedings of the EnePro conference*. Kalevaprint, Oulu, pp. 89–93 (in Finland).

Lazdiņš, A., Butlers, A., Makovskis, K. & Lazdiņa, D. 2014. Case study on ash properties in pellet factory. In: *Proceedings of the Nordic Baltic Conference OSCAR14*. Skogforsk, Knivsta, pp. 19–21 (in Sweden).

Levula, T., Saarsalmi, A. & Rantavaara, A. 2000. Effects of ash fertilisation and prescribed burning on macronutrient, heavy metal, sulphur and 137 Cs concentrations in lingon berries (*Vaccinium vitis-idaea*). Forest Ecology and Management **126**, 269–279.

Liepa, I. 1996. *Increment science*. LLU, Jelgava, 123 pp. (in Latvian).

Magnusson, T., & Hånell, B. 1996. Ashes for peatland forests. Framework for ash recycling. Nutek. R, 42 pp. (In Swedish with English summary).

Mandre, M. 2006. Influence of wood ash on soil chemical composition and biochemical parameters of young Scots pine. *Proceedings of the Estonian Academy of Sciences, Biology and Ecology* **55**, 91–107.

Moilanen, M. & Silfverberg, K. 2004. Short-term effects of wood ash fertilisation on two drained mires in central Finland. In: *Proceedings of the 12th International Peat Congress Vol. 1. Wise use of peatlands, oral presentations.* International Peat Society, Tampere, pp. 464–471 (in Finland).

Moilanen, M., Silfverberg, K. & Hokkanen, T.J. 2002. Effects of wood-ash on the tree growth, vegetation and substrate quality of a drained mire: a case study. *Forest Ecology and Management* **171**, 321–338.

Moilanen, M., Silfverberg, K., Hökkä, H., & Issakainen, J. 2004. Comparing effects of wood ash and commercial PK fertiliser on the nutrient status and stand growth of scots pine on drained mires. *Baltic Forestry* **10**, 2–10.

Moilanen, M., Silfverberg, K., Hökkä, H. & Issakainen, J. 2005. Wood ash as a fertilizer on drained mires — growth and foliar nutrients of Scots pine. *Canadian Journal of Forest Research* **35**, 2734–2742.

Moilanen, M., Issakainen, J. & Silfverberg, K. 2012. Peat ash as a fertilizer on drained mires – effects on the growth and nutritional status of Scots pine. *Working Papers of the Finnish Forest Research Institute* **231**, 20 pp.

Naylor, L.M. & Schmidt, E.J. 1986. Agricultural use of wood ash as a fertilizer and liming material. *Tappi Journal* **10**, 114–119.

Norström, S.H., Bylund, D., Vestin, J.L. & Lundström, U.S. 2012. Initial effects of wood ash application to soil and soil solution chemistry in a small, boreal catchment. *Geoderma* **187**, 85–93.

Obernberger, I. & Biedermann, F. 1998. Fractionated heavy metal separation in Austrian biomass grate-fired combustion plants: approach, expenses, results. *Thermal Biomass Utilization* **3**, 55–76

Ohno, T. 1992. Neutralization of soil acidity and release of phosphorus and potassium by wood ash. *Journal of Environmental Quality* **21**(3), 433–438.

Perkiömäki, J. & Fritze, H. 2002. Short and long-term effects of wood ash on the boreal forest humus microbial community. *Soil Biology and Biochemistry* **34**(9), 1343–1353.

Perkiömäki, J. 2004. Wood ash use in coniferous forests: a soil microbiological study into the potential risk of cadmium release. *Finnish Forest Research Institute. Research papers* **917**, 54 pp.

Perkiömäki, J., Kiikkilä, O., Moilanen, M., Issakainen, J., Tervahauta, A. & Fritze, H. 2003. Cadmium containing wood ash in a pine forest: effects on humus microflora and cadmium concentrations in mushrooms, berries and needles. *Canadian Journal of Forest Research* **33**, 2443–2451.

Persson, T., Rudebeck, A. & Wirén, A. 1995. Pools and fluxes of carbon and nitrogen in 40-year-old forest liming experiments in Southern Sweden. *Water, Air, and Soil Pollution* **85**(2), 901–906.

Pitman, R.M. 2006. Wood ash use in forestry – a review of the environmental impacts. *Forestry* **79**(5), 563–588.

Reid, C. & Watmough S.A. 2014. Evaluating the effects of liming and wood-ash treatment on forest ecosystems through systematic meta-analysis. Canadian *Journal of Forest Research* **44**(8), 867–885.

Rosenberg, O., Persson, T., Högbom, L. & Jacobson, S. 2010. Effects of wood-ash application on potential carbon and nitrogen mineralisation at two forest sites with different tree species, climate and N status. *Forest Ecology and Management* **260**(4), 511–518.

Saarsalmi, A. & Mälkönen, E. 2001. Forest Fertilization Research in Finland: A Literature Review. *Scandinavian Journal of Forest Research* **16**, 514–535.

Saarsalmi, A., Kukkola, M., Moilanen, M. & Arola, M. 2006. Long-term effects of ash and N fertilization on stand growth, tree nutrient status and soil chemistry in a Scots pine stand. *Forest Ecology and Management* **235**, 116–128.

Saarsalmi, A., Mälkönen, E. & Kukkola, M. 2004. Effect of wood ash fertilization on soil chemical properties and stand nutrient status and growth of some coniferous stands in Finland. *Scandinavian Journal of Forest Research* **19**, 217–233.

Saarsalmi, A., Smolander, A., Kukkola, M., Moilanen, M. & Saramäki, J. 2012. 30-Year effects of wood ash and nitrogen fertilization on soil chemical properties, soil microbial processes and stand growth in a Scots pine stand. *Forest Ecology and Management* **278**, 63–70.

Saarsalmi, A., Smolander, A., Moilanen, M. & Kukkola, M. 2014. Wood ash in boreal, low-productive pine stands on upland and peatland sites: Long-term effects on stand growth and soil properties. *Forest Ecology and Management* **327**, 86–95.

Silfverberg, K. & Hotanen, J.P. 1989. Long-term effects of wood-ash on a drained mesotrophic *Sphagnum papillosum* fen in Oulu district, Finland. *Folia Forestalia (Finland)* **742**, 23 pp. (In Finnish with English summary).

Silfverberg, K. & Huikari, O. 1985. Wood ash fertilization on drained peat-lands. *Folia Forestalia (Finland)* **633**, 25 pp. (In Finnish with English summary).

Vance, E.D. 1996. Land application of wood-fired and combination ashes: an overview. *Journal of Environmental Quality* **25**, 937–944.

Zālītis, P. & Jansons, J. 2013. *Latvian forest typology and its beginnings.* Daugavpils: Daugavpils University Acdemic Publishing 'Saule', 167 pp. (in Latvian).

Zalitis, P. 2006. *Preconditions of Forestry*. Riga, et cetera, 217 pp. (in Latvian).

Zalitis, P. & Indriksons, A. 2010. The hydrological properties of waterlogged and drained forests in Latvia. *Journal of Water and Land Development* **13b**, 69–86.

Zimmermann, S. & Frey, B. 2002. Soil respiration and microbial properties in an acid forest soil: effects of wood ash. *Soil Biology and Biochemistry* **34**(11), 1727–1737.

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Shifting to proactive risk management: Risk communication using the RAMP tool

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Abstract. Ergonomic risk factors are major contributors to work-related musculoskeletal disorders and quality deficiencies in the manufacturing industry. Due to lack of tools or systems that can support a systematic risk management of these production and health related factors, a new risk management tool (RAMP) was developed. In this paper, the risk communication system (the Results module) of this tool is presented along with a description of its development. An example of how it can be used, based on assessments performed in industry, is given. An evaluation of its usability, which included twenty practitioners active in the industry, gives support to the notion that the system is usable both for risk communication and as a decision base.

Key words: Risk assessment, risk reduction, manual handling, ergonomics.

INTRODUCTION

Manual materials handling, repetitive movements and frequently adopting stressful postures are major risk factors for work-related musculoskeletal disorders (WMSDs) (Punnett & Wegman, 2004). These ergonomic risk factors are common in several industry branches, such as in the food and vehicle manufacturing industries, as well as in the transport sector, where a high prevalence of WMSDs has been reported (Schneider & Irastorza, 2010; SWEA, 2014). In addition to lost work days and human suffering, poor ergonomic working conditions have also been linked with increased financial cost for companies (Falck et al., 2010; Uegaki et al., 2011), for example, due to increased numbers of quality deficiencies (Eklund, 1995; Falck et al., 2010; Eklund & Yeow, 2015). In some production processes, poor ergonomic working conditions have been related to about 40% of the quality deficiencies (Axelsson, 2000). Information on production performance indicators, such as quality and productivity, is often visualised and reported back to different levels within the organisation and thereby enables the planning and steering of production. Despite the strong link between ergonomics and quality outcomes, there is a lack of visualisation of the 'ergonomic status' (e.g. occurrence of ergonomic risk factors) (Törnström et al., 2008). Feed-back on the ergonomic status of the work and the health status of the workers (e.g. discomfort, pain) is often delayed or lacking, and may instead show up later as sickness absence (Neumann et al., 2009). Because of the time lag, as well as often imprecise information on ergonomic risk factors and their link to a specific job or task, this may result in reactive measures (e.g. reintegration after sickness absence), instead of proactive measures (e.g.

preventing occurrence of sickness absence). However, in order to shift to a proactive mode, early feedback on these performance related factors is needed. By using systematic occupational health and safety management (OHSM), a significant reduction in musculoskeletal disorders has been reported (Cantley et al., 2014), as well as a reduction in the number of accidents (Paas et al., 2015). The commitment of management to this process is often seen as a key factor for an effective OHSM (Cameron & Duff, 2007b; Zanko & Dawson, 2012), and by the use of goal setting, management's safety performance can be enhanced (Cameron & Duff, 2007a, 2007b). Although several assessment tools exist for assessing physical ergonomic risks related to manual handling operations (MHOs) (e.g. Takala et al., 2010), most of them only support a part of the risk management process, usually the identification and evaluation of the risks. Few of them facilitate the OHSM process in terms of supporting design of action plans and design of measures. In addition, few of these tools have integrated systems for communicating their results at different levels of detail, in order to target the needs of the different stakeholders. Therefore, based on the needs from two global organisations in the food and vehicle manufacturing industry, and the identified gap in ergonomic tools, it was decided to develop a new risk management tool (the RAMP tool, 'Risk Assessment and Management tool for manual handling Proactively') (Rose et al., 2011; Lind et al., 2014), which included a system for risk communication.

The RAMP tool consists of two assessment tools (*RAMP I* and *RAMP II*), a risk communication system (*the Results module)* and a system for creating action plans (*the Action module* (Fig. 1). RAMP I can be used by the companies themselves (e.g. managers together with safety representatives) for quick screening of work tasks or work stations for physical ergonomics risks related to MHOs. If the screening using RAMP I identifies a potential risk, an in-depth assessment can be performed using RAMP II by e.g. occupational health and safety experts (e.g. ergonomists from the occupational health services, OHS). The results from RAMP I and RAMP II can then be displayed and communicated using the Results module (which is presented in this paper) at different levels of detail (e.g. from a single workstation or as a plot from multiple workstations). Based on this information, interventions can be designed and implemented with the support of the Action module (design of action plans and suggestions for measures). Using the Action module, the effect of the intervention can be evaluated against the ergonomic status prior to the intervention. Thus, the RAMP tool facilities the whole risk management process (ISO, 2009) including: identification and assessment of physical ergonomic risks, communication of risks to and between different stakeholders within an organisation, support for designing and implementing measures, and evaluations of their effect.

RAMP I Quick screening of potential ergonomic risks	**RAMP II** In-depth assessment of ergonomic risks
Results module Displays results at different levels of detail & scope	**Action module** Action model, Action suggestions & Action plan

Figure 1. The four modules of the RAMP tool: RAMP I, RAMP II, The Results module and the Action module.

The objective of this paper is to describe the risk communication system (the Results module) in the RAMP tool, its development, to give examples on how it can be used for risk communication within companies, and to describe how end-users perceive its usability.

MATERIALS AND METHODS

Development of the risk communication system

The development of the risk communication system (the Results module) was integrated in the development process of the RAMP tool. An iterative process was used, based on close co-operation between researchers and practitioners, using an interactive research approach (Svensson el al., 2007) in which scientific 'knowledge' was combined with expertise of practitioners within the industry. Four companies, (two large, one medium, and one small-sized company) from the food and vehicle manufacturing industries, and the transportation sector, participated. All of these had work sites located in Sweden and had a large amount of jobs which required different types of MHOs, including heavy lifting, pushing and pulling. The development was initiated due to the need for a risk management tool that could be used by one of the large-sized companies and its occupational health services. Together with the other large-sized company with similar needs, and researchers at KTH Royal Institute of Technology the project was started (Rose et al., 2011). A reference group was connected to the project. It consisted of OHS experts from the two large-sized companies, representatives from the Swedish labour market parties (the Association of Swedish Engineering Industries and a labour union 'IF Metall'), an association within the transport sector in Sweden ('TYA'), the Swedish Work Environment Authority, and researchers at KTH (Rose et al., 2011). The role of the reference group was, for example to monitor that the needs for small and medium-sized enterprises (SMEs) were considered and the two small and medium-sized enterprises (SMEs) were recruited from the projects reference group. An inventory of the practitioners' needs (Rose et al., 2011) showed that the users requested a tool that: facilitates communication of the risk assessment to different stakeholders, supports a proactive approach, and presents suggestions of measures for improving the working environment (Rose et al., 2011). A clear presentation of the results (from the assessment) which are easy to interpret, was also seen as an important prerequisite for the efficient facilitation of risk communication.

The development was carried out using recurrent (usually weekly or monthly) workshops from the middle of 2010 to 2014. The number of participants varied, but usually involved a handful. In total, more than 80 practitioners and occupational health and safety experts participated, including managers, one CEO, production engineers, safety representatives, operators, ergonomists from the OHSs and researchers within the field of ergonomics. During visits to 13 production sites, several existing risk communication systems used in industry were examined and input from this was also used in the design process. In the development process, input and feedback from the participating companies were prioritised and influenced the module's structure and design. In addition, ten practitioners and researchers formed a 'usability group' to evaluate and give input on the usability aspect of the Results module. This iterative process continued until the participants signalled that the design of the Results module prototypes met the needs of the users.

Usability survey

Twenty practitioners and occupational health and safety experts (including, managers, safety representatives, OHSM personnel and ergonomists) volunteered to participate in an evaluation of the RAMP tool's usability in terms of communicating risks and facilitating risk management. The managers, safety representatives, and the OHSM-personnel were all employed at a large-sized manufacturing company (250 persons employed, EUROSTAT, 2014) and the ergonomists were all employed at the same OHS-organisation. A paper based questionnaire was distributed to each participant at the end of a half-day training session, where participants also had carried out assessments of three video-recorded work tasks using the RAMP tool. The questionnaire contained questions regarding the ease-of-use of making assessments with RAMP I and RAMP II, and questions concerning its usability. In this paper, two of the questions are reported: 1) how the results from the tools can be communicated (Risk communication), and 2) its usability as a decision base. The participants responded to these questions using a five-graded Likert scale (fully agree, partly agree, neutral, partly disagree or totally disagree).

RESULTS AND DISCUSSION

Communication of risks and prioritisation of measures

Based on the workshops with involvement of the practitioners, a three-graded 'traffic light model' was developed for communication of risk and priority (action) level (RPL) (Fig. 2).

	High risk. The loading situation has such a magnitude and characteristics that many employees are at an increased risk of developing musculoskeletal disorders. Improvement measures should be given high priority.
	Investigate further. An in more in depth analysis is required to assess the risk level. A refined analysis can be carried out for example with the RAMP II module.
	Low risk. The loading situation has such a magnitude and characteristics that most employees are at a low risk of developing musculoskeletal disorders. However, individuals with reduced physical capacity may be at risk. Individually tailored improvement measures may be needed.
	High risk. The loading situation has such a magnitude and characteristics that many employees are at an increased risk of developing musculoskeletal disorders. Improvement measures should be given high priority.
	Risk. The loading situation has such a magnitude and characteristics that certain employees are at an increased risk of developing musculoskeletal disorders. Improvement measures should be taken.
	Low risk. The loading situation has such a magnitude and characteristics that most employees are at a low risk of developing musculoskeletal disorders. However, individuals with reduced physical capacity may be at risk. Individually tailored improvement measures may be needed.

Figure 2. The three-graded 'traffic light model' for communication of risk- and priority-level used in RAMP I (top) and RAMP II (bottom). Screenshots from the RAMP tool, https://www.kth.se/sth/forskning/halso-och-systemvetenskap/ergonomi/framtagna-verktyg/ramp/om-ramp-1.511671 (Retrieved 12.2.2016).

The result from RAMP I is communicated using a green, grey, and red colour code representing a low RPL, an unspecified RPL (investigate further) and a high RPL. The result from RAMP II is communicated using a green, yellow, and red colour code, representing a low RPL, intermediate RPL and a high RPL. The use of a three-graded colour code was highlighted by several ergonomists and practitioners as an important facilitator for communicating risks and has been used in several other ergonomic risk assessment tools (Hägg, 2003; Koningsveld et al., 2005, SWEA, 2012). The choice of using a grey colour code instead of a yellow for representing an unspecified RPL (which requires further investigation to settle the RPL) emerged after discussing the practitioners' perceptions of the yellow colour code in a similar risk model (red-yellow-green) from the Swedish Work Environment Authority (SWEA, 2012, p. 35). Using this model from SWEA, several of the practitioners interpreted 'yellow' as an intermediate risk although it is stated that a more in-depth assessment is required to determine if the risk can be regarded as acceptable or not. To avoid potential confusion about the intermediate level in RAMP I, a grey colour code was used signalling that further investigation is needed to assess the risk level. In addition to the colour code in RAMP II, each risk factor (Fig. 4a, factor 1.1–7.1), has an accompanying score (see Fig. 3 for an example). The score allows for a refined risk evaluation and risk communication within each RPL category (red-yellow-green), due to the multiple scale increments. However, when using these for prioritisation, the score is subordinate of the colour.

4 hours or more	10
3 to < 4 hours	7
2 to < 3 hours	5
1 to < 2 hours	3
30 minutes to < 1 hour	2
5 to < 30 minutes	1
< 5 minutes	0

Figure 3. Example of scores and colour assessments of duration of stressful trunk postures using RAMP II, displayed at the detailed risk-factor level. Screenshot from the RAMP tool, https://www.kth.se/sth/forskning/halso-och-systemvetenskap/ergonomi/framtagna-verktyg/ramp/om-ramp-1.511671 (Retrieved 2016-02-12).

The Results module and a case

In order to illustrate the Results module, assessments completed at eleven workstations at a manufacturing site in Sweden are used. At the site, the production is carried out at multiple departments and several of the job tasks consist of MHOs. The names of the departments and workstations have been altered for anonymisation. Using the Results module, assessment performed with RAMP II (or RAMP I) can be displayed at several levels of detail: from a single workstation (Fig. 4) to multiple work stations at a one or several departments (Fig. 5) or sites (Fig. 7). As shown in Fig. 4, each of the assessed factors (number 1.1–7.1) is accompanied by a colour code and a score. As shown at the bottom of the figure, the number of green, yellow and red assessments (RPLs) is summarised, as well as the total score. In this example, the assessment of *Workstation A* using RAMP II has resulted in twenty-nine green and five yellow assessments and a total (risk) score of twelve.

Department	Dep.A	
Workstation	A1	
1. Postures		
1.1 Posture of the head - forwards and to the side		**2**
1.2 Posture of the head - backwards		**0**
1.3 Back posture - moderate bending		**1**
1.4 Back posture - considerable bending and twisting		**1**
1.5 Upper arm posture - hand in/above shoulder height*		**0**
1.6 Upper arm posture - hand in/outside outer work area*		**0**
1.7 Wrist posture*		**0**
1.8 Leg and foot space and surface		**0**
2. Work movements and repetitive work		
2.1 Movements of the arm*		**0**
2.2 Movements of the wrist*		**0**
2.3 Type of grip*		**0**
2.4 Shorter recovery/variation		**0**
2.5 Longer recovery/variation		**0**
3. Lifting		
3.1 Lifting (average case)		**0**
3.1 Lifting (worst case)		**0**
4. Pushing and pulling		
4.1 Pushing and pulling (average case)		**0**
4.2 Pushing and pulling (worst case)		**0**
5. Influencing factors		
5.1 Influencing physical factors hand/arm		
a+b. Hand-arm vibrations		**0**
c. Manually handling of warm or cold object		**0**
d. Hand used as impact tool		**0**
e. Holding hand-tools weighing > 2.3 kg, > 30 min.		**0**
f. Holding precision tools weighing > 0.4 kg > 30 min.		**0**
5.2 Other physical factors		
a+b. Whole body vibrations		**0**
c. Insufficient visual conditions		**0**
d. Hot, cold or draughty environment		**0**
e. Prolonged standing or walking on hard surfaces		**2**
f. Prolonged sitting		**0**
g. Prolonged standing		**2**
h. Kneeling/squatting		**0**
5.3 Work organizational and psychosocial factors		
a. No possibility to influence the work pace		**0**
b. No possibility to influence the work setting		**2**
c. Difficulties in keep up with the work tasks		**0**
d. Employees work rapidly in order to take longer breaks		**0**
6. Reports on physically strenuous work		
6.1 Documented reporting on physically strenuous work		**0**
6.2 Type of work that has led to reporting:		**0**
7. Perceived physical discomfort		
7.1 Perceived physical discomfort		**2**
7.2 The worst task:		
Total score		12
Number of red assessments - High risk/action level	**0**	
Number of yellow assessments - Risk/action level	**5**	
Number of green assessments - Low risk/action level	**29**	

Figure 4. The results from an assessment of workstation A1 (using RAMP II), displayed at risk-factor level using the Results module.

In the next example, eleven workstations from two departments have been assessed using RAMP II, and the results are displayed using the Results module (Fig. 5). This presentation indicates that lifting, and pushing/pulling operations have been categorised as high RPL, and that a reduction in the exposures should be given high priority. Prolonged standing or walking on hard surfaces was, additionally identified as a risk (Fig. 5, factor 5.2e) at all of the assessed workstations. This means that this hazard could not be eliminated by introducing work rotation between these eleven workstations. Instead other measures are needed, such as changing the floor type, or enlarging the rotation schedule to other types of work tasks with lower exposure to hard floors.

Department	Dep.A					Dep.B					
Workstation	A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6
1. Postures											
1.1 Posture of the head - forwards and to the side											
1.2 Posture of the head - backwards											
1.3 Back posture - moderate bending											
1.4 Back posture - considerable bending and twisting											
1.5 Upper arm posture - hand in/above shoulder height*											
1.6 Upper arm posture - hand in/outside outer work area*											
1.7 Wrist posture*											
1.8 Leg and foot space and surface											
2. Work movements and repetitive work											
2.1 Movements of the arm*											
2.2 Movements of the wrist*											
2.3 Type of grip*											
2.4 Shorter recovery/variation											
2.5 Longer recovery/variation											
3. Lifting											
3.1 Lifting (average case)											
3.1 Lifting (worst case)							-				-
4. Pushing and pulling											
4.1 Pushing and pulling (average case)											
4.2 Pushing and pulling (worst case)											
5. Influencing factors											
5.1 Influencing physical factors hand/arm											
a+b. Hand-arm vibrations											
c. Manually handling of warm or cold object											
d. Hand used as impact tool											
e. Holding hand-tools weighing > 2.3 kg, > 30 min.											
f. Holding precision tools weighing > 0.4 kg > 30 min.											
5.2 Other physical factors											
a+b. Whole body vibrations											
c. Insufficient visual conditions											
d. Hot, cold or draughty environment											
e. Prolonged standing or walking on hard surfaces											
f. Prolonged sitting											
g. Prolonged standing											
h. Kneeling/squatting											
5.3 Work organizational and psychosocial factors											
a. No possibility to influence the work pace											
b. No possibility to influence the work setting											
c. Difficulties in keep up with the work tasks											
d. Employees work rapidly in order to take longer breaks											
6. Reports on physically strenuous work											
6.1 Documented reporting on physically strenuous work						-	-	-	-	-	-
6.2 Type of work that has led to reporting:	-	-	-	-	-	-	-	-	-	-	-
7. Perceived physical discomfort											
7.1 Perceived physical discomfort						-	-	-	-	-	-
7.2 The worst task:	-	-	-	-	-	-	-	-	-	-	-
Number of red assessments - High risk/action level	0	2	2	0	1	3	1	3	2	3	1
Number of yellow assessments - Risk/action level	5	4	3	3	4	5	5	5	5	5	5
Number of green assessments - Low risk/action level	29	28	29	31	29	24	25	24	25	24	25

Figure 5. The results from assessments of eleven workstations from two different departments (using RAMP II), displayed at risk-factor level using the Results module.

At department B (Fig. 5), movements of the upper arm were categorised as a risk (yellow RPL) at all of the workstations (B1–B6). As shown in Fig. 5, the RPL-level cannot be reduced to an acceptable level (low RPL) by simply introducing work rotation between these six workstations. Other measures are needed, e.g. engineering controls (redesign of work). To communicate the cause of the risk in more detail, an in-depth analysis of each factor can be made using the RAMP tool. In order to illustrate this, factor 2.1 (*Movements of the upper arm*) from workstation B1 is used. This factor (2.1) was given a score of '2' due to the movement pattern of the left and right arm (see the white boxes in Fig. 6), which resulted in a yellow RPL level. In order to reduce the RPL level, measures targeting altering the movement pattern for both arms are needed.

2. Work movements and repetitive work

2.1 Movements of the arm (upper and lower arm)

How are the movements of the arm generally?		Left	Right
	Constant movements mainly without pause	5	5
	Frequent movements with some pauses	2	2
	Varied movements, movement now and then (up to 2/min)	0	0

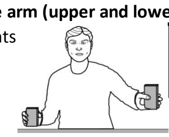

Figure 6. The results from an assessment of the arm movement pattern at workstation B1 (using RAMP II), displayed at detailed risk-factor level.

The assessment can also be displayed at a less detailed level (Figs 7 and 8). The assessments from the two departments (A and B) are displayed in Fig. 7 at risk-category level. This level facilitates a quick overview of the seven risk categories, and, in addition, the total number of red, yellow and green assessments at each workstation. According to the assessments (Fig. 7), both lifting and pulling/pushing have been identified as high risk (high RPL) at the two departments.

In Fig. 7, a hypothetical case of an overview of assessment made at an enterprise with production sites in both Sweden and in Canada is displayed. The overview shows that departments G:A (in Gothenburg) and T:B (in Toronto) have a large amount of factors categorised as high risk (high RPL). This information can be used within the company for prioritising resources and measures targeted at these two departments.

Department	Dep.A					Dep.B					
Workstation	A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6
1. Postures	1										
2. Work movements and repetitive work						1	1	1	1	1	1
3. Lifting					1	1	1	1	2	1	1
4. Pushing and pulling		2	2		1	2		2		2	
5. Influencing factors	3	3	3	3	2	4	4	4	4	4	4
6. Reports on physically strenuous work											
7. Perceived physical discomfort	1	1			1	-	-	-	-	-	-
Number of red assessments - High risk/action level	0	2	2	0	1	3	1	3	2	3	1
Number of yellow assessments - Risk/action level	5	4	3	3	4	5	5	5	5	5	5
Number of green assessments - Low risk/action level	29	28	29	31	29	24	25	24	25	24	25

Figure 7. The results from assessments of eleven workstations from two different departments (using RAMP II), displayed at risk category level using the Results module. The colours at the top of the figure show the highest RPL (red, yellow or green) for each risk-category (1–7) and its quantity (e.g. *two* red RPLs for 'Lifting' at workstation B4). At the bottom of the figure, the total number of red, yellow and green assessments are shown for each workstation.

Country	Sweden					Canada				
Site	Stockholm			Gothenburg		Toronto			Montréal	
Department	S:A	S:B	S:C	G:A	G:B	T:A	T:B	T:C	M:A	M:B
Number of red assessments - High risk/action level	6	3	10	30	10	10	20	8	15	12
Number of yellow assessments - Risk/action level	16	10	20	60	15	18	35	14	30	20
Number of green assessments - Low risk/action level	148	191	242	182	145	176	149	148	227	138

Figure 8. A hypothetical exaple of assessments of ten departments at four sites in two countries, displayed as an overview at site and country level.

The Results module can be used for both prioritisation and goal setting. For example, resources can be targeted at first hand at those workstations or job tasks which have been evaluated as constituting a high risk, and thereafter at those evaluated as moderate risk level (yellow). In addition, at the overview level, the presentation of results s (e.g. Figs 5, 7 and 8) can be used for goal setting (e.g. of a certain reduction of 'red' or 'yellow' workstations), to enhance management's safety performance (Cameron & Duff, 2007a, 2007b). Although the RAMP tool facilitates assessment and communication of a broad range of physical ergonomic factors, several other types of risks may need to be addressed. Therefore, this tool should be complemented with other methods or tools, e.g. observational based risk assessment tools, measurements, observation and interviews (David, 2005). The assessment and communication of risk is aimed at risks at group level, and assessment of individual risk is not supported by the tool. Furthermore, the risk levels used within the RAMP tool should be treated with some caution. The aetiology of WMSD is complex and a clear cut-off between a low risk exposure, a moderate risk exposure and a high risk exposure is currently not sufficiently supported (Viikari-Juntura, 1997; Fallentin, 2003; Lind et al., 2015; Lind, 2016; Coenen et al., 2016).

Usability survey

The results from the evaluation (Fig. 9) show that a majority (90% and 95%) of the respondents fully agreed or partly agreed that the RAMP tool (RAMP I and RAMP II respectively), presented the results clearly. About the same proportion (84% and 85%) also agreed (fully or partly) that the tool is usable as a decision base. These results indicate that the RAMP tool is usable in the risk management process for communication of risks and as a base for decisions and both aspects might be important in order to integrate ergonomics in the decision process for implementing measures. Easiness to interpret the results for the client was rated as one of the most important qualities of ergonomic assessment tools among ergonomists (Eliasson et al., 2016). Several methods have been criticised for lack of involvement of the needs of end-users (practitioners) in the development process (David et al., 2008). The development of this tool included more than 80 practitioners and the iterative development process with feedback from the end users was seen as an important prerequisite of the final design of the tool. Most of the practitioners (non-ergonomists) from the manufacturing industry came from large-sized companies, which may result in that primarily the large-sized companies' needs were prioritised.

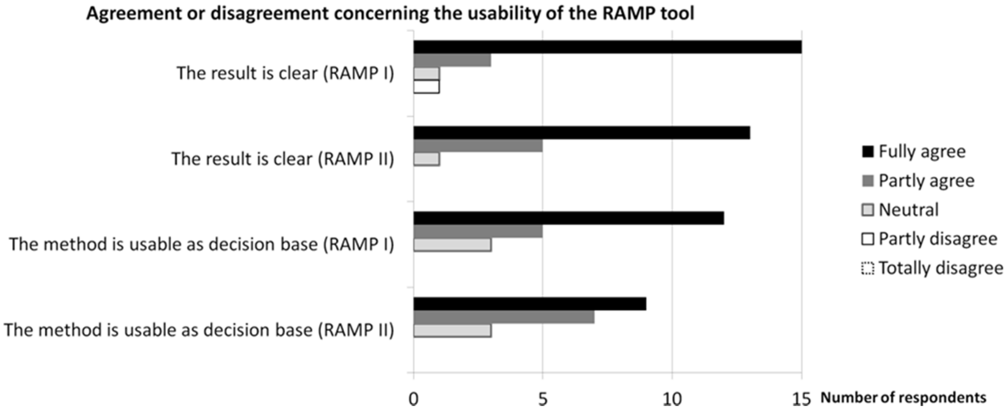

Figure 9. Results from the questionnaire evaluating RAMP I and II display results for RAMP I, while 3 and 4 display results for RAMP II. (n = 20).

Therefore, efforts were also made to ensure that the needs of the SMEs were addressed. This was done during recurrent discussions of the needs of the SMEs with the reference group, and with the two participating SMEs. In addition, the inclusion more than 30 ergonomists in the development process is also likely to enhance the usability for SMEs. It should be noted that the usability evaluation was only based on answers from twenty practitioners. These results should therefore not be generalised to other potential users. The RAMP tool is presently being implemented in several European countries as well as in South America, something that gives support to its overall usability.

CONCLUSIONS

A risk management tool (‘RAMP’) was developed to facilitate practitioners in risk management of manual handling activities. It includes a module for risk communication (the Result module). To accommodate the users‘ needs, an iterative development process was used which included participation from more than 80 practitioners. The Result module is presented and described together with examples of how it can be used at companies in the manufacturing industry, and how risk assessments in industries can be visualized. An evaluation of its usability, which included twenty practitioners active in industry, gives support to the notion that the system is usable both for risk communication and as a decision base.

CONFLICTS OF INTEREST. The authors declare no conflicts of interest.

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REFERENCES

Axelsson, J.R.C. 2000. Quality and ergonomics: towards successful integration. Ph.D dissertation No. 616. Linköping University. Linköping. ISBN 91-7219-652-1, pp. 225–244.

Cameron, I. & Duff, R. 2007a. Use of performance measurement and goal setting to improve construction managers' focus on health and safety. *Constr. Manage and Econ.* **25**, 869–881.

Cameron, I. & Duff, R. 2007b. A critical review of safety initiatives using goal setting and feedback. *Constr Manage and Econ* **25**, 495–508.

Cantley, L.F., Taiwo, O.A., Galusha, D., Barbour, R., Slade, M.D., Tessier-Sherman, B. & Cullen, M.R. 2014. Effect of systematic ergonomic hazard identification and control implementation on musculoskeletal disorder and injury risk. *Scand. J. Work Environ. Health* **40**, 57–65.

Coenen, P., Douwes, M., van den Heuvel, S. & Bosch, T. 2016. Towards exposure limits for working postures and musculoskeletal symptoms – a prospective cohort study. *Ergonomics*, 1–11.

David, G.C. 2005. Ergonomic methods for assessing exposure to risk factors for work-related musculoskeletal disorders. *Occup. Med.* **55**, 190-199.

David, G., Woods, V., Li, G. & Buckle, P. 2008. The development of the Quick Exposure Check (QEC) for assessing exposure to risk factors for work-related musculoskeletal disorders. *Appl. Ergon.* **39**, 57–69.

Eklund, J.A.E. 1995. Relationships between ergonomics and quality in assembly work. *Applied Ergonomics* **26**, 15–20.

Eklund, J.A.E. & Yeow, P.H.P. 2015. Integrating Ergonomics and Quality Concepts. In Wilson, J.R. & Sharples, S. (ed): *Evaluation of Human Work*: 4th Edition. Boca Ranton: Taylor & Francis (CRC Press), pp. 931–956. ISBN: 9781466559615.

Eliasson, K., Lind, C.M. & Nyman, T. 2016. Usage of observational risk assessment methods among ergonomists – which, when and why? Manuscript.

EUROSTAT. 2014. Glossary:Enterprise size. *http://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Enterprise_size.* Accessed 23.2.2016.

Falck, A.C., Örtengren, R. & Högberg, D. 2010. The impact of poor assembly ergonomics on product quality: A cost-benefit analysis in car manufacturing. *Hum. Factors Man* **20**, 24–41.

Fallentin, N. 2003. Regulatory actions to prevent work-related musculoskeletal disorders – The use of research-based exposure limits. *Scand. J. Work Environ. Health* **29**, 247–250.

Hägg, G.M. 2003. Corporate initiatives in ergonomics – An introduction. *Appl. Ergon.* **34**, 3–15.

International Organization for Standardization (ISO). 2009. 31000:2009 Risk management – Principles and guidelines. Geneva.

Koningsveld, E.A.P., Dul, J. Van Rhijn, G.W. & Vink, P. 2005, Enhancing the impact of ergonomics interventions. *Ergonomics* **48**, 559–580.

Lind, C., Rose, L., Franzon, H. & Nord-Nilsson, L. 2014. RAMP: Risk management Assessment tool for Manual handling Proactively, *11th International Symposium on Human Factors in Organisational Design and Management (ODAM) and 46th Annual Nordic Ergonomics Society Conference (NES).* Copenhagen, Denmark, 17–20 Aug, 2014.

Lind, C., Eklund, J. & Rose, L. 2015. A practitioner model for assessing manual lifting and lowering operations – included in the RAMP tool, *Proceedings of the 19th Triennial Congress of the International Ergonomics Association , 'Reaching Out', Melbourne. http://ergonomics.uq.edu.au/iea/proceedings/Index_files/papers/611.pdf.* Accessed 11.2.2016.

Lind, C.M. 2016. Pushing and pulling: An assessment tool for OHS practitioners. Submitted manuscript.

Neumann, W.P., Ekman, M. & Winkel, J. 2009. Integrating ergonomics into production system development – The Volvo Powertrain case. *Appl. Ergon.* **40**, 527–537.
Paas, Õ., Reinhold, K. & Tint, P. 2015. OHSAS 18001 contribution to real and formal safety elements in safety management system in manufacturing. *Agronomy Research* **13**, 1260–1274.
Punnett, L. & Wegman, D.H. 2004. Work-related musculoskeletal disorders: The epidemiologic evidence and the debate. *J Electromyogr. Kinesiol.* **14**, 13–23.
Schneider, E. & Irastorza, X. 2010. OSH in Figures: Work-related Musculoskeletal Disorders in the EU – Facts and Figures. European Agency for Safety and Health at Work. Luxembourg: Publications Office of the European Union. *https://osha.europa.eu/en/tools-and-publications/publications/reports/TERO09009ENC*. Accessed 11.2.2016.
SWEA (Swedish Work Environment Authority). 2014. *Work-Related Disorders 2014*, Arbetsmiljöstatistik ISSN 1652–1110. Stockholm.
Svensson, L., Ellström, P-E. & Brulin, G. 2007. Introduction – on interactive research. *Int J Act. Res.* **3**, 233–249.
Rose, L., Lind, C., Franzon, H., Nord-Nilsson, L. & Clausén, A. 2011. Development, implementation and dissemination of RAMP: Risk management Assessment tool for Manual handling Proactively, in: Lindfors, J., Savolainen, M., Väyrynen, S. (ed.), *43rd Annual Nordic Ergonomics Society Conference (NES)*. Oulu, Finland, pp. 255–260.
Takala, E.P., Pehkonen, I., Forsman, M., Hansson, G.A., Mathiassen, S.E., Neumann, W.P., Sjogaard, G., Veiersted, K.B., Westgaard, R.H. & Winkel, J. 2010. Systematic evaluation of observational methods assessing biomechanical exposures at work. *Scand. J. Work Environ. Health.* **36**, 3–24.
Törnström, L., Amprazis, J., Christmansson, M. & Eklund, J. 2008. A corporate workplace model for ergonomic assessments and improvements. *Appl. Ergon* **39**, 219–228.
Uegaki, K., De Bruijne, M.C., van der Beek, A.J., van Mechelen, W. & van Tulder, M.W. 2011. Economic evaluations of occupational health interventions from a company's perspective: A systematic review of methods to estimate the cost of health-related productivity loss. *Occup. Rehabil.* **21**, 90–99.
Viikari-Juntura, E.R.A. 1997. The scientific basis for making guidelines and standards to prevent work-related musculoskeletal disorders. *Ergonomics* **40**, 1097–1117.
Zanko, M. & Dawson, P. 2012. Occupational Health and Safety Management in Organizations: A Review. *Int J Manag. Rev.* **14**, 328–344.

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Combustion of briquettes from oversize fraction of compost from wood waste and other biomass residues

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Abstract. This article aims to determine experimentally the energy potential of samples from oversize compost fraction formed into briquettes. Theoretical combustion characteristics of the briquettes are determined and are compared with a reference fuel. Elemental analysis and stoichiometric calculations were performed for the samples. Classical grate combustion device with manual fuel supply was chosen for combustion tests. Flue gas temperature and emission parameters, such as the emission levels of carbon monoxide, carbon dioxide and nitrogen oxides, were monitored by a multi-purpose flue gas analyzer Madur GA-60. Dependence of these parameters on air input was followed.

Elemental analyses and stoichiometric calculations of individual samples indicate favourable properties of the energy compost for further energy utilisation, namely the gross calorific value of 16.42 MJ kg^{-1}. Excess air was causing high losses through heat of the flue gas during the experiments on combustion device. This fact occurred in a situation when the temperature of flue gas leaving the chimney reached high levels. The excess air coefficient also significantly influenced emissions of carbon dioxide and monoxide and nitrogen oxides in the flue gas. The trends are analysed statistically and are expressed by regression equations. The results can serve in practice for optimization of combustion processes in grate boilers with manual feed of the fuel.

Key words: biomass, combustion device, calorific value, combustion gases, heat loss.

INTRODUCTION

Interest in the production of alternative fuels from compost has increased and not only due to the volatility of oil prices in the market. Current composting technologies enable simultaneous production of quality compost as well as a product for energetic use (Winkler et al., 2007). The actual energy utilization of compost depends on the amount of combustibles. Most important is the content of carbon in the final compost, which is dependent on the composition of the original mixture and the composting process itself which is evident from studies of Mohee et al. (2015).

Oversize fraction of the composti consists mainly of non-compostable wood material that can be represented by a wide range of wood biomass (Skanderová et al., 2015). Characteristics of wood biomass are described by the author Brožek (2015), who evaluated quality of briquettes from wood biomass. Moisture and mineral composition in the final compost affect not only the energetic value, but also the mechanical properties of pressed fuel from the compost as shown in the study Zafari & Kianmehr

(2014). Therefore it is also important to focus on the optimization of the composting process to obtaine quality alternative fuel (Oh et al., 2013).

The increasing demands for processing of biodegradable by-products, not only from agriculture, leads to expansion of new utilization options for these products. One of these options is the energy use of composts (Kranert et al., 2010, Skanderová et al., 2015). Therefore, the aim is the experimental determination of the energy potential of samples from oversize compost fracton (composting in heaps) pressed into briquettes (briquetting press BrikStar 150), and also the determination of theoretical combustion characteristics in comparison with conventional fuel: wood logs. Elemental analysis and stoichiometric calculations are determined for these materials (semiautomatic calorimeter LECO AC-600, elemental analyzer CHN628 + S and analyzer LECO TGA-701). A classical grate combustion device with manual fuel supply was chosen for combustion tests (stove CALOR CZ). Heat and emission parameters are monitored by multi-purpose combustion analyzer (Madur GA-60), such as the flue gas temperature and the emission levels of carbon monoxide, carbon dioxide and nitrogen oxides depending on the amount of supplied combustion air.

MATERIALS AND METHODS

To fulfill the objectives of this research work oversize fraction from classical composting technology in piles without forced aeration was sampled. Oversize components increase the volume of compost, prolong the period of maturation and reduce market sales so an alternative use for them is beneficial. The original compost was made by composting of forestry waste, sawdust, shavings, cuttings, wood, veneers, biodegradable waste from paper, cardboard and wood and biodegradable waste from gardens and parks. Oversize fraction left after screening of this compost through a sieve with mesh size of 40 mm was used. It contained a higher percentage of wood material with the ratio of wood components to other components in samples being on average 85:15 by weight.

Subsequently the samples were pressed into the form of briquettes by a briquetting press BrikStar 150 with a hydraulic unit. This processing eliminates the need for finer crushing of the various components. Density of the briquettes reaches 1,100 kg m^{-3} at the operating pressure to 18 MPa and the operating temperature of 60 °C. Briquettes have a cylindrical shape with a diameter of 65 mm and length 50 mm. For comparison of the measurement results a reference standard fuel was chosen. It was a pure spruce wood in the form of logs.

Briquettes and logs were analyzed for elemental composition. Carbon (C), hydrogen (H), nitrogen (N) and sulfur (S) were analyzed in a laboratory elemental analyzer LECO CHN628 + S. The detection method for carbon and hydrogen is non-dispersive infrared absorption, for nitrogen thermal conductivity and for sulfur infrared absorption. Accuracy range is from 0.01 mg to 0.05 mg. Non-combustible substances in fuel, i.e. the ash content, total water content and volatile matter were determined in a thermogravimetric analyzer LECO TGA-701 with an accuracy of ± 0.02%. Calorific values of examined fuel samples were determined by measuring in a semi-automatic calorimeter LECO AC-600 according to DIN 14918 (2010). Net calorific value was calculated. Results of the elemental analysis of individual samples were used for the calculations.

Subsequently stoichiometric analysis was done for individual samples in which real molar volumes of gas were used to determine the theoretical dependences of carbon monoxide CO and carbon dioxide CO_2 emission concentration on excess air coefficient.

The theoretical amount of emission concentrations of *CO* ($m^3\ kg^{-1}$) is based on the equation:

$$CO = a \cdot \frac{22.37}{12.01} \cdot C \tag{1}$$

where: *a* is the proportion of carbon which burns to *CO* (-); *C* – the relative amount of carbon in the sample (% wt.).

The theoretical amount of emission concentrations of CO_2 ($m^3\ kg^{-1}$) is based on the equation:

$$CO_2 = \frac{22.27}{12.01} \cdot C + 0.0003 \cdot L \tag{2}$$

where the theoretical amount of dry air *L* ($m^3\ kg^{-1}$) is determined from the equation:

$$L = O_{\min} \cdot \frac{100}{21} \cdot n \tag{3}$$

where *n* is the excess air coefficient (-).

The theoretical amount of oxygen O_{min} ($m^3\ kg^{-1}$) is based on the equation:

$$O_{\min} = \frac{22.39}{12.01} \cdot C + \frac{22.39}{4.032} \cdot H + \frac{22.39}{32.06} \cdot S - \frac{22.39}{31.99} \cdot O \tag{4}$$

where *C, H, S,* and *O* are contents of carbon, hydrogen, sulfur and oxygen in the fuel sample (% wt.).

The experimental measurements were carried out with a hot air combustion device CALOR CZ with grate fireplace and manual fuel feeding. Nominal thermal parameters of the combustion device were nominal power of 12 kW, controllable output 6–12 kW and fuel consumption 1.1 to 3.6 kg h^{-1}.

The fuel samples were burned at the nominal thermal parameters of the combustion device, where constant fuel supply was maintained and combustion air supply was modified. Each sample was burnt for six hours. Emission concentration measurement was performed by a multi-purpose flue gas analyzer Madur GA-60. The values of ambient temperature, exhaust temperature and the chemical composition of gases (O_2, CO, SO_2, NO, NO_2) were measured. Concentrations were measured in ppm and converted to $mg.m^{-3}$. Recording time of each measurement was set to one minute. The measuring device was calibrated before each measurement. Emission concentrations of dry flue gas were converted from ppm concentrations to normal conditions, to $mg.m^{-3}$ and to reference oxygen content in the flue gas of 13%.

Subsequently the results of measurements were processed by statistical regression analysis for expressing the mathematical relationship between carbon monoxide and dioxide, flue gas temperature and the total of nitrogen oxides against the excess air coefficient.

The equation of excess air coefficient (n):

$$n = 1 + \left(\frac{CO_{2,\max}}{CO_2} - 1 \right) \cdot \frac{V_{sp,\min}}{L_{\min}} \tag{5}$$

where: $CO_{2,max}$ – theoretical volumetric concentration of carbon dioxide in dry flue gases (%); CO_2– real (measured) volumetric concentration of carbon dioxide in dry flue gases (%); $V_{sp,min}$– theoretical mass amount of dry flue gas (m^3 kg^{-1}); L_{min}– theoretical amount of air for complete combustion (m^3 kg^{-1}).

RESULTS AND DISCUSSION

The resulting values of the elemental analysis of original samples shown in Table 1 indicate that the most decisive parameter for energetic utilization of selected samples of compost briquettes and spruce logs is the net calorific value, which depends on water and ash contents in the fuel (Ruzbarsky et al., 2014).

Table 1. Elemental analysis of samples

Sample / Average values	Water Content (% wt.)	Ash (% wt.)	Gross Calorific Value (MJ kg^{-1})	Net Calorific Value (MJ kg^{-1})	Carbon C (% wt.)	Hydrogen H (% wt.)	Nitrogen N (% wt.)	Sulphur S (% wt.)	Oxygen O (% wt.)
	W	A	Q_s	Q_i	C	H	N	S	O
Briquettes from compost	**7.87**	**11.30**	16.42	**15.23**	44.88	4.57	1.39	0.00	**29.97**
Reference standard fuel – wood logs	**6.60**	**2.23**	18,95	**17.48**	47.19	5.98	0,12	0.02	**37.40**

A positive factor is the low water content in the samples because moisture affects behaviour during combustion process and flue gas volume produced per unit of energy (Malaťák & Bradna, 2014). The results of elemental analysis show several times higher content of ash in the samples of compost briquettes in comparison with woody biomass. Wood logs were analysed together with bark, which forms a small percentage of wood matter. That is the reason why the determined ash content in reached value of 2.23% wt. DM rather than usual ash content of wood around 1% wt. DM. High content of ash significantly reduces the calorific value of briquette samples and consequently affects both the selection and the adjustment of combustion device. This fact is confirmed by Johansson et al. (2004). Other parameters which directly influence the combustion process are the amount of oxygen in the fuel and the amount of volatile matter. Spruce logs provided higher percentage of oxygen in the fuel and 77.29% wt. amount of volatile matter. Volatile matter in briquettes from compost is 67.34% wt. Determination of the briquettes properties and its comparison to chosen standard fuel in the form of wood logs is very important for its application as additional heating source. This type of fuel is still applying as additional heating source for residential as well as commercial premises.

The resulting trends of combustion experiments are compared with theoretical values and shown in Figs 1–4.

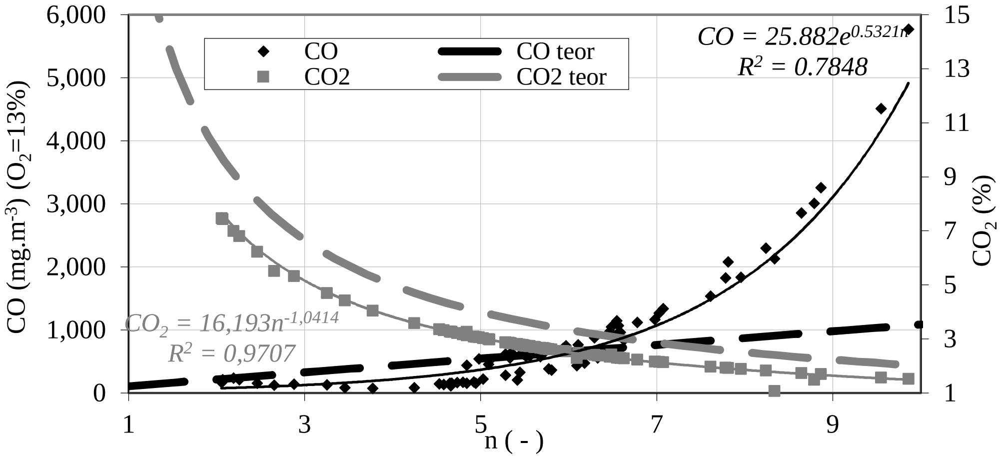

Figure 1. Theoretical and real dependence of carbon monoxide and carbon dioxide on the excess air coefficient – combustion of briquettes from compost.

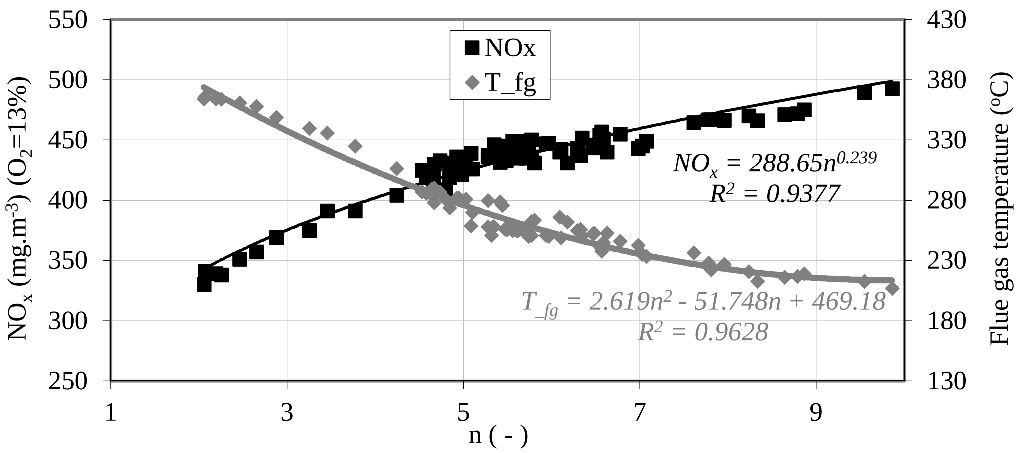

Figure 2. Dependence of nitrogen oxides and flue gas temperature on the excess air coefficient – combustion of briquettes from compost.

The trends of the carbon dioxide emission concentrations correspond well to the theoretical ones. Emission concentrations of carbon dioxide decrease with increasing amounts of excess air coefficient in a power law fashion. The measured values of carbon monoxide grow exponentially with increasing excess air coefficient. While theoretically linear dependence can be derived this does not correspond to the actual values at higher excess air coefficient values.

Flue gas temperature and nitrogen oxides show similar trends against excess air coefficient during combustion of samples. With increasing excess air coefficient dampening of combustion processes occurs and also combustion temperatures is reduced. At the same time there is a perceptible increase in nitrogen oxides emission concentration with increasing excess air.

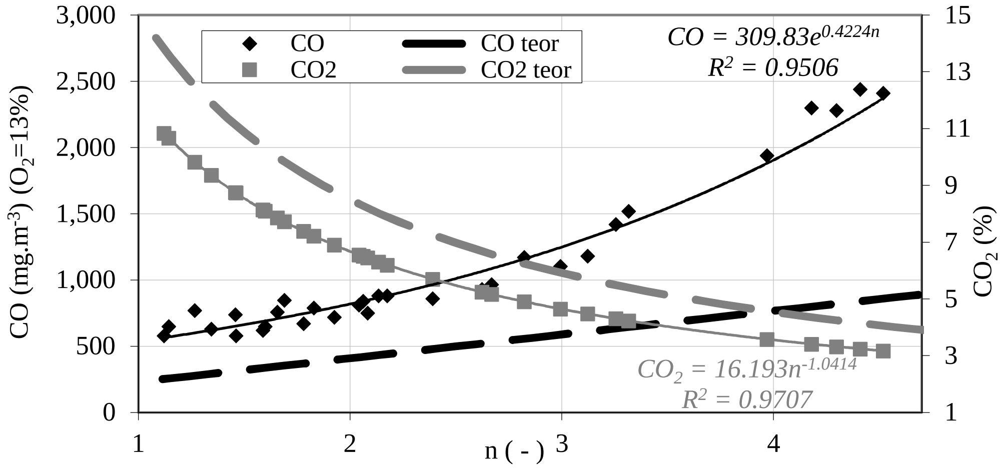

Figure 3. Theoretical and real dependence of carbon monoxide and carbon dioxide on the excess air coefficient – combustion of spruce logs.

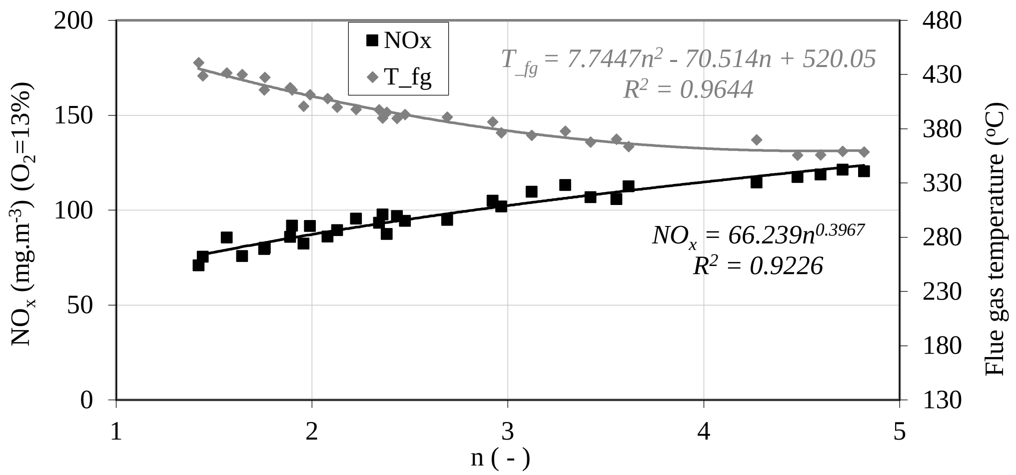

Figure 4. Dependence of nitrogen oxides and flue gas temperature on the excess air coefficient – combustion of spruce logs.

The resulting values of emission measurements showed high concentrations of carbon monoxide *CO* and nitrogen oxides *NOx* in the areas of high excess air coefficient *n*. As shown in a research work of Fiedler & Persson (2009), the combustion process is the most efficient at nominal parameters. Any uncontrolled change in the flow of combustion material and combustion air leads to high emissions of carbon monoxide and nitrogen oxides, and reduces the combustion temperature. Much lower emission concentrations in flue gas were measured for the reference fuel, but also only, a small range of excess air coefficient has been achieved.

The quality (efficiency) of combustion process (Johansson et al., 2003) can be inferred from the content of CO_2 in the flue gas. If excess air coefficient is low (complete combustion) and the highest possible concentration of CO_2 is achieved, the loss caused by the flue gas is then minimal (at otherwise the same temperature of flue gas). For each solid fuel, there is a maximum achievable stoichiometric proportion of carbon dioxide CO_2 in the flue gas, which is determined by the elemental composition of combustible in the fuel. This value is unattainable within the experimental measurements.

Major impact on the overall efficiency of the combustion device has the flue gas temperature. Both samples achieved high flue gas temperatures during measurements. High flue gas temperature was measured with the reference fuel from spruce logs during the whole time of combustion. This resulted in very high losses through heat of combustion device. The same results were achieved in the work of the Oh et al. (2013). Rossi et al. (2015), Kranet et al. (2010) etc. recommend energy use of compost and by-products from composting technology through combustion at medium and large combustion plants. Despite claims by these authors, who point to higher emission levels primarily in combustion of energy compost pellets in small combustion plants, there is a lot of research outputs looking for new construction of combustion devices for these alternative fuels, eg. combustion installations with a rotary burner. The results of the experimental measurements published in this article refer to energy utilization of this type of alternative fuel in small combustion devices with manual fuel supply, which are still currently used.

CONCLUSIONS

Elemental analyses of the compost briquette samples indicate optimal characteristics of oversize compost fraction for its energy utilization. Above all, it was the moisture content of the compost briquettes (7.87% wt.) and the value of gross calorific value, which averaged at 16.42 MJ kg^{-1}. On the other hand the high percentage of ash content (11.30% wt.) in the samples causes not only rapid clogging of the combustion device, but also reduces the rate of burning fuel. Slower speed of burning is often perceived by users as a positive element in the comfort way of using briquettes as a supplementary source of heat.

During combustion of samples excess air caused high losses through heat of the flue gas mainly in spruce logs, where the temperature of the flue gases, leaving to chimney, reached high values at low excess air. The coefficient of excess air also significantly affected the emission levels of carbon dioxide, carbon monoxide and nitrogen oxides in the flue gas. The most problematic part of flue gas is carbon monoxide, which reached high concentrations at higher excess air coefficient.

The concentration of nitrogen oxides emissions increased with the coefficient of excess air and reached high values during combustion of compost briquettes in contrast to wood logs combustion. These trends were analysed statistically and expressed by regression equations, which in practice can be used to optimize the combustion process in small devices with manual fuel supply. The measurement results provided additional suggestions for optimum energy use of material as an oversize compost fraction, which might not be suitable as a fertilizer for various reasons mentioned above. The efficiency of energy recovery is the aim of further research.

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REFERENCES

Brožek, M. 2015. Briquettes made from wood residues. *Manufacturing Technology* **15**(2), 126–130.

DIN 14918: 2010. Solid biofuels - Determination of calorific value. Standard is the Czech version of the European Standard EN 14918: 2009. *Czech Office for Standards, Metrology and Testing*, 52.

Fiedler, F. & Persson, T. 2009. Carbon monoxide emissions of combined pellet and solar heating system. *Applied Energy*, **86**(2), 135–143.

Johansson, L.S., Leckner, B., Gustavsson, L., Cooper, D., Tullin, C. & Potter, A. 2004. Emission characteristics of modern and old-type residential boilers fired with wood logs and wood pellets. *Atmospheric Environment* **38**(25), 4183–4195.

Johansson, L.S., Tullin, C., Leckner, B. & Sjövall, P. 2003. Particle emissions from biomass combustion in small combustors. *Biomass and Bioenergy* **25**, 435 – 446.

Kranert, M., Gottschall, R., Bruns, C. & Hafner, G. 2010. Energy or compost from green waste? – A CO2 – Based assessment. Waste Management **30**(4), 697–701.

Malaták, J. & Bradna, J. 2014. Use of waste material mixtures for energy purposes in small combustion devices. *Research in Agricultural Engineering* **60**(2), 50–59.

Mohee, R., Boojhawon, A., Sewhoo, B., Rungasamy, S., Somaroo, G.D. & Mudhoo, A. 2015. Assessing the potential of coal ash and bagasse ash as inorganic amendments during composting of municipal solid wastes. *Journal of Environmental Management* **159**, 209–217.

Oh, I.H., Choi, E.Y. & Park, H. 2013. Optimizing the production process of fuel pellets from swine dung compost. *Applied Engineering in Agriculture* **29**(4), 539–545.

Rossi, V., Cleeve-Edwards, N., Lundquist, L., Schenker, U., Dubois, C., Humbert, S. & Jolliet, O. 2015. Life cycle assessment of end-of-life options for two biodegradable packaging materials: Sound application of the European waste hierarchy. *Journal of Cleaner Production* **86**, 132–145.

Ruzbarsky, J., Müller, M. & Hrabe, P. 2014. Analysis of physical and mechanical properties and of gross calorific value of Jatropha curcas seeds and waste from pressing process. *Agronomy Research*, **12(**2), 603–610.

Skanderová, K., Malaťák, J. & Bradna, J. 2015. Energy use of compost pellets for small combustion plants. *Agronomy Research* **13**(2), 413–419.

Zafari, A. & Kianmehr, M.H. 2014. Factors affecting mechanical properties of biomass pellet from compost. *Environmental Technology (United Kingdom)* **35**(4), 478–486.

Winkler, G., Krüger, S. & Beckmann, M. 2007. Biomass fuel from fractions of a compost facility. In: *A and WM, Annual International Conference on Incineration and Thermal Treatment Technologies, IT3*, ISBN: 978-092320482-2.

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Quantitative research SME and STK in the Czech Republic

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Abstract. The article deals with the emission control stations (SME) and technical inspection stations (STK) in the Czech Republic. The increasing number of vehicles and their operational age has significant impact on these stations. The nowadays situation in the both stations does not react adequately to the changing conditions. The use of quantitative research, which was conducted through an Internet poll in September 2015, obtained responses from SME and STK staff, as well as from the public. The questionnaire didn't show substantial dissatisfaction with the current controls on SME and STK and there is no urgent need for immediate and major changes, but rather the need for continuous improvement and better control on SMEs, at least as at STK, i.e. the introduction of a central information database (preferably shared by STK and SME) and a camera system for better control. The cardinal question is not whether the existing emission checks on vehicles in no-load mode of the engines are able to detect all faults.

Key words: emission control, vehicle, inspection station.

INTRODUCTION

Transportation is a very important part of the global economy as well as people´s everyday life. These days there are lots of people who are interested in reducing pollution and protecting the environment and it is crucial to be strict during the inspection and maintenance of vehicles, because in the Czech Republic the age of the vehicles is increasing (Automotive Industry Association, 2015). The average age of vehicles increases also in European Union - the average vehicle age was 9.65 years in 2014, but it is still lower than in the Czech Republic (European Automobile Manufacturers Association, 2015).

In the Czech Republic to 30th September 2015 a total of 7,069,206 motor vehicles exist, and from this number is over 5 million passenger vehicles. The number of vehicles increases every year, as the average age of the fleet of the Czech Republic. Average age of vehicles increased to 17.45 years, while the average age of passenger cars is 14.73 of the year, but is still increasing, so that vehicles older than 10 years account for approximately 66% of the fleet of the Czech Republic (Fig. 1). For these vehicles, there is a high probability of partial loss of efficiency, eg. Catalysts.

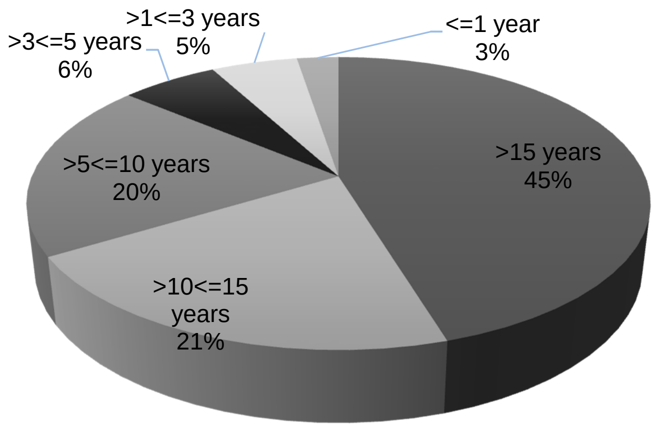

Figure 1. The total number of motor vehicles in accordance with the operating time from first registration (as of September 30, 2015, (Automotive Industry Association, 2015).

According to the OECD economic survey of the Czech Republic (2011) it is necessary to 'tighten its obligations regarding the inspection and maintenance of vehicles to better control of emissions from old vehicles and to support fleet renewal cars, trucks and buses'.

The production of harmful emissions (such as NOx, carbon monoxide, particulate matter), decreases in all Member States for the period from 1990 to 2010 because of the stricter homologation regulation according to European Environment Agency (2012).

Many studies follow up the pollution from vehicles in the world. Shancita et al. (2014) consider the most efficient technologies because of reducing fuel consumption and exhaust emissions from vehicles. Keall & Newstedad (2013) evaluate the costs and benefits of the frequency of periodic vehicle inspections. There are annual vehicle periodic inspection in New Zealand and they consider the 6–monthly inspections but the result is not cost-effective.

Selim et al. (2011) made a survey of vehicle inspection and emission standards in the United Arab Emirates, which results in insufficient integrity standards, tests carried out and the quality of testing. Questionnaires were completed by employees of vehicle inspection centres, importing ports, experts and car owners across the United Arab Emirates.

The Czech Republic put emphasis mainly on the technical inspection station and it is not so much interested in the emissions of vehicles. However, in other countries they have different rules. For example in the United States they measure only the emissions and they do not have to go to the technical inspection stations.

There are various tests in different countries and also the frequency of the inspections is not the same. In some countries the emission inspection is part of the technical inspection. These tests are used in Europe (Hromádko et al., 2011): Unloaded test, Transient Loaded Tests, Remote Sensing, Fuel Evaporative Tests, On Board Diagnostic, etc.

The United States is the leader when it comes to emissions inspection. Some states have the most stringent tests in the world. They measures not only the exhaust gases but also the noise. The emission tests in the United States are unloaded test, Remote Sensing, Fuel Evaporative Tests, Transient Loaded, On Board Diagnostic and also Steady State Loaded, etc. (Hromádko et al., 2011).

Vehicles have to pass an emission inspection every two years in the Czech Republic (the first is after four years for a new car). The new law no. 239/2013 Coll. for measuring emissions is valid from 1st January 2015 and it is still improving. If the vehicle passes the emissions inspection, it will be able to go to the technical inspection. There are only two results during the emission inspection – satisfactory or unsatisfactory.

According to the Decree of the Ministry of Transport (2013) the emission measuring in the Czech Republic is split by fuel type (engine type):

- spark-ignition engines with uncontrolled emission system and uncontrolled emission system with catalytic converter;
- spark-ignition engines with controlled emission system with catalytic converter
- diesel engines uncontrolled system
- diesel engines with a controlled system
- the motors for driving the fuel gas (e.g. LPG, CNG, H2, ...)
- more fuel drive.

Detailed scope and method of measuring emissions is described in Decree of the Ministry of Transport 342/2014 Coll. And in Transport Bulletin 12/2015 Appendix 1 – Methodology emission vehicles in measuring emissions stations (Table 1).

Table 1. Framework emission measurement procedures for different categories of vehicles (Bulletin of Transport, 2015)

	Vehicle identification	Visual control	Diagnostics of engine management system	Depending on the outcome of the diagnostic engine management system/ optional additional procedures	Concentrations measuring (spark-ignition engines)/ smoke (diesel engines)
Spark-ignition engines					
– uncontrolled system	x	x			x
– a controlled system without OBD	x	x	x		x
– a controlled system with OBD	x	x	x	x	x
Diesel engines					
– uncontrolled system	x	x			x
– a controlled system without OBD	x	x	x		x
– a controlled system with OBD	x	x	x	x	x

OBD = on-board diagnostics

Each emission measurement station is authorized to measure emissions of certain vehicles. Emission measuring stations must use the measuring device that is approved by the Ministry of Transport.

MATERIALS AND METHODS

Quantitative research titled Cars and emission measuring stations (Table 2) took place in the Czech Republic for a week in September 2015, namely from 16th September to 23th September 2015. The research method was used CASI (Computer Assisted Self Interviewing) or technique, where the respondent itself fills in the questionnaire on your computer without having to interfere with the interviewer. The questionnaire was created on the website www.vyplnto.cz and contained 15 questions (Table 3).

Table 2. Quantitative research – CASI

Name	Vehicles and Emission Control Station
Method	CASI
Target group	STK and SME staff, general public
Sample size	N = 119
Location	The Czech Republic
Research tools	15 questions in the questionnaire
Questioning term	16th September – 23th September 2015
Rate of return	67.3%*
Average time filling	4:48 min

* Rate of return is determined by the ratio of completed questionnaires and displayed - data is approximate (www.vyplnto.cz).

Table 3. List of the questions

Number	Question
Q1	Do you have a vehicle (own, use, take care of...)?
Q2	Do you go to the emission control with your vehicle regularly?
Q3	How many vehicles do you have (in the household, have the use of it)?
Q4	What is the age of your vehicle?
Q5	What is the age of your second car?
Q6	What fuel do you prefer (what do you choose in case of purchase new car)?
Q7	How often would be the emission control (what frequency)?
Q8	Do you consider the frequency satisfactory (enough)?
Q9	What changes do you suggest during the measuring at the emission control stations?
Q10	Are you a worker (employee, owner...) of the emission control station?
Q11	Gender
Q12	Age
Q13	Region
Q14	Education
Q15	If you have any comment to the emission control station, you can write it here

If we counted the return polled people it would be lower, about 17%. Email with questionnaire was sent to about 330 e-mail addresses of technical inspection stations (and others about 15 e-mails were not delivered). 55 questionnaires were filled by staff of technical inspection stations or emissions inspections stations.

RESULTS AND DISCUSSION

Out of 119 respondents, only 5% owned or used automobile. People who responded that they have or used car, were automatically redirected to question no. 6 – What type of fuel do you prefer.

Nine out of ten respondents personally run on emission measuring stations. Only 10% of people do not go to regular checks and sends the vehicle to someone else. Based on the results of question 11 – Sex can be assumed that half of those who do not go to SMEs are women.

For questions 3 can be seen that almost half of respondents have two vehicles, which may be associated with an increasing number of cars. The largest group of vehicles aged 10–15. Fortunately, nearly 30% of the cars are aged 5–10 years and only 13% of cars are older than 15 years. Nearly 1/3 of respondents have no second car. The order of frequency of answers to the age of the other vehicle remains very similar to the previous issues.

Almost half of the respondents would choose diesel fuel if acquiring a new car. Less than 40% by opting for gasoline, only about 10% gas and 1% electric car. This order can depend on low awareness of alternative fuels, a small number of service stations and even an emission control station or unwillingness to choose something relatively new and unextended.

53% of respondents are satisfied with the current status, (i.e. the first inspection after 4 years, and then every two years), and the rules should not change (Fig. 2). 15% of people is very similar variation with the difference that the first inspection would be after two years. And almost equally large group would regulate the timing of the second check, which would be after three years. These results suggest that only about 15% of those surveyed would shorten the intervals of emission controls.

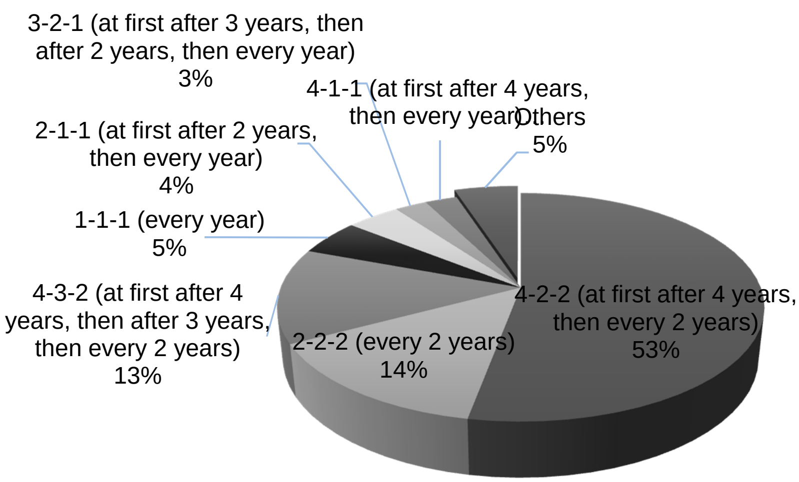

Figure 2. How frequent should inspections be at the stations of measuring emissions (SME)?

More than half of the responses to the question whether the controls are adequate emission stations, is positive. Approximately 25% of people admit that checks on the technical emission not always take place according to the rules and 15% of people are aware of the imperfection of current measurement methods.

Approximately 1/4 of the respondents would not change inspections at emission stations during measurements done. Popular innovation would be the introduction of a central information system, emission measuring stations. This change was expressed by 36% of respondents. Almost 30% of respondents would welcome a change in the final assessment, which would be more opportunities in an unsatisfactory condition of the vehicle. Now it is a very small percentage of inspections with unsatisfactory results (about 1%), so it can be assumed that if the vehicle fails to meet the conditions for supervision and control instead of towing it 'does not count' and the car is towed away, but 'leave' home. 27% of respondents would be for cameras introduction.

Over 50% of respondents work on emission measurement station or in the station of technical inspections. Due to this result, it is possible to consider the response from this questioning for a really beneficial because they are made by people in the field who 'knows what they are talking about'.

Men were interviewed mostly, only 15% were women. This result is quite expected considering the subject questionnaire. The age representation was fairly even, where only about 5% of the respondents were over 60 and less than 2% younger than 18, which is related to the ownership and driving a motor vehicle.

Even the distribution of responses by region is relatively uniform, the highest number of responses were from Prague and Central Bohemia, which is logical considering the number of inhabitants and the capital of the Central Region, which surrounds Prague. The least respondents were from the Hradec Kralove Region and Zlín Region. More than half of the respondents have secondary education and 30% of respondents received a college degree.

Question number 15 was open while the optional question (unlike the previous questions). Therefore, the answer was a small amount, but on the other hand, the responses were much more valuable (in terms of their content). For this question, therefore, it is more of a qualitative research.

The response was that there are more SMEs than is needed; it would be appropriate to establish a central information system as the STK, as well as the proposal to introduce emission plaques in larger cities, such as in Germany, and especially the need for a new measurement methodology.

CONCLUSIONS

The answers are considered sufficient expertise to this questionnaire because more than half of the respondents worked at stations for technical inspection stations and emission measurement. The questionnaire does not imply a fundamental dissatisfaction and the urgent need for immediate and major changes, but rather the need for continuous improvement. The result of the questionnaire is different from the OECD economic survey of the Czech Republic.

The most important is considered the introduction of a central information system, as is already the case for technical inspection stations. Given the relatively high number of respondents from the field (STK and SME staff), the emphasis is on accuracy, which can bring a new methodology for measuring emissions.

Probably the people who work in SME or STK calls for the introduction of CCTV and an extension of the inspection results. Increasing number of vehicles means the station for emission controls more regular inspections and also theoretical inspections, which are not compulsory and will depend on the decision of the owner of the vehicle.

Ever increasing average age of vehicles could lead to a renewal of the fleet and thus again increased the number of inspections at stations measuring emissions. The high average age of cars is not good for both security and even the environment, so there is much room for innovation, whether measuring device or measurement methodology that would lead to a tightening of the rules and disposal of vehicles that are most harmful to human health.

The new methodology of emissions measuring should be fundamentally different from existing ones. Measurements of emissions should be carried out also in stress mode engines.

REFERENCES

European Automobile Manufacturers Association (ACEA): Average vehicle age 2015 [online]. [cit. 2016-18-03]. Available at: *http://www.acea.be/statistics/article/average-vehicle-age*

European environmental agency. The contribution of transport to air quality. TERM 2012: Indicators tracking transport and environment in the European Union. EEA Report No. 10/2012 [online]. [cit. 2015-01-05]. Available at: *http://www.eea.europa.eu/publications/transport-and-air-quality-term-2012*

Hromádko, J., Hromádko, J., Hönig, V. & Miler, P. 2011. Spalovací motory. Praha: Grada Publishing. ISBN 978-80-247-3475-0.

Keal, M. & Newstead, S. 2013. An evaluation of costs and benefits of vehicle periodic inspection scheme with six-monthly inspections compared to annual inspections. *Accident Analysis and Prevention* **58**, 81–87.

The Department of International Relations: Conclusions and recommendations of the Economic survey of the Czech Republic. 2011. [online]. [cit. 2011-11-05]. Available at: *http://www.mfcr.cz/cps/rde/xbcr/mfcr/CZE_2011_PB_CZ.pdf*

Selim, M., Maraqa, M.A., Hawas, Y.E. & Mohamed, A.M.O. 2011. Assessment of vehicle inspection and emission standards in the United Arab Emirates. *Transportation Research Part D* **16**, 332–334.

Shancita, I., Masjuki, H., Kalam, M, Raizwanul, I., Rashed, M. & Rashedul, H. 2014. A review on idling reduction strategies to improve fuel economy and reduce exhaust emission of transport vehicles. *Energy conversion and management* **88**, 794–807.

Automotive Industry Association: The composition of motor vehicle fleet in the Czech Republic. 2015. [online]. [cit. 2016-07-01]. Available at: *http://www.autosap.cz/zakladni-prehledy-a-udaje/slozeni-vozoveho-parku-v-cr/*

Transport Bulletin 12/2015. Ministry of Transport. 2015. [online]. [cit. 2016-18-03]. Available at: *http://www.mdcr.cz/cs/Vestniky/Vestnik_dopravy.htm*

Decree of the Ministry of Transport 342/2014 Coll. The technical inspection and emission measuring controls of vehicles. 2014. [online]. [cit. 2015-10-05]. Available at: *http://www.sagit.cz/pages/sbirkatxt.asp?zdroj=sb14342&cd=76&typ=r*

Vyplnto.cz. The cars and emission stations. 2015. [online]. [cit. 2015-23-09]. Available at: *https://www.vyplnto.cz/moje-pruzkumy/?did=49825*

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Estimation of mulching energy intensity

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Abstract. Mulching is one of the energy-intensive activities in agriculture. The energy is gained from the consumed fuel. Besides the consumed fuel the combustion engine produces harmful and unharmful exhaust gases. The general trend is to reduce the production of harmful constituents of emissions as well as carbone dioxide. This can be achieved by various construction modifications or additional modifications of exhaust gases. It is possible to estimate the energy intensity in advance by several different ways. The paper presents the estimation based on measured complete characteristics of emissions production and the fuel consumption of used combustion engine and on the measured on-board data. The results show that the estimation of fuel consumption and thus also production of carbon dioxide can be relatively successful. The estimation differs quite significantly for other emissions components. During different transition modes of the combustion engine there is a change of emissions production which is hard to describe. The solution could lie in use of other parameters determining the operation mode of the engine in addition to the commonly used speed and torque of the combustion engine.

Key words: Fuel consumption, emissions, operation modelling, combustion engine.

INTRODUCTION

There is a worldwide pressure put on the manufacturers and operators of machines with combustion engine to minimize the fuel consumption and to minimize the production of harmful emissions Aleš et al., 2015. At the same time the engine and medical industry discuss harmful effects of the individual emission components (Hirvonen et al., 2005; Xu & Jiang, 2010; Kvist et al., 2011; Jalava et al., 2012). Harmful effects of the individual emission components are generally known but the problem is to express these harmful effects financially.

Rules and regulations push the manufacturers to produce increasingly sophisticated machines which produce minimum of harmful emissions (Ryu et al., 2014). However, verification of these machines is done only during the homologation measurements (Maass et al., 2009; Lijewski et al., 2013; Cordiner et al., 2014; Liu et al., 2015). Thus the measurement carried out during operation is only indicative and does not achieve sufficient accuracy in order to prove that the combustion engine of the used machine still meets the homologation regulations.

Widely discussed question concerns the evaluation of emissions within the operation which is not easy (Dace & Muizniece, 2015). Measurement of emissions in operation brings number of difficulties such as accuracy of analyzers, speed of response on dynamic change of the measured quantity etc. It would be much easier to monitor the operation mode of the machine and then quantify the actually produced emissions on the basis of complete characteristics of the engine. Within the regular operation test the task would be to specify current complete characteristics of the engine. The vehicle operators would be taxed not according to which machine have they bought but how do they care about it and whether its characteristics are still close to the characteristics determined by the producer or whether the technical condition of the machine has changed so that these characteristics significantly differ from the characteristics determined by the producer. The used type of fuel or biofuel which significantly affects emissions may also be included in the evaluation (Sada et al., 2012; Repele et al., 2013; Hönig et al., 2014; Čedík et al., 2015; Pexa et al., 2015).

The paper presents example of modelling the tractor operation in connection with a mulcher with a vertical axis of rotation. The aim of the paper is to use complete characteristics of the engine and on-board data, achieved during the actual field measurement, to model operation of this set and subsequently compare measured emissions production and fuel consumption of the tractor with the modelled values.

MATERIALS AND METHODS

Measuring and modelling of the operation was done by means of the tractor John Deere 7930 in connection with the triple-rotor mulcher MZ 6000 with a vertical axis of rotation made by Bednar FMT, s.r.o. (Fig. 1). A rotor diameter is 2 meters and the width including overlap of rotors is 5.85 m. John Deer tractor is equipped with the engine supercharged by a turbocharger and also with a common–rail fuel injection system.

Figure 1. Working set of tractor John Deere 7930 and mulcher MZ 6000 during measurement.

Measurement in field conditions was done on a grass field with area of approx. 1.25 ha. The amount of the fuel consumed during the ride of the tractor with the mulcher was measured by means of the flow meter (AIC VERITAS 4004 – measurement error 1%) and also by the on-board diagnostics (on-board diagnostics system monitored by means of the device Texa Navigator TXTs – frequency 4 Hz). The amount of intake air, engine load, engine speed and tractor speed were measured also by means of Texa, the power necessary for the drive of the mulcher was measured by the dynamometer (MANNER Mfi 2500Nm_2000U/min – accuracy 0.25%) and the amount of produced harmful emissions of carbon dioxide (FTIR), carbon monoxide (FTIR), hydrocarbons (FTIR),nitrogen oxides (electrochemical cell) and oxygen (electrochemical cell) was measured by means of the emission analyzer (VMK – frequency 1 Hz, Table 1). Movement of the set was monitored by the GPS sensor (GPS receiver Qstarz BT-Q100X – frequency 5 Hz) and by a drone. All data were synchronized at frequency of 1 Hz.

Table 1. Parameters of the emission analyser VMK

Measured component	Scope	Resolution	Accuracy
CO	0–10% vol.	0.001% vol.	0–0.67%: 0.02% 0.67–10%: 3% from measured value
CO_2	0–16% vol.	0.1% vol.	0–10%: 0.3% 10–16%: 3% from measured value
HC	0–20,000 ppm	1 ppm	10 ppm or 5% from measured value
NO_X	0–5,000 ppm	1 ppm	0–1,000 ppm: 25 ppm 1,000–4,000 ppm: 4% from measured value
O_2	0–22% vol.	0.1% vol.	0–3%: 0.1% 3–21%: 3% from measured value

The yield map was created during measurement on the chosen field. In order to create the yield map, approx. 100 samples of the plant material were taken and weighed and GPS coordinates were also recorded for each sample. The trajectory of the set during measurement and the yield map are presented in the Fig. 2.

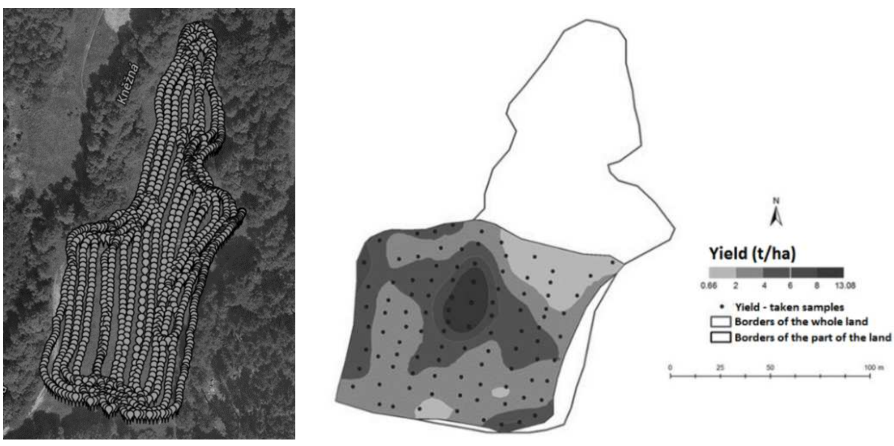

Figure 2. Field measurement: a) measured points, b) yield map.

It was necessary to determine the complete characteristics of the engine to be able to implement modelling. The measurement was carried out in the laboratory by means of the dynamometer (AW NEB 400 – accuracy 2%). The external rotation characteristics was measured. Based on this characteristics the measurement points were determined in order to cover the working range of the engine rotation speed (measured at rotation speed 1,450, 1,600, 1,750, 1,950 and 2,100 at several steps of the engine load up to 100% load – total of 27 points were measured). The fuel consumption and the emission parameters were measured during the measurement. Using functions of MathCad (especially interp and spline) continuous areas were created in coordinates engine speed and torque. The example of continuous area for the fuel consumption is shown in the Fig. 3 and continuous area for the nitrogen oxides is presented in the Fig. 4.

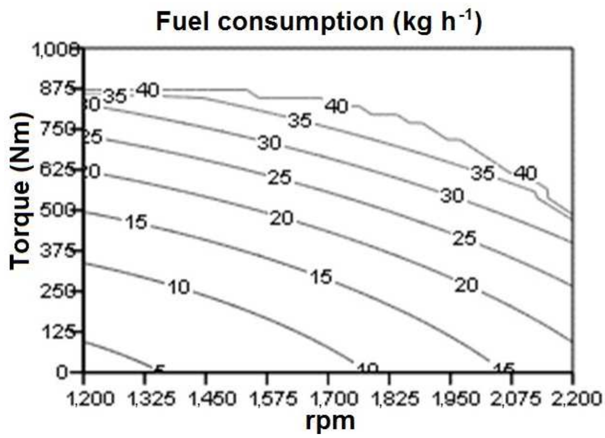

Figure 3. Continuous area of fuel consumption.

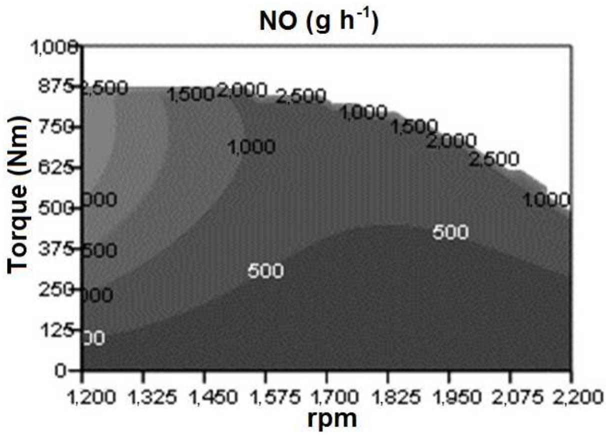

Figure 4. Continuous area of nitrogen oxides.

RESULTS AND DISCUSSION

Altogether 1,417 points were recorded during mulching of the area which is depicted in the Fig. 2, while the driving time was 23.6 minutes. These 1,417 measured points were applied in the model. Production of CO_2, CO, NO, HC and fuel consumption were established for each point using measured complete characteristics of the engine. The total fuel consumption is presented in the Table 2 and the production of the individual emission constituents within the whole ride is presented in the Table 3.

Table 2. Measured and modelled values of fuel consumption for the whole ride

	Measured values l	Model - MathCad l	Deviation %
Fuel consumption	12.86	12.98	0.88

Table 3. Measured and modelled values of produced emissions for the whole ride

	Measured values kg	Model - MathCad kg	Deviation %
CO_2	42.69	56.09	31.40
CO	80.62	121.86	51.15
NO	140.04	226.93	62.05
HC	2.37	0.633	-73.32

The recorded drive points were used to simulate the driving cycle of the tractor and mulcher in the MathCad interface. The resulting values of the whole cycle are presented in Table 2 and 3. It is evident that except the HC production, higher values were reached during modelling of fuel consumption, CO_2, CO and NO_X production than during the real ride (the reason could be the delay of the emission analyser VMK in combination with the low sampling frequency (1 Hz) and very fast change of the engine load during the real ride of the tractor). The best results were reached during modelling of fuel consumption where the average measurement error was 0.88%. The results of CO_2 production are satisfactory but in other cases the measurement error is more than 50%.

Together 14 rides were selected for more detailed analysis of accuracy. These rides were carried out in one direction (elimination of surface inclination and wind direction) and next to each other, in the area where the yield of grass is described. Resulting values of production of individual emissions constituents and the fuel consumption of all 14 rides are evaluated in the Statistica software (Fig. 5).

Table 4. Comparison of measured and modelled values

	Modelled values in comparison with measured value (%)				
	Fuel consumption	CO_2	CO	NO	HC
Mean value	102.66	139.15	172.59	191.15	37.07
Standard deviation	14.51	13.12	31.01	67.15	29.59

The Fig. 5 makes it evident that as in case of the evaluation of the whole ride the model reaches very good values for fuel consumption. The other constituents of emissions acquired from the model are less accurate. The measured values of CO_2 were still acceptable. The accuracy of other emissions constituents is significantly reduced. Resulting values of average and standard deviations are presented in the Fig. 4 and in the Table 4. The results make it evident that the analysis of the tractor set ride based on the on-board values and measured complete characteristics of the engine is not an easy task. It is necessary to introduce correction coefficients for the individual emissions constituents, the coefficients will include dynamics of the engine such as speed change and load change.

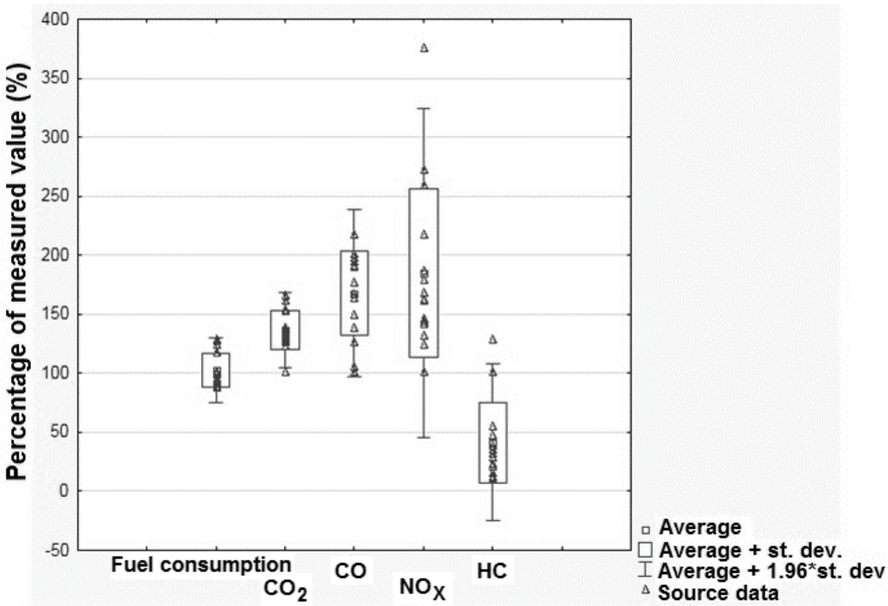

Figure 5. Evaluation of rides – Statistica.

CONCLUSIONS

Modelling the operation of machines and predicting the production of harmful substances of the combustion engine is problematic. The results in Table 2, 3 and 4 show that it is necessary to pay attention to each individual produced emissions constituent. Very good results are reached during modelling of fuel consumption and CO_2. In case of other constituents there are deviations from measured values.

It is possible to make values of produced emissions more accurate when the dynamics of the tractor set ride is taken into consideration. Speed change, course of the speed change and especially load change and speed of load change seem to be appropriate parameters.

Photographic methods for recording of the land are already known. The analysis of the image provides a lot of information which may help to estimate the load of the engine. The tractor set would have to overcome such load during the ride. In connection with complete engine characteristics these maps could be used to predict the fuel consumption and production of harmful substances by the combustion engine.

The aim could be creation of a system of machines evaluation and their impact on the environment. The operation would be taxed on the basis of actual produced amount of harmful substances. The amount of taxes would put a pressure on the operators to renew the vehicle fleet or take care of the fleet in order to produce as little harmful substances as possible.

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REFERENCES

Aleš, Z., Pavlů, J. & Jurča, V. 2015. Maintenance interval optimization based on fuel consumption data via GPS monitoring. *Agronomy Research* **13**(1), 17–24.

Cordiner, S., Mulone, V., Nobile, M. & Rocco, V. 2014. Impact of biodiesel fuel on engine emissions and Aftertreatment System operation. *Applied Energy*, Article in Press

Čedík, J., Pexa, M., Mařík, J., Hönig, V., Horníčková, Š. & Kubín, K. 2015. Influence of butanol and FAME blends on operational characteristics of compression ignition engine. *Agronomy Research* **13**(2), 541–549.

Dace, E. & Muizniece, I. 2015. Modeling greenhouse gas emissions from the forestry sector – the case of Latvia. *Agronomy Research* **13**(2),464–476.

Hönig, V., Kotek, M. & Mařík, J. 2014. Use of butanol as a fuel for internal combustion engines. *Agronomy Research*, **12**(2), 333–340.

Hirvonen, P., Huttunen, H. & Lappi, M. 2005. Estimating the distribution of particle dimensions from electron microscope images. *Proceedings of SPIE - The International Society for Optical Engineering* **5672**, 248–256.

Jalava, P.I., Aakko-Saksa, P., Murtonen, T., Happo, M.S., Markkanen, A., Yli-Pirilä, P., Hakulinen, P., Hillamo, R., Mäki-Paakkanen, J., Salonen, R.O., Jokiniemi, J. & Hirvonen, M.-R. 2012. Toxicological properties of emission particles from heavy duty engines powered by conventional and bio-based diesel fuels and compressed natural gas. *Particle and Fibre Toxicology* **9**, art. no. 37.

Kvist, T., Frohn, U.M. & Jørgensen, L. 2011. Environmental optimisation of natural gas fired engines. *International Gas Research Conference Proceedings* **3**, 1945–1954.

Lijewski, P., Merkisz, J. & Fuc, P. 2013. The analysis of the operating conditions of farm machinery engines in regard to exhaust emissions legislation. *Applied Engineering in Agriculture* **29**(4), 445–452.

Liu, Z.G., Wall, J.C., Ottinger, N.A. & McGuffin, D. 2015. Mitigation of PAH and nitro-PAH emissions from nonroad diesel engines. *Environmental Science and Technology* **49**(6), 3662–3671.

Maass, B., Stobart, R. & Deng, J. 2009. Prediction of NOx emissions of a heavy duty diesel engine with a NLARX model. *SAE Technical Papers.*

Pexa, M., Čedík, J., Mařík, J., Hönig, V., Horníčková, Š. & Kubín, K. 2015. Comparison of the operating characteristics of the internal combustion engine using rapeseed oil methyl ester and hydrogenated oil. *Agronomy Research* **13**(2), 613–620.

Repele, M., Dudko, M., Rusanova, J., Valters, K. & Bazbauers, G. 2013. Environmental aspects of substituting bio-synthetic natural gas for natural gas in the brick industry. *Agronomy Research* **11**(2), 367–372.

Ryu, K., Zacharakis-Jutz, G.E. & Kong, S.-C. 2014. Effects of gaseous ammonia direct injection on performance characteristics of a spark-ignition engine. *Applied Energy* **116**, 206–215.

Sada, O., Mikson, E. & Reppo, B. 2012. Ammonia emission in cowsheds and pigsties during the summer period. *Agronomy Research* **10**(SPEC. ISS. 1), 211–218.

Xu, L. & Jiang, X. 2010. Control of exhaust pollutants from gasoline engine of vehicle. *International Conference on Computer Application and System Modeling, Proceedings* **13**, V13564–V13567.

Agronomy Research **14**(2), 547–555, 2016

Smoke and NO_X emissions of combustion engine using biofuels

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Abstract. Production of solid particles significantly increases the dangerousness of combustion engines. The excellent sorbtion characteristics of the solid particles increases their harmful effects and makes them very dangerous component of emissions which causes health problems. Currently there are many design solutions which aim to reduce smoke of combustion engines. One of the most significant solutions suggests increasing the injection pressures up to the limit of 250 MPa and filtering the exhaust gases. The paper compares different fuels and biofuels, whether used alone or in mixtures, and their effect on smoke of supercharged CI engine. The comparison uses the 8-point NRSC (Non-Road Steady Cycle) test during which the following fuels were used: diesel, rapeseed methyl ester, rapeseed oil, Jatropha curcas oil, biobutanol, hydrotreated oil and other blended fuels. The measurement and comparison results show that using biofuels can significantly reduce smoke of combustion engine by up to tens of percent in comparison to diesel.

Key words: Combustion engine, biofuels, harmful emissions, performance.

INTRODUCTION

Environmental protection makes the polluters reduce production of harmful substances. This restriction significantly affects the automotive industry as well, i.e. cars, trucks and agricultural machinery. Agricultural machines are driven mainly by diesel combustion engines. The most harmful products of diesel combustion engines are particles, smoke and nitrogen oxides.

The literature describes several basic possibilities of how to reduce smoke of diesel combustion engines in order to meet increasingly strict limits set by the international regulations. (Armas et al., 2013; Sun et al., 2013; Amanatidis et al., 2014; Hwang et al., 2014; Athappan et al., 2015; Liu et al., 2015; Cao et al., 2016; Kang & Choi, 2016; Woo et al., 2016). Utilitzation of different biofuels is also one of the options.

– Butanol – In comparison with ethanol, butanol has a lower auto-ignition temperature, it is less evaporative and releases more energy per unit of mass. It also has a higher cetane number, higher energy content and better lubricating ability than ethanol and methanol. It is also less corrosive and better miscible with vegetable oils, diesel and FAME (Hönig et al., 2015a; Hönig et al., 2015b; Müller et al., 2015).

– Fame (Fatty acid methylester) – FAME has a lower mass calorific value, higher density and higher viscosity than diesel (Pexa & Mařík, 2014). FAME can be made from vegetable oil and animal fat (Sirviö et. al., 2014; Čedík et al., 2015). The inferior storage and oxidative stability are the main disadvantages of FAME. Another disadvantage of FAME is a high feedstock cost, especially when the vegetable oil is used as a raw material.

– Vegetable oil – Utilization of the vegetable oil as a fuel is known for many years. In comparison with diesel the vegetable oil is denser and has a higher viscosity. In order to utilize the vegetable oil in a conventional combustion engines it is necessary to lower its viscosity. This is usually done by preheating or in a chemical way. The rapeseed oil, sunflower oil, palm oil or oil from jatropha curcas are the most commonly used oils. (Altaie et al., 2015, Abu-Hamdeh et al., 2015; Fernandes et al. 2015; Kumar et al., 2015, Reham et al., 2015, Verma et al., 2016).

– HVO (Hydrotreated Vegetable Oil) – HVO is fuel obtained by hydrodeoxygenation of vegetable oil. It consists of paraffinic hydrocarbons with a linear chain, it is free from aromatics, oxygen and sulphur, it has a high cetane number, lower density than diesel oil and comparable calorific value. Thus there are no problems usually connected with bio diesel (FAME), such as increased NOX emission, deposit formation, storage stability problems, faster aging of engine oil or high cloud point (Aatola et al., 2008; Kučera & Rousek, 2008; Knothe, 2010; Hartikka et al., 2012; Naik et al., 2010;No, 2014;). HVO has lower fuel consumption, lower loss of power and higher motor efficiency than conventional bio diesel (Duckhan et al., 2014; Kim et al., 2014).

The aim of this paper is to verify the possibility of reducing the emission production of nitrogen oxides and solid particles (PM – Particulate Matter) by using different kinds of biofuels. The verification is done by means of the 8-point NRSC (Non-Road Steady Cycle) test applied on a turbocharged engine Zetor Forterra 8641. The purpose of the verification is to find fuels or appropriate fuel additives which reduce the production of nitrogen oxides and solid particles, do not affect other harmful emissions and do not significantly reduce the performance parameters.

MATERIALS AND METHODS

The measurement was done using the tractor engine Zetor 1204 supercharged by means of turbocharger and placed in the tractor Zetor Forterra 8641 (Fig. 1). It is in-line 4 cylinder engine, its displacement volume is 4.156 l and rated power 60 kW (it is 53.4 kW on PTO (Power Take Off) according to the measurement made by Deutsche Landwirtschafts-Gesellschaft), the maximum torque is 35l Nm, the nominal specific fuel consumption is 253 g kWh^{-1} and the rated speed is 2,200 min^{-1}. The fuel is delivered to the engine by means of mechanical in-line injection pump, injecting is done by one injection with pressure 22 MPa. The injection pressure is given by manufacturer and before measurement it was checked on the manual measuring device. The start of the injection is kept constant at 12° before top dead center. The operating time of the mentioned engine does not exceed 100 operating hours.

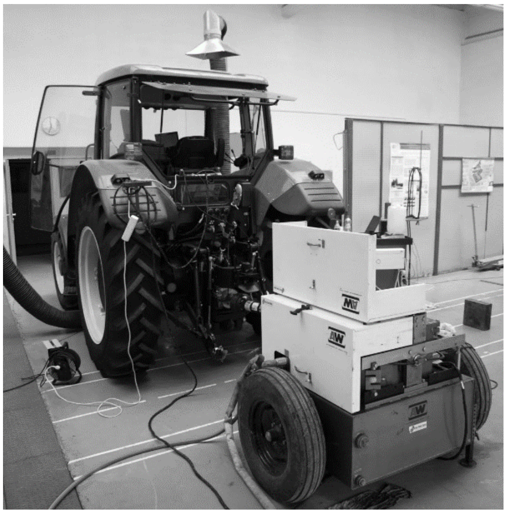

Figure 1. Tractor Zetor Forterra 8641 and dynamometer AW NEB 400.

The engine was loaded by the dynamometer AW NEB 400 (Fig. 1) connected to PTO, torque was recorded by the torque sensor MANNER Mfi 2,500 Nm_2,000 U min^{-1} with accuracy 0.25%. The torque values recorded by the sensor placed on PTO are converted to the engine torque by means of appropriate gear ratio (3.543). The losses in the gearbox have no effect on the comparative measuring of the influence of fuel on the external speed characteristics of the engine and therefore they are not taken into consideration. Data were saved on the hard disk of the measuring computer HP mini 5103, with the use of A/D converter LabJack U6 with frequency of 2 Hz, in the form of text file. For measurement of gaseous emissions components the emission analyser BrainBee AGS 200 was used. For measurement of the PM concentration, the opacimeter Atal AT 600 was used. The values of opacity were converted into mass concentration using the converting table given by manufacturer. The precision and measurement range of both devices is shown in the Table 1.The programmes MS Excel and Mathcad were used for data evaluation.

Table 1. Parameters of the emission analysers

	Resolution	Measurement range	Precision
NO_X	1 ppm	0–5,000 ppm	10 ppm vol. or 5% read value
PM	1 mg m^{-3}	0–900 mg m^{-3}	20 mg m^{-3}

Mixed fuels were made from the following basic fuels presented in Table 2: diesel which meets the standard EN 14 214 rapeseed methyl ester (RME), rapeseed oil, Jatropha curcas oil, n-butanol (BUT) and hydrotreated vegetable oil (HVO). The table presents parameters for these basic fuels such as: density, viscosity, cetane number and calorific value (the values of cetane number and calorific value were taken from literature). The selected mixed fuels do not harm the fuel system of the combustion engine. These fuels have appropriate viscosity and density determined by standard EN 590 and EN 14 214.

Table 2. Basic parameters of the fuels (Aatola et al., 2008; Tziourtzioumis & Stamatelos, 2012; Murali Krishna, et al., 2014; Qi et al., 2014; Atmanli et al., 2015; Kibuge, et al., 2015)

Fuel	Density at 15°C (kg m^{-3})	Calorific value (MJ kg^{-1})	Viscosity at 40 °C (mm^2 s^{-1})	Cetane number
HVO	780	44	2.5–3.5	80–99
RME	880	37.5	4.5	51
n-butanol	810	33.1	2.63	17
Rapeseed oil	918	36.995	23.91	44–48
Jatropha Curcas oil	914	39.63	46.82	45
diesel – EN 590	825	43.3	2.5	50

Based on the fuels analysis (the viscosity and density of selected fuels are presented in Table 3) the following mixed fuels were chosen:

– 100% diesel according to the regulation EN 590 (Diesel - EN 590) – the tested diesel oil contained 5.5% RME, diesel without RME additive was used for other fuel mixtures,
– 100% rapeseed oil methyl ester (100% RME),
– 100% hydrotreated vegetable oil (100% HVO),
– 19.7% rapeseed oil methyl ester / 80.3% diesel oil (19.7% RME / 80.3% Diesel),
– 33.9% rapeseed oil methyl ester / 67.1% diesel oil (33.9% RME / 67.1% Diesel),
– 48% rapeseed oil methyl ester / 52% diesel oil (48% RME / 52% Diesel),
– 5.5% Jatropha curcas oil / 94.5% diesel oil (5.5% Jatropha curcas / 94.5% Diesel),
– 19.7% Jatropha curcas oil / 80.3% diesel oil (19.7% Jatropha curcas / 80.3% Diesel),
– 5.5% rapeseed oil / 94.5% diesel oil (5.5% rapeseed oil / 94.5% Diesel),
– 19.7% rapeseed oil / 80.3% diesel oil (19.7% rapeseed oil / 80.3% Diesel),
– 10% n-butanol / 90% rapeseed oil methyl ester (10% BUT / 90% RME),
– 30% n-butanol / 70% rapeseed oil methyl ester (30% BUT / 70% RME),
– 50% n-butanol / 50% rapeseed oil methyl ester (50% BUT / 50% RME),
– 60% n-butanol / 40% rapeseed oil (60% BUT / 40% rapeseed oil),
– 30% HVO / 70% rapeseed oil methyl ester (30% HVO / 70% RME),
– 50% HVO / 50% rapeseed oil methyl ester (50% HVO / 50% RME).

Table 3. Viscosity and density of selected mixed fuels

Mixed fuels	Density at 15 °C (kg m^{-3})	Viscosity at 40 °C (mm^2 s^{-1})
10% BUT / 90% RME	869.9	3.301
50% BUT / 50% RME	844.5	2.214
30% HVO / 70% RME	851.2	3.965
50% HVO / 50% RME	831.5	3.533
60% BUT / 40% rapeseed oil	858.5	5.381

The external speed characteristics of the engine were measured for all tested fuels. Then the measuring points of the eight-point NRSC test were determined according to ISO 8178-4 (type C1) (Fig. 2.). The points of the test are defined by rotation speed (idle, at max. torque and rated) and load in percentage (0, 10, 50, 75 and 100%). The test was used for measuring the specific emissions production. According to the standard ISO 8178-4, the time spend at each speed/load point was 3 minutes and the last 60 s was used for the calculation. Specific emissions production for the whole NRSC test was calculated according to the equation (1). In every predetermined measurement point the measured parameters were stabilized.

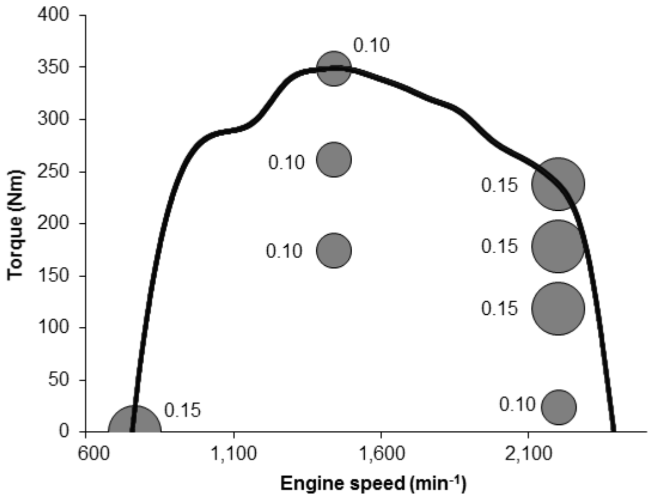

Figure 2. Measurements points for the NRSC test for HVO with weight factors.

$$m_{NRSC} = \frac{\sum_{i=1}^{8}\left(M_{Pi} \cdot WF_i\right)}{\sum_{i=1}^{8}\left(P_{PTO,i} \cdot WF_i\right)} \qquad (1)$$

where: m_{NRSC} – specific emission production for whole NRSC test (g kWh^{-1}); $M_{P,i}$ – hourly emision production (g h^{-1}); WF_i – weight factor (–); $P_{PTO,i}$ – power on the PTO (kW).

RESULTS AND DISCUSSION

The resulting values showing smoke of all measured fuels are presented in Fig. 3. The mixed fuels are sorted according to the amount of smoke, from the smallest to the largest. 0.365 g kWh^{-1} was the largest smoke value reached by Diesel – EN 590. By contrast, the lowest amount of smoke 0.026 g kWh^{-1} was reached by the fuel 50% BUT / 50% RME. Changing the fuel helped to significantly reduce smoke by up to 90%. The NRSC test determined the limit of 0.4 g kWh^{-1} for this tractor engine. It can be stated that this limit was met in all cases and it is depicted in figure 3 as a line marked as Limit – PM. As a progressive value for higher category of the engines of non-road vehicles, the standard is determined more strictly to 0.025 g kWh^{-1}. Therefore it would seem that from the point of view of smoke the engine can be shifted to a higher category of emission standards only by means of using a different fuel. However, the value

0.025 g kWh^{-1} is reached during the transient NRTC cycle (Non Road Transient Cycle) which is much more demanding and the engines produce more pollutants.

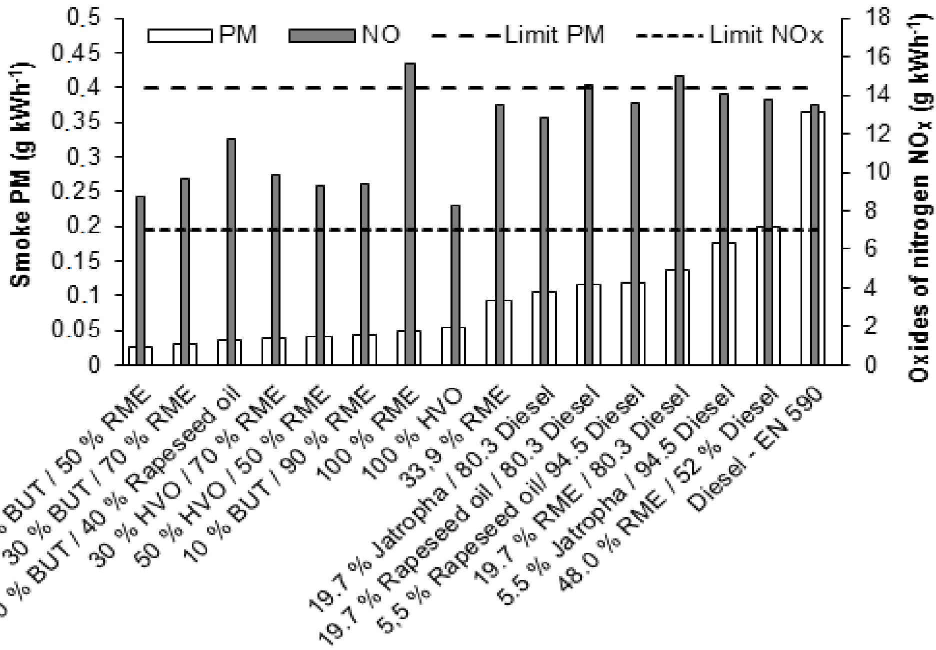

Figure 3. Production of NOx and smoke during NRSC test using different fuels.

However, the performance parameters decreased simultaneously with the smoke parameters which is a negative impact of most biofuels. Performance parameters of the best fuels decreased by more than 10%. Fig. 4 presents the limit values of torque and engine power and the performance parameters of other fuels.

From the point of view of smoke and performance parameters the best fuels are the following: 30% HVO / 70% RME, 50% HVO / 50% RME, 10% BUT / 90% RME, 100% RME and 100% HVO. From the point of view of other emission parameters for diesel engines, the nitrogen oxides are particularly monitored. Measured values of production of nitrogen oxides during the NRSC test are presented in the figure 3, as well as the limit value. It is evident that the standard value 7 g kWh^{-1} NOx is not reached by any fuel. However, the production of NOx was significantly reduced by using the fuel 100% HVO or 10% BUT / 90% RME. When compared to Diesel – EN 590 the production was reduced by 30–40% to the value close to the limit determined by the NRSC test.

Using the BUT fuel increased production of carbon monoxide, but none of the fuel samples exceeded the value determined by the NRSC test. To conclude, fuels containing n-butanol and HVO could be used more in the future.

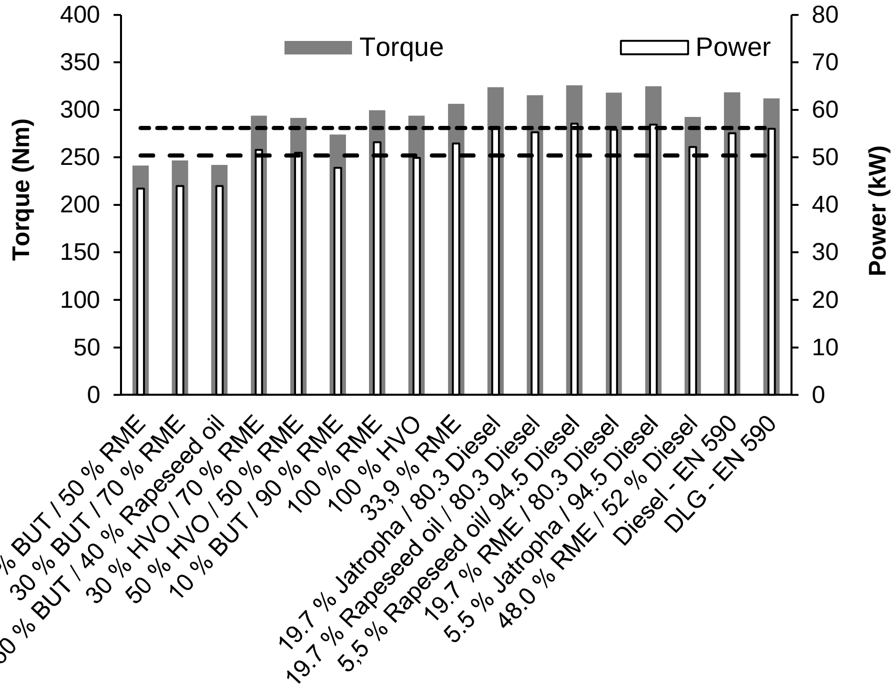

Figure 4. Performance parameters of the engine using different fuels.

CONCLUSIONS

The measuring results proved that change of fuel significantly affects the production of combustion engine pollutants. Smoke was reduced in all used mixed fuels during the standard NRSC test. It was reduced by up to 90% in comparison to the standard fuel Diesel – EN 590.

The HVO fuel and fuels containing n-butanol proved to be the most suitable because the smoke was reduced as well as and the production of nitrogen oxides which was reduced by up to 40%. The fuels containing 30 and 50% of n-butanol managed to reduce smoke the most. However, along the reduction of smoke, the performance parameters were reduced as well, by more than 10%. The resulting values of production of nitrogen oxides and smoke are presented in the figure 3 and decrease of performance parameters is presented in the figure 4.

The performed tests proved that the most suitable fuels for common CI combustion engines are fuels based on HVO or fuels containing n-butanol.

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REFERENCES

Aatola, H., Larmi, M., Sarjovaara, T. & Mikkonen, S. 2008. Hydrotreated vegetable oil (HVO) as a renewable diesel fuel: trade-off between NO_X, particulate emission, and fuel consumption of a heavy duty engine. *SAE paper*, 2008–01–2500.

Abu-Hamdeh, N.H. & Alnefaie, K.A. 2015. A comparative study of almond and palm oils as two bio-diesel fuels for diesel engine in terms of emissions and performance *Fuel* **150**, 318–324

Altaie, M.A.H., Janius, R.B., Rashid, U., Taufiq Yap, Y.H., Yunus, R. & Zakaria, R. 2015. Cold flow and fuel properties of methyl oleate and palm-oil methyl ester blends *Fuel* **160**, 238–244.

Atmanli, A., İleri, E. & Yüksel, B. 2015. Effects of higher ratios of n-butanol addition to diesel–vegetable oil blends on performance and exhaust emissions of a diesel engine *Journal of the Energy Institute* **3**, 209–220.

Amanatidis, S., Ntziachristos, L., Giechaskiel, B. Bergmann, A. & Samaras, Z. 2014. Impact of selective catalytic reduction on exhaust particle formation over excess ammonia events, Environmental Science and Technology **48(**19), 11527–11534.

Armas, O., Gómez, A. & Ramos, Á. 2013. Comparative study of pollutant emissions from engine starting with animal fat biodiesel and GTL fuels. *Fuel* **113**, 560–570.

Athappan, A., Sattler, M.L. & Sethupathi, S. 2015. Selective catalytic reduction of nitric oxide over cerium-doped activated carbons. *Journal of Environmental Chemical Engineering* **3**(4) Part A, 2502–2513.

Cao, Y., Feng, X., Xu, H., Lan, L., Gong, M. & Chen, Y. 2016. Novel promotional effect of yttrium on Cu–SAPO-34 monolith catalyst for selective catalytic reduction of NOx by NH3 (NH3-SCR). *Catalysis Communications* **76**, 33–36.

Čedík, J., Pexa, M., Mařík, J., Hönig, V., Horníčková & Kubín, K. 2015. Influence of butanol and FAME blends on operational characteristics of compression ignition engine. *Agronomy Research* **13**(2), 541–549.

Duckhan, K., Seonghwan, K., Sehun, O. & No, S.-Y. 2014. Engine performance and emission characteristics of hydrotreated vegetable oil in light duty diesel engines. *Fuel* **125**, 36–43

EN 14214 Liquid petroleum products. Fatty acid methyl esters (FAME) for use in diesel engines and heating applications. Requirements and test methods. 2014.

EN 590 Automotive fuels. Diesel. Requirements and test methods. 2013.

Fernandes, A.M.A.P., El-Khatib, S., Cunha, I.B.S., Porcari, A.M., Eberlin, M.N., Silva, M.J., Silva, P.R., Cunha, V.S., Daroda, R.J. & Alberici, R.M. 2015. Chemical characterization of Jatropha curcas L. seed oil and its biodiesel by ambient desorption/ionization mass spectrometry, *Energy and Fuels* **29**(5), 3096–3103.

Hartikka, T., Kuronen, M. & Kiiski, U. 2012. Technical performance of HVO (hydrotreated vegetable oil) in diesel engines, *SAE Technical Papers* **9**.

Hönig, V., Smrčka, L., Ilves, R. & Küüt, A. 2015a. Adding biobutanol to diesel fuel and impact on fuel blend parametres. *Agronomy Research* **13**(5), 1227–1233.

Hönig, V., Orsák, M., Pexa, M. & Linhart, Z. 2015b. The distillation characteristics of automotive gasoline containing biobutanol, bioethanol and the influence of the oxygenates. *Agronomy Research* **13**(2), 558–567.

Hwang, J., Qi, D., Jung, Y. & Bae, Ch. 2014. Effect of injection parameters on the combustion and emission characteristics in a common-rail direct injection diesel engine fueled with waste cooking oil biodiesel. *Renewable Energy* **63**, 9–17.

ISO 8178-4 Reciprocating internal combustion engines-Exhaust emission measurement-Part 4: Steady-state test cycles for different engine applications. 2007.

Kang, W. & Choi, B. 2016. Effect of copper precursor on simultaneous removal of PM and NOx of a 2-way SCR/CDPF. *Chemical Engineering Science* **141**, 175–183.

Kim, D. Kim, S., Oh, S. & No, S.-Y. 2014. Engine performance and emission characteristics of hydrotreated vegetable oil in light duty diesel engines *Fuel* **125**, 36–43.

Knothe, G. 2010. Biodiesel and renewable diesel: A comparison, *Progress in Energy and Combustion Science* **36**(3), 364–373.

Kumar, A.P.M., Sreekumar, J.S. & Mohanan, P. 2015. The effect of cordierite/Pt catalyst on the NOx reduction in a diesel and Jatropha bio-diesel operated single cylinder engine, *Journal of Environmental Chemical Engineering* **3**(2), 1125–1136.

Liu, J., Yao, A. & Yao, Ch. 2015. Effects of diesel injection pressure on the performance and emissions of a HD common-rail diesel engine fueled with diesel/methanol dual fuel. *Fuel* **140**, 192–200.

Kibuge, R.M., Kariuki, S.T. & Njue, M.R. 2015. Influence of fuel properties on the burning characteristics of sour plum (Ximenia americana L.) seed oil compared with Jatropha curcas L. seed oil. *Renewable Energy* **78**, 128–131.

Kučera, M. & Rousek, M. 2008. Evaluation of thermooxidation stability of biodegradable recycled rapeseed-based oil NAPRO-HO 2003. *Research in Agricultural Engineering* **54**(4), 163–169.

Murali Krishna, M.V.S., Seshagiri Rao, V.V.R., Reddy, K.K.T. & Murthy, P.V.K. 2014. Performance evaluation of medium grade low heat rejection diesel engine with carbureted methanol and crude jatropha oil. *Renewable and Sustainable Energy Reviews* **34**, 122–135.

Müller, M., Šleger, V., Pexa, M., Mařík, J. & Mizera, Č. 2015. Evaluation of stability of elastomer packing exposed to influence of various biofuels. *Agronomy Research* **13**(2), 604–612.

Naik, S.N., Goud, V.V., Rout, P.K. & Dalai, A.K. 2010. Production of first and second generation biofuels: A comprehensive review, *Renewable and Sustainable Energy Reviews* **14**(2), 578–597.

No, S.-Y. 2014. Application of hydrotreated vegetable oil from triglyceride based biomass to CI engines - A review. *Fuel* **115**, 88–96.

Pexa, M. & Mařík, J. 2014. The Impact of biofuels and technical condition to its smoke – Zetor 8641 Forterra. *Agronomy Research* **12**(2), 367–372.

Qi, D.H., Lee, C.F., Jia, C.C., Wang, P.P. & Wu, S.T. 2014. Experimental investigations of combustion and emission characteristics of rapeseed oil–diesel blends in a two cylinder agricultural diesel engine. *Energy Conversion and Management* **77**, 227–232.

Reham, S.S., Masjuki, H.H., Kalam, M.A., Shancita, I., Rizwanul Fattah, I.M. & Ruhul, A.M. 2015. Study on stability, fuel properties, engine combustion, performance and emission characteristics of biofuel emulsion, *Renewable and Sustainable Energy Reviews* **52**, 1566–1579.

Sirviö, K., Niemi, S., Vauhkonen, V. & Hiltunen, E. 2014. Antioxidant studies for animal-based fat methyl ester. *Agronomy Research* **12**(2), 407–416.

Sun, Z., Sun, P., Wu, Q.M., Hu, J. & Zhang, M. 2013. Study of diesel particulate filter filtration efficiency and the effects on performance of diesel engine. *Advanced Materials Research* **726–731**, 2280–2283.

Tziourtzioumis, D. & Stamatelos, A. 2012. Effects of a 70% biodiesel blend on the fuel injection system operation during steady-state and transient performance of a common rail diesel engine. *Energy Conversion and Management* **60**, 56–67.

Verma, P., Sharma, M.P. & Dwivedi, G. 2016. Evaluation and enhancement of cold flow properties of palm oil and its biodiesel, *Energy Reports* **2**, 8–13.

Woo, Ch., Kook, S., Hawkes, E.R., Rogers, P.L. & Marquis, Ch. 2016. Dependency of engine combustion on blending ratio variations of lipase-catalysed coconut oil biodiesel and petroleum diesel. *Fuel* **169**, 146–157.

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Evaluation of shelf-life of fruit baby food

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Abstract. Fruit baby food is an important food source in infant nutrition. This ambient stable product is processed using heat treatment and can be stored for one or more years at ambient temperature. An accelerated shelf-life storage test of fruit baby food was carried out. Sets of samples were stored at various storage temperatures (40, 55, 70 and 90 °C) for 3 weeks. Selected markers were followed and correlated with sensory evaluation during the storage. The markers were: DPPH, total phenols, ascorbic acid, 5-HMF, furfural and colour (expressed as L, a*, b* and ΔE). Kinetic data (reaction rate constants, activation energies, Q_{10}, z values) were calculated. The aim of the paper was to evaluate shelf-lives of fruit baby food. The colour parameters, especially ΔE, seem to be a robust criterion which could be used to predict shelf-lives of fruit baby food.

Key words: kinetics, modelling, storage experiment, colour.

INTRODUCTION

Determination of storage periods is one of the most important steps in food production. A shelf-life is defined as a period during which food products meet specific criteria. Food safety is the key criterion that must be fulfilled. Approach to determination of storage periods depends on a type of food product (Fu & Labuza, 1993). Microbial growth is an important criterion in case of perishable foods (Dalgaard, 1995; Corbo et al., 2006). In case of imperishable foods, selected parameters are associated with nutritionally important compounds, such as vitamins, antioxidants etc., or with changes of sensory properties of food (especially colour and texture). Conventional storage tests can be used to estimate storage periods; during such tests, food is stored for a long time under conditions which are expected during normal storage of the particular commodity. Another option for estimating storage periods is an accelerated storage test. Appropriate markers are then chosen on the basis of a literature review.

An accelerated shelf-life test (ASLT) is carried out for several selected markers; during the test, a particular foodstuff is stored for a specific period of time at higher temperatures or exposed to higher concentrations of oxygen etc. (Ragnarsson & Labuza, 1997; Hough et al., 2006; García-García et al., 2008). Changes of the markers are evaluated by ordinary kinetic procedures. The choice of a reaction order of the chosen markers may be based on literature research. If relevant data has not been published, it is necessary to determine a reaction order experimentally. Determination of a reaction order is governed by different types of algorithms and testing by kinetic modelling software (Sande & Karlsen, 1993; Larsson & Pardue, 1990). The key point of shelf-life determination is to estimate limits of the selected markers. Sensory markers are the most important parameters for shelf-life prediction. The Weibull model and some others (e.g. Markov model) are the most widely used tools for determination of sensorial limits (Freitas & Costa, 2006; Ledauphin et al., 2006; Palazón et al., 2009).

Commercial fruit baby food is a preserved fruit product usually made of fruit purees, sugar, water and different additives (thickening agents, antioxidants, etc.), which is aseptically bottled and pasteurized and then subjected to another heat treatment and pasteurization; finally the final product is put into long-time storage. As a foodstuff intended for specific nutritional uses, baby foods for infants and young children conform to a set of strict guidelines, e.g. maximum levels for pesticide residues, microbiological contamination, addition of additives, labelling, etc. (Čížková et al., 2009).

Evaluation of changes of chemical markers is important for prediction of shelf-lives of fruit-based products. Sucrose isomerisation (Opatová et al., 1992), formation of 2-furaldehyde and 5-hydroxymethyl furfural (Rada-Mendozaet al., 2002; Burdurlu & Karadeniz, 2003; Gentry & Roberts, 2004), furosine (Rada-Mendosa et al., 2004), levulenic acid (Opatová et al., 1992) and degradation of ascorbic acid (Palazón et al., 2009) etc. are the principal markers. Physical changes to fruit-based products as rheology and colour (expressed as the a*, b*, a*/b*, L or ΔE) are also important markers in shelf-life evaluation (Rocha & Morais, 2003; Ahmed & Ramaswamy, 2005; Oszmiański et al., 2008). Colour changes of fruit products (purées, juices etc.) are often discussed in literature (Ibarz et al., 1999; Chutintrasri & Noomhorn, 2007; Ávila & Silva, 1999). Microbiological shelf-life is not important for fruit baby food because this commodity belongs to non-perishable foodstuffs (Van Boekel, 2009). The aim of the paper is to evaluate shelf-lives of fruit baby food. A procedure for shelf-life determination is shown in the storage experiment bellow.

MATERIALS AND METHODS

Commercially available apple/raspberry fruit baby food from the Czech market was used. Preservation method used: pasteurization; composition: apple puree, water, raspberry puree (20%), sugar, modified corn starch, citric acid, and ascorbic acid; production date: 17th September 2008; best before date: 18th March 2010; lot: 080917.

Shelf-life estimation

Thermal degradation kinetics of fruit baby food filled in original packaging was studied by isothermal heating at selected temperatures (40 °C, 55 °C, 70 °C and 90 °C) for 19 days. The storage test temperatures were chosen according to Rajchl et al., 2010.

DPPH determination

Antioxidant capacity of fruit baby food was determined using the free radical 2,2-diphenyl-1-picrylhydrazil (DPPH) according to (Brand-Williams et al., 1995). Absorbance was measured at 517 nm against blank samples with methanol solution (80%) (Brand-Williamset al., 1995).

Colour measurement

Colour measurements were carried out using the standard CIE L*, a*, b* coordinates on a Minolta CM-2600d spectrophotometer (Minolta, Osaka, Japan). The measurements were carried out on SCI modality using a 10° standard observer and D65 illuminant. Before the analysis, the instrument was calibrated on a white standard tile (L^* = 98.82; a^* = −0.18; b^* = −0.31). A colour change was described as $\Delta E = \sqrt{(L^* - L_0^*)^2 + (a^* - a_0^*)^2 + (b^* - b_0^*)^2}$ (L* – lightness, a* – redness/greenness b* – yellowness/blueness. L_0, a_0, b_0 indicates initial value of these parameters).

Total phenols determination

Total phenol content was determined using a spectrophotometric assay on a UV-visible Thermo spectronic Genesys 20 spectrophotometer (Thermo Fisher Scientific, Waltham, Massachusetts, USA) and was measured using the Folin-Ciocalteau reaction. (Shaghaghi et al., 2008). Briefly, aliquots of samples and standards (0.5 ml) were mixed with 2.4 mL of deionized water, 2 ml of 2% sodium carbonate (Na_2CO_3), and 0.1 ml of the Folin-Ciocalteau reagent. After incubation at room temperature for 60 min, absorbance of the reaction mixture was determined at 750 nm using gallic acid as a standard. Total phenol content was expressed in gallic acid equivalents.

Ascorbic acid determination

A homogenised sample (5 g) was weighted into a 50 ml volumetric flask and 0.5% solution of oxalic acid (40 ml) was added. The sample was extracted in an ultrasonic bath at 25 °C for 15 minutes. Then the content was cooled down to 20 °C and filled to volume of 50 ml with 0.5% solution of oxalic acid. The extract was filtrated (0.45 μm filter) and ascorbic acid content was analysed. HPLC analyses were performed on a Dionex HPLC (Amedis, Prague, Czech Republic) instrument consisting of a P680 pump, an Ultimate 3000 photodiode array detector and an ASI 100 autosampler controlled by Chromeleon 6.80 software package (Amedis, Prague, Czech Republic). Chromatographic separation of ascorbic acid was carried out by a Phenomex® (Chromservis, Prague, Czech Republic) Synergi 4u Hydro-RP 80A column (4 μm, 250 mm × 4.6 mm i.d.). The column temperature was kept at 30 °C. The injected volume was 20 μl. The mobile phase consisted of 5 mM sulphuric acid in distilled water. Isocratic elution was applied at the flow rate of 1 ml min^{-1}.

5-HMF and furfural determination

A homogenised sample (5 g) was weighted into a 50 ml volumetric flask and 10% solution of methanol (40 ml) was added. The sample was extracted in an ultrasonic bath at 25 °C for 15 minutes. Then the content was cooled down to 20 °C and filled to volume with 10% solution of methanol. The extract was filtrated (0.45 μm filter) and5-HMF/furfural content was analysed. HPLC analyses were performed on a Dionex HPLC (Amedis, Prague, Czech Republic) instrument consisting of a P680 pump, an Ultimate 3000 photodiode array detector and an ASI 100 autosampler controlled by Chromeleon 6.80 software package (Amedis, Prague, Czech Republic). Chromatographic separation of 5-HMF and furfural was carried out by a Hibar®RT (Chromservis, Prague, Czech Republic), Purospher® STAR RP-18e column (5 μm, 125 mm × 4.0 mm i.d.). The column temperature was kept at 30 °C. The injected volume was 20 μl. The mobile phase consisted of 10% methanol in water. Isocratic elution was applied at the flow rate of 1 ml min^{-1}.

Sensory analysis

The test room was equipped according to the requirements of the international standard (ISO 8589 – Sensory analysis – General guidance for the design of test rooms). The sensory evaluation was performed by ten panellists (6 female and 4 male) from the Faculty of Food and Biochemical Technology at the Institute of Chemical Technology (PhD students and staff of the Faculty). The assessors were selected, trained and monitored according to the above-mentioned standard (ISO 8586 – Sensory analysis – General guidance for selection, training and monitoring of assessors – selected assessors).Samples from each tested group were served in a session, each time 20 g of each sample in a 50 ml coded beaker. The temperature of all served samples was 20 °C. Samples were neutralized by water and bread. The sample serving was in agreement with the above-mentioned international standard (ISO 6658 – Sensory analysis – Methodology – General guidance). The assessors evaluated differences among the samples using a triangle test (ISO 4120 Sensory analysis – Methodology –Triangle test). Colour, taste and flavour were tested. Two samples of fruit baby food stored at 2 °C were used as a reference material for the triangle test. All analysed samples were from the same lot. The first change of the product was identified by the evaluators when they recognized statistically significant differences between samples (probability level of P = 0.99). A consumer preference test was used to determine unacceptability of samples. The samples of fruit baby food were tested by 51 consumers and a product was identified as sensory unacceptable if more than 50% of the evaluators identified it as sensory unacceptable (Lawless & Heymann, 1999).

Data processing

The pseudo first order and zero order kinetic models were used. These kinetic types are expressed by the following equations:

Zero order:

$$c = c_0 + k_0 t \tag{1}$$

Pseudo first order:

$$c = c_0 e^{k_{ps} t} \tag{2}$$

where:

$$k_{ps} = k_1 C \tag{3}$$

where c is the concentration at the time t, c_0 is the concentration at time zero, k_0 is the zero order kinetic constant, C is the concentration of the constant reactant, k_{ps} is the pseudo first order kinetic constant and k_1 is the first order kinetic constant. Temperature sensitivity of the rate constant was analysed using the Arrhenius equation:

$$\ln k = \ln k_{ref} - \left(\frac{Ea}{R}\right)\left(\frac{1}{T} - \frac{1}{T_{ref}}\right) \tag{4}$$

where k_{ref} is the rate constant at the reference temperature (T_{ref}), E_a is the activation energy of the studied reaction and R is the universal gas constant.

Q_{10} (temperature acceleration factor) is defined as:

$$Q_{10} = \frac{reaction\ rate\ at\ temperature\ (T+10)}{reaction\ rate\ at\ temperature\ (T)} \quad (5)$$

(Rajchl et al., 2010).

The value of z is the temperature change that causes a 10-fold change in the reaction rate constant.

Statistical analysis

The tests were triplicated for each sample and mean values are mentioned. Differences at $p < 0.05$ were considered to be significant. All statistical analyses were performed using Statistica 9.0 (StatSoft CR s.r.o., Prague, Czech Republic) and Excel 2007 (Microsoft Corporation).

RESULTS AND DISCUSSION

The following storage experiment shows a general procedure to estimate a shelf-life of fruit baby food. Typical fruit baby food produced from apples and other red-fruit was chosen. Physical and chemical markers potentially suitable for predicting a shelf-life of baby food were selected. Antioxidant capacity, ascorbic acid content and total phenol content were chosen as nutritionally important markers. Colour was chosen as an appropriate parameter for monitoring sensory changes. 5-HMF and 2-furfural contents were monitored, because these compounds are suitable for evaluation of heat treatment of products.

Changes of the selected markers are shown in the plots in Figs 1– 6, and kinetic data (k, E_a, z, Q_{10}) calculated from the results of the selected markers are given in Table 1.

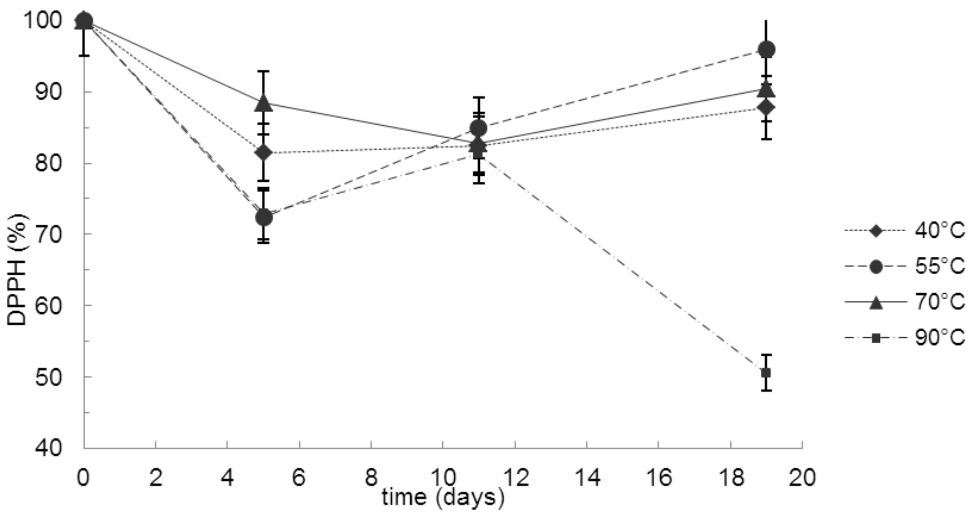

Figure 1. Changes of DPPH content during the storage of fruit baby-food in various temperatures.

The trend of DPPH changes (see Fig. 1) is ambiguous. The antioxidant capacity decreased during the first 4 days. After the decline, growth followed, which is typical for other types of foodstuffs as well. This trend is probably caused by formation of substances with antioxidant properties during heating, e.g. products of the Maillard reactions, or by increasing availability of substances with antioxidant properties from the food matrix. (Pérez-Conesa et al., 2009; Votavová et al., 2009) Interpretation of changes in antioxidant capacity of food products is generally very difficult because food matrices are very complex and interactions between food components have not been comprehensively described.

The decrease of total phenol content (see Fig. 2) in baby food had exponential trend for the temperatures of 40, 55 and 70 °C. The 'increase' of total phenols during heating up to 90 °C was probably due to production of the Maillard reaction products and due to non-specificity of the Folin-Ciocalteu method. The changes in the content of ascorbic acid, furfural and 5-HMF (see Fig. 3 and 4) in baby food had an exponential trend for each selected temperature. 5-HMF and furfural formation at the temperature of 90 °C was not monitored because concentration of those compounds increases dramatically during heating.

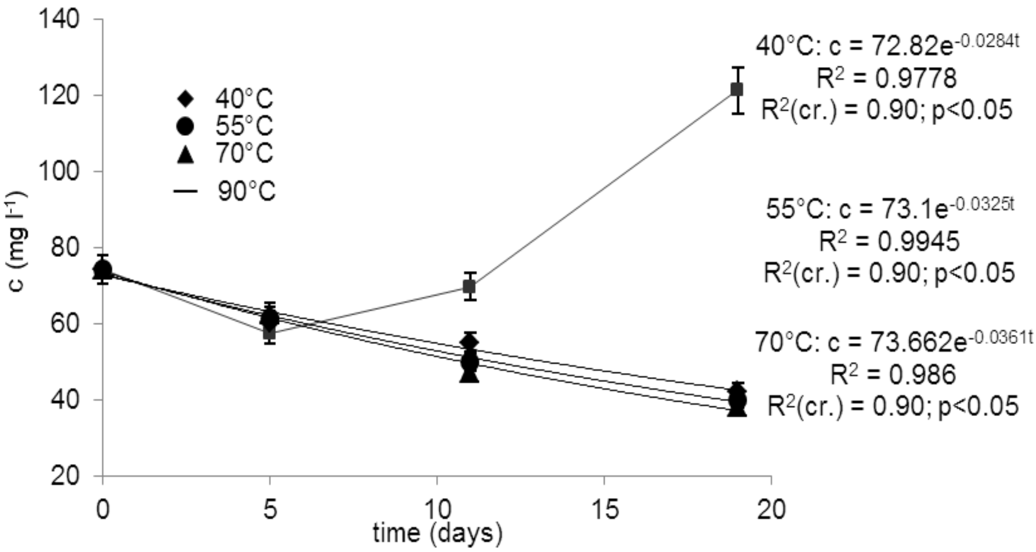

Figure 2. Changes of total phenols content during the storage of fruit baby-food in various temperatures.

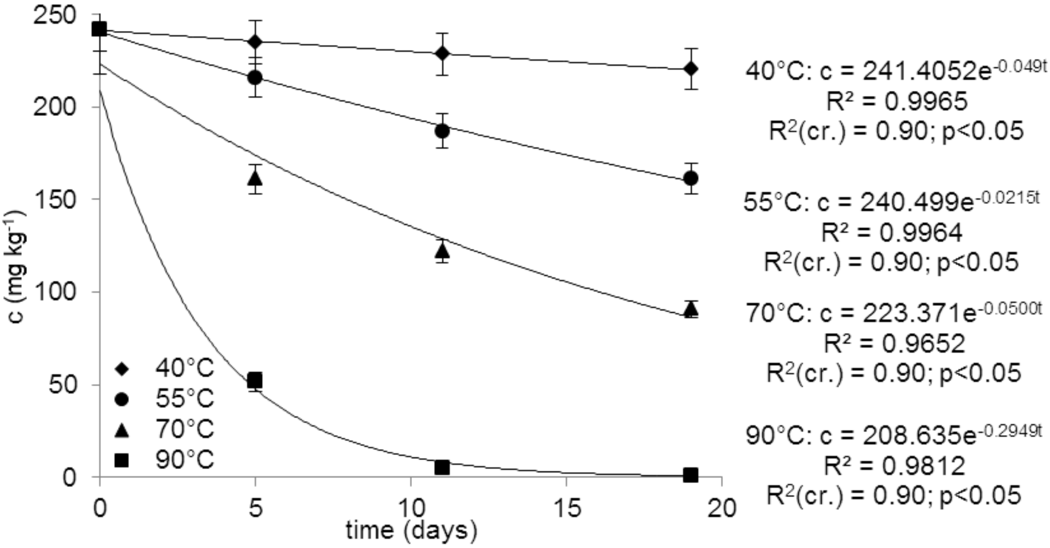

Figure 3. Changes of ascorbic acid content during the storage of fruit baby-food in various temperatures.

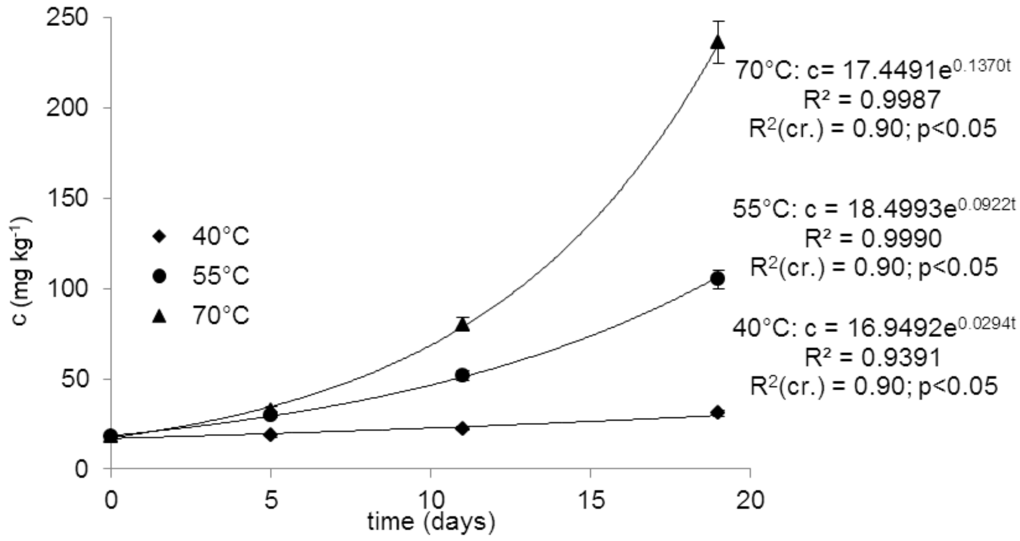

Figure 4. Changes of HMF content during the storage of fruit baby-food in various temperatures.

The changes of colour were expressed as a*, b*, L and ΔE (see Fig. 5 and 6). The b* parameter decreased at the lower temperatures and increased at the higher temperatures. The changes of the a* parameter were inconsistent and hardly applicable for data processing.

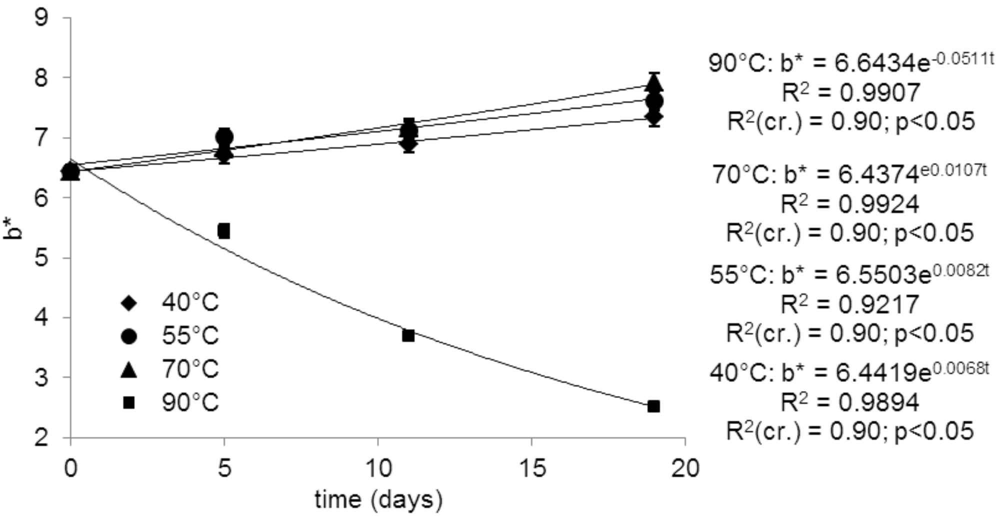

Figure 5. Changes of colour expressed as b* during the storage of fruit baby food in various temperatures.

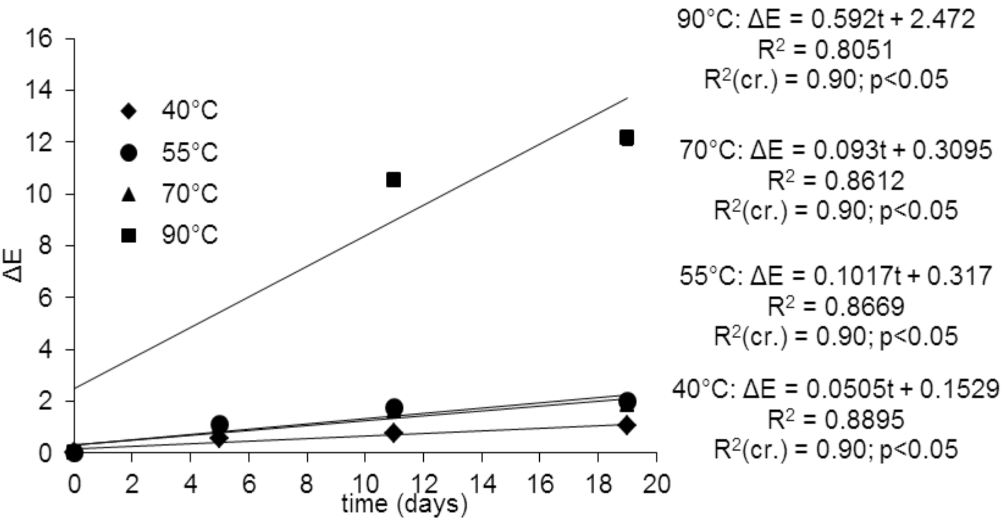

Figure 6. Changes of colour expressed as ΔE during the storage of fruit baby food in various temperatures.

Colour changes, expressed as ΔE, a* and L, and total phenol contents are applicable for shelf-life evaluation of fruit baby food. Considering that the z-value for total phenols is very high, total phenol content is less useful for evaluation of heat treatment or prediction of a shelf-life, but thermal stability of total phenols is advantageous in nutritional terms. Colour is more suitable for shelf-life evaluation, because this marker is one of the most important parameters for consumers. The colour changes correlated well with other markers commonly used for assessment of heat treatment of fruit products. Changes of colour are probably affected by anthocyanin degradation. Ambiguous trends of anthocyanin degradation during heating were observed in literature (Tsai et al., 2005). Colour changes are generally well applicable for assessment of a shelf-life and heat treatment. The calculated kinetic data are given in Table 1. The obtained results roughly correspond with the data of Opatová et al. (1992) and Ibarz et al. (1999). The relatively high standard deviation of the measured data is due to complexity of the matrix and difficulty in evaluating a shelf-life of fruit baby food. The order of reaction for the selected parameters was verified by adjusting the experimental data to the kinetic equations of zero, first and second order using a regression analysis. The changes of total phenols, ascorbic acid, 5-HMF, furfural content and colour parameters expressed as a*, b* followed the pseudo first order kinetics. The colour changes expressed as ΔE and L followed the zero order kinetics ($\Delta E = \Delta E_0 + kt$).

Table 1. Kinetic data calculated from the results of the storage experiments. The results are the average of five analyses and expressed as mean ± SD. ($p < 0.90$)

	Temperature (°C)	k (day^{-1}) ($p < 0.90$)	Ea* ($kJ\ mol^{-1}$) ($p < 0.90$)	z (°C) ($p < 0.90$)	Q_{10} ($p < 0.90$)
Total phenols	40	$28.4\times10^{-3} \pm 8.8\times10^{-3}$	7.2 ± 2.0	245.0 ± 69.0	1.1 ± 0.3
	55	$32.5\times10^{-3} \pm 5.0\times10^{-3}$			
	70	$36.1\times10^{-3} \pm 8.9\times10^{-3}$			
	90	-			
b*	40	$6.8\times10^{-3} \pm 1.5\times10^{-3}$	13.5 ± 10.8	127.0 ± 102.0	1.2 ± 1.0
	55	$8.2\times10^{-3} \pm 4.9\times10^{-3}$			
	70	$10.7\times10^{-2} \pm 1.9\times10^{-3}$			
	90	-			
ΔE	40	$50.5\times10^{-3} \pm 36.7\times10^{-3}$	47.0 ± 15.6	43.0 ± 14.0	1.7 ± 0.6
	55	$101.7\times10^{-3} \pm 82.3\times10^{-3}$			
	70	$93.0\times10^{-3} \pm 77.1\times10^{-3}$			
	90	$592\times10^{-3} \pm 601.5\times10^{-3}$			
L	40	$0.3\times10^{-3} \pm 1.5\times10^{-3}$	73.3 ± 81.8	26.0 ± 29.0	2.4 ± 2.7
	55	$2.1\times10^{-3} \pm 1.9\times10^{-3}$			
	70	$1.4\times10^{-3} \pm 2.3\times10^{-3}$			
	90	$16.5\times10^{-3} \pm 17.5\times10^{-3}$			
Ascorbic acid	40	$4.9\times10^{-3} \pm 0.6\times10^{-3}$	75.4 ± 14.9	29.0 ± 3.2	2.2 ± 0.2
	55	$21.5\times10^{-3} \pm 2.7\times10^{-3}$			
	70	$50.0\times10^{-3} \pm 19.6\times10^{-3}$			
	90	$294.9\times10^{-3} \pm 84.2\times10^{-3}$			
5-HMF	40	$29.4\times10^{-3} \pm 15.4\times10^{-3}$	46.1 ± 73.4	45.0 ± 72.0	1.7 ± 2.7
	55	$92.2\times10^{-3} \pm 5.9\times10^{-3}$			
	70	$137.0\times10^{-3} \pm 10.0\times10^{-3}$			
	90	-			
Furfural	40	$46.0\times10^{-3} \pm 14.2\times10^{-3}$	31.1 ± 26.9	61.0 ± 52.0	1.5 ± 1.3
	55	$95.4.5\times10^{-3} \pm 31.0\times10^{-3}$			
	70	$143.8\times10^{-3} \pm 20.5\times10^{-3}$			
	90	-			

For shelf-life prediction, changes of ascorbic acid content during storage are not useful due to deliberate addition of this substance to final products. In the end of a shelf-life, baby foods with added vitamin C can contain more ascorbic acid than just produced fruit baby food with no addition of vitamin C. Generally, antioxidant activity is contrary determined by ascorbic acid and therefore, ascorbic acid content was analysed. The results of the accelerated storage experiment suggest definite unsuitability of antioxidant capacity for estimation of shelf-lives.

5-HMF/furfural contents as well as changes are not applicable for shelf-life prediction because formation of these compounds is strongly affected by temperature history of a given product during production (filling, pasteurisation etc.). Changes of carbohydrate content (sucrose inversion) are not a suitable marker in case of baby food because sugar is often added to fruit-based infant food. Colour expressed as b* is not a suitable marker for shelf-life estimation, because the changes of the b* parameter have not an explicit trend.

The example of Arrhenius plots between natural logarithm of *k* values and l/T is given in Fig. 7; the calculated kinetic equations were used for extrapolation of shelf-lives at the model storage temperatures. The value of sensory difference was determined by the sensory analysis: (unacceptable shift: (L): 37; (ΔE): 4).

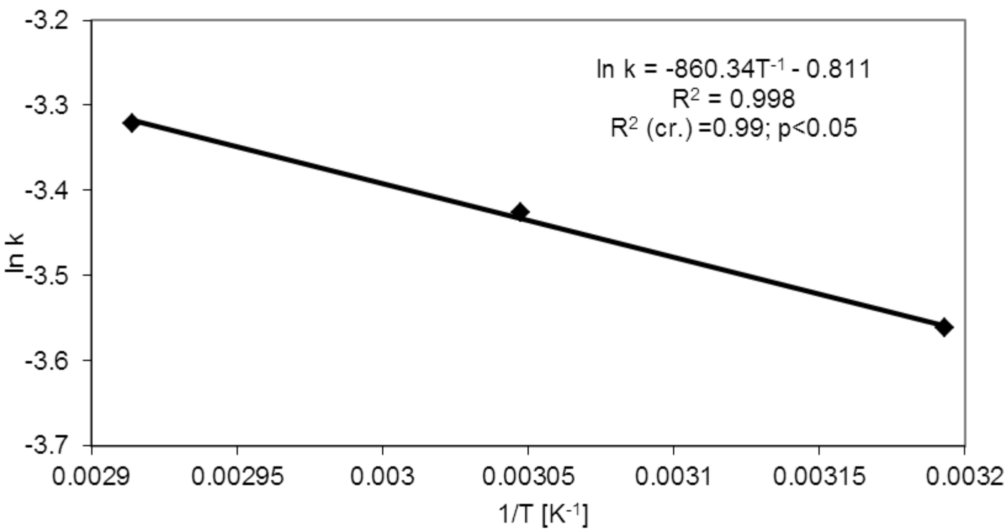

Figure 7. Example of Arrhenius plot for total phenols changes.

Determination of the first change of a selected marker is statistically more objective, because limits of unacceptability are perceived differently by consumers from different parts of the world. The data were used for construction of shelf-life plots, which are used to estimate storage stability of frozen foods (time-temperature-tolerance) according to Tressler et al. (1968). An example of the shelf-life plots is given in Fig. 8. The shelf-life of fruit baby food calculated according to the L and ΔE at the temperature 20 and 30 °C is given in Table 2.

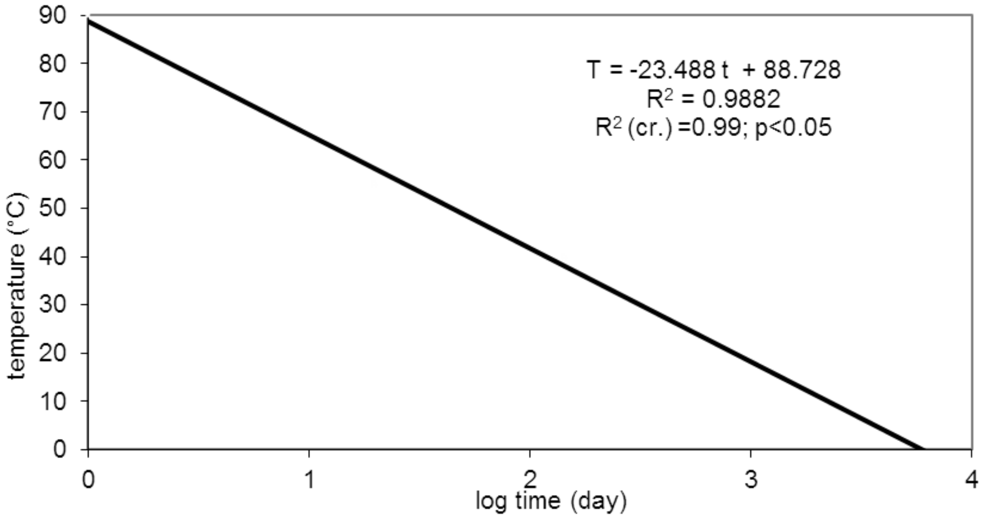

Figure 8. Example of shelf life plot for the baby food according to the L.

Table 2. The estimated storage time

	Storage time for the selected markers [days]	
Temperature [°C]	ΔE	L
20	692	843
30	318	316

The shelf-life extrapolated for the average storage temperature of 20 °C corresponds roughly with the shelf-life declared by the producer. Changes of chemical markers, such as total phenols, seem to be generally simpler and more suitable to be used for assessing shelf-lives; however sensorial parameters should be used to determine product unacceptability or the first change of a selected marker. The problem with chemical markers is high variability of their initial concentrations.

CONCLUSIONS

Estimation of shelf-lives is very complicated due to difficulties in determining limits of product acceptability. So far, there has been no definite approach for determination of shelf-lives. Therefore it is necessary to carry out high-quality preliminary research focusing on chemical and physical changes in food commodities before shelf-life testing. Results must be critically assessed and variability of food matrices must be considered. Colour expressed as ΔE and L is the most appropriate marker for shelf-life estimation of fruit baby food. In comparison with chemical markers, colour seems to be a more robust parameter allowing more general estimations. But using colour as a marker for assessing heat treatment and/or a shelf-life is complicated due to thermal damage to input raw material.

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REFERENCES

Ahmed, J. & Ramaswamy, H.S. 2005. Effect of temperature on dynamic rheology and colour degradation kinetics of date paste. *Food and Bioproducts Processing* **83**, 198–202.

Ávila, I.M.L.B. & Silva, C.L.M. 1999. Modelling kinetics of thermal degradation of colour in peach puree. *Journal of Food Engineering* **39**, 161–166.

Brand-Williams, W., Cuvelier, M.E. & Berset, C. 1995. Use of Free Radical Method to Evaluate Antioxidant Activity. *Lebensmittel-Wissenschaft und Technologie* **28**, 25–30.

Burdulu, H.A. & Karadeniz, F. 2003. Effect of storage nonenzymatic browning of apple juice concentrates.*Food Chemistry* **80**, 91–97.

Chutintrasri, B. & Noomhorm, A. 2007. Color degradation kinetics of pineapple puree during thermal processing. *LWT – Food Science and Technology* **40**, 300–306.

Čížková, H., Ševčík, R., Rajchl, A. & Voldřich, M. 2009. Nutritional Quality of Commercial Fruit Baby Food. *Czech Journal of Food Sciences* **27**, S134–S137.

Corbo, M.R., Nobile, M.A.D. & Sinigaglia, M. 2006. A novel approach for calculation shelf life of minimally processed vegetables. *International Journal of Food Microbiology* **106**, 69–73.

Dalgaard, P. 1995. Modelling of microbial activity and prediction of shelf life for packed fresh fish. *International Journal of food Microbiology* **26**, 305–317.

Freitas, M.A. & Costa, J.C. 2006. Shelf life determination using sensory evaluation scores: A general Weibull modeling approach. *Computers & Industrial Engineering* **51**, 652–670.

Fu, B. & Labuza, T.P. 1993. Shelf-life prediction: theory and application. *Food Control* **4**, 125–133.

García-García, P., López-López, A. & Garrido-Fernández, A. 2008. Study of the shelf life of ripe olives using an accelerated test approach. *Journal of Food Engineering* **84**, 569–575.

Gentry, T.S. & Roberts, J.S. 2004. Formation kinetics and application of 5-hydroxymethylfurfural as a time-temperature indicator of lethality for continuous pasteurization of apple cider. *Innovative Food Science & Emerging Technologies* **5**, 327–333.

Hough, G., Garitta, L. & Gómez, G. 2006. Sensory shelf-life prediction by survival analysis accelerated models. *Food Quality and Preference* **17**, 468–473.

Ibarz, A., Pagán, J. & Garza, S. 1999. Kinetic models for colour changes in pear puree during heating at relatively high temperatures. *Journal of Food Engineering* **39**, 415–422.

Lawless, H.T. & Heymann, H. 1999. Sensory evaluation of food: principles and practices (pp. 173–181). New York: Aspen Publishers Inc.

Larsson, J.A. & Pardue, H.L. 1990. Comparison of algorithms for error-compensated kinetic determination without prior knowledge of reaction order or rate constant. *Talanta* **37**, 223–236.

Ledauphin, S., Pommeret, D. & Qannari, E.M. 2006. A Markovian model to study products shelf-lives. *Food Quality and Preference* **17**, 598–603.

Opatová, H., Voldřich, M., Dobiáš, J. & Čurda, D. 1992. Quality changes during the storage of apple puree. *Die Nahrung* **36**, 129–134.

Oszmiań, J., Wolniak, M., Wojdyło, A. & Wawer, I. 2008. Influence of apple purée preparation and storage on polyphenol contents and antioxidant activity. *Food Chemistry* **107**, 1473–1484.

Palazón, M.A., Pérez-Conesa, D., Abellán, P., Ros, G., Romero, F. & Vidal, M.L. 2009. Determination of shelf-life of homogenized apple-based beikost storage at different temperatures using Weibull hazard model. *LWT – Food Science and Technology* **42**, 319–326.

Pérez-Conesa, D., García-Alonso, J., García-Alonso, V., Iniesta, M.D., Jacob, K., Sánchez-Siles, L.M., Ros, G. & Periago, M.J. 2009. Changes in bioactive compounds and antioxidant activity during homogenization and thermal processing of tomato puree. *Innovative Food Science & Emerging Technologies* **10**, 179–188.

Rada-Mendoza, M., Olano, A. & Villamiel, M. 2002. Determination of hydroxymethylfurfural in commercial jams and in fruit-based infant foods. *Food Chemistry* **79**, 513–516.

Rada-Mendoza, M., Sanz, M.L., Olano, A. & Villamiel, M. 2004. Formation of hydroxymethylfurfural and furosine during the storage of jams and fruit-based infant foods. *Food Chemistry* **85**, 605–609.

Ragnarsson, J.O. & Labuza, T.P. 1977. Accelerated shelf-life testing for oxidative rancidity in foods – A review. *Food Chemistry* **2**, 291–308.

Rajchl, A, Voldřich, M., Čížková, H., Hronová, M., Ševčík R. & Dobiáš, J. 2010. Stability of nutritionally important compounds and shelf life prediction of tomato ketchup. *Journal of Food Engineering* **99**, 465–470.

Rocha, A.M.C.N. & Morais, A.M.M.B. 2003. Shelf life of minimally processed apple (cv. Jonagored) determined by colour changes. *Food Control* **14**, 13–20.

Sande, S.A. & Karlsen, J. 1993. Evaluation of reaction order. Software in pharmaceutics:III. *International Journal of Pharmaceutics* **98**, 209–218.

Shaghaghi, M., Manzoori, J.L. & Jouyban, A. 2008. Determination of total phenols in tea infusions, tomato and apple juice by terbium sensitized fluorescence method as an alternative approach to the Folin-Ciocalteu spectrophotometric method, *Food Chemistry* **108**, 695–701.

Tresler, D.K., Van Arsdel, W.B. & Copley, M.J. 1968. The Freezing Preservation of Foods. (4th ed.). New York: Avi Publishing Co., Inc., Westport, Conn.(Chapter I–IV).

Tsai, P.J., Delva, L., Yu, T.Y., Huang, Y.T. & Dufossé, L. 2005. Effect of sucrose on the anthocyanin and antioxidant capacity of mulberry extract during high temperature heating. *Food Research International* **38**, 1059–1065.

Van Boekel, M.A.J.S. 2009. Kinetic Modeling of Reactions in Foods (Food science and technology). Shelf-life from the Product Point of View. 15-2–15-4. New York: CRC Press Taylor & Francis Group.

Votavová, L., Voldřich, M., Ševčík, R., Čížková, H., Mlejnecká, J., Stolař, M. & Fleišman, T. 2009. Changes of antioxidant capacity of robusta coffee during roasting. *Czech Journal of Food Science* **27**, S49–S52.

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Explosive decompression pretreatment: nitrogen vs. compressed air

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Abstract: Lignocellulosic material is the most promising feedstock for the bioethanol production however, due to complicated physico-chemical characteristics of biomasses, it is necessary to pretreat the biomass before the bioethanol production. The goal of the pretreatment is to open the biomass structure for enzymatic hydrolysis to gain higher sugar and ethanol yields in further processes. In this paper a novel explosive decompression pretreatment is studied where two gases – nitrogen and compressed air are utilized for pressure generation. For this, traditional three-step bioethanol production process was used, where explosive decompression pretreatment with N_2 gas or compressed air was applied for biomass pretreatment. Glucose and ethanol concentrations were measured during the process. Glucose and ethanol yields and process efficiencies were used to evaluate the effect of explosive decompression pretreatment and its suitability for biomass pretreatment in bioethanol production process. Results show that the highest glucose yield was gained when nitrogen gas was used, while difference in glucose yield compared to that of autohydrolysis was negligible when compressed air was applied.

Key words: lignocellulose, explosive decompression, bioethanol, pretreatment.

INTRODUCTION

Lignocellulosic material is widely used source of biomass for energy production. This kind of biomass is usually burned directly for heat and energy production or converted to other types of fuel. In addition, due to the depletion of conventional fossil fuels and EU 2020 targets (Commission) the conversion of biomass to liquid fuels, like ethanol, has attracted particular attention. Lignocellulosic biomass is promising feedstock for the ethanol production considering its great availability, low cost, and sustainable supply (Agbor et al., 2011; Min et al., 2013; Phitsuwan et al., 2013). Plant biomass is primarily composed of plant cell walls of which about 75% are polysaccharides (Phitsuwan et al., 2013) that could be used for ethanol production. Therefore, it has become a major focus of intensive research and development (Agbor et al., 2011; Tutt et al., 2013; Raud et al., 2014; Tutt et al., 2014).

The bioethanol production includes three step process – pretreatment of biomass, hydrolysis of cellulose to sugars and fermentation of sugars to ethanol (Tutt et al., 2012; Raud et al., 2015). The conversion of cellulose to ethanol is difficult since the cellulose fibers in the biomass are tightly packed with hemicellulose and lignin cover. The pretreatment is necessary in order to break down the biomass structure to gain access to the sugars from cellulose and hemicellulose. The goal of the pretreatment is to improve the further conversion steps (Conde-Mejía et al., 2012) and therefore, various pretreatment methods have been proposed to enhance bioethanol production process (Alvira et al., 2010; Demirbas, 2011; Chiaramonti et al., 2012).

The pretreatment methods can be divided into biological, chemical, – physical, and combined chemical-physical methods. However, since various types of biomasses have different characteristics, there is no ideal pretreatment method, but the suitable pretreatment method must be adopted to each specific lignocellulosic biomass (Alvira et al., 2010). The biological pretreatment methods apply various types of fungi to degrade hemicellulose and lignin however, the method is ineffective due to low hydrolysis rate (Alvira et al., 2010). The physical methods on the other hand are mainly targeted to increasing the surface area and reduction of particle size of biomass and they are used usually in combination with other pretreatment methods (Haghighi Mood et al., 2013). Chemical pretreatment methods use chemicals such as acids, alkali, organic solvents, and ionic liquids, which have a significant effect on the native structure of biomass (Agbor et al., 2011; Tutt et al., 2012). However, the use of chemicals makes the production process too expensive due to the high cost of chemicals and the production of toxic materials during the process (Shirkavand et al., 2016).

More effective methods of enhancing the biomass digestibility are combinational pretreatments, where physical parameters like temperature and pressure are combined with other pretreatment methods. Amongst them steam-explosion, ammonia fibre explosion (AFEX), CO_2 or SO_2 explosion are the most used methods (Agbor et al., 2011). These methods include pretreatment of biomass with pressurized steam, ammonia, CO_2 or SO_2, respectively, which is followed by rapid decompression to an atmospheric pressure (Tutt et al., 2014). The decompression causes destruction of lignin and hemicellulose, which enables enzymes to gain better access to cellulose in further treatment. Additionally, the CO_2 forms carbonic acid when dissolved in water, which increases the hydrolysis rate (Shirkavand et al., 2016). However, the disadvantage of these methods is the formation of inhibitory compounds and they are more effective on low-lignin content biomass (Chiaramonti et al., 2012).

In this paper a novel combinational biomass pretreatment method – explosive decompression pretreatment is evaluated. In case of explosive pretreatment, the biomass is mixed with water and additionally N_2 gas is added to the reactor to elevate the pressure (Raud et al., 2016). As an economical alternative to N_2 gas, the compressed air could be used since air consists in approximately 78% of nitrogen. Nitrogen molecules are smaller than water molecules and gas molecules used in other pretreatment methods (like CO_2 and SO_2) and under high pressure and temperature can more effectively penetrate the cell walls of biomass. When the pressure is released in an explosive manner, the dissolved nitrogen gas expands and thereby, opens the biomass structure and increases its surface area for following enzymatic hydrolysis. The explosive decompression pretreatment method is economically attractive since no catalysts or chemicals are added in these processes, which makes the pretreatment process cheaper.

The purpose of this work was to assess the effect of explosive decompression pretreatment method using nitrogen and, as an alternative, compressed air. Experiments were conducted using several different temperature and pressure combinations. Resulting pretreated biomass was used in the standard three-step lignocellulosic bioethanol production process. Glucose and ethanol concentrations of the samples were measured after hydrolysis and fermentation processes, respectively. Results were analysed in order to find the most suitable pretreatment conditions and to study the efficiency of the pretreatment.

MATERIALS AND METHODS

Biomass

Barley straw was used as a biomass in all experiments. The biomass was grown in Tartu area (Estonia), on loamy soil and harvested in August. The samples were dried to a moisture content less than 10% and ground with Cutting Mill ZM 200 (Retsch GmbH) to a particle-size 1 mm or less.

Pretreatment

The explosive decompression pretreatment method was used to break the cell structure of the biomass and expose the cellulose to further enzymatic treatment. The experimental setup with the pressure reactor and heater is presented in Fig. 1. 100 g of dry biomass was weighed, placed into a pressure vessel and mixed with distilled water until watery biomass paste with a volume of 1 litre was gained. The reactor was closed and pressurised with compressed air or nitrogen gas to a pressure of 1 to 60 bars. The pressurized samples were then heated in the reactor vessel with ceramic heater to temperatures of 25–175 °C. The temperature in the pressure vessel was measured with a thermocouple and controlled using electronic controller unit. When the intended temperature was reached, the reactor was cooled down to at least 80 °C, if necessary, and pressure was released through a valve in an explosive manner. The biomass was kept in the reactor for 3 hours from the start of the heating until the explosive decompression. After the pre-treatment the samples were cooled to a temperature below 50 °C for enzymatic hydrolysis.

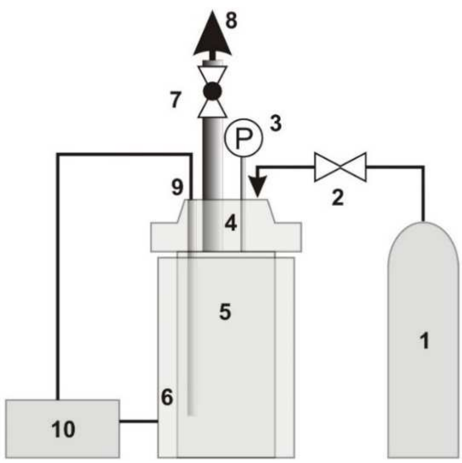

Figure 1. Schematic of the explosive decompression pretreatment system: 1 – nitrogen tank; 2 – pressure control valve; 3 – manometer; 4 – modified reactor vessel cap; 5 – reactor vessel; 6 – ceramic contact heater; 7 – pressure release valve; 8 – into ventilation system; 9 – thermocouple; 10 – controller unit.

Hydrolysis

Enzymatic hydrolysis with enzyme complex Accellerase 1500 was used to convert cellulose in the biomass to glucose. Enzyme mixture was added to samples pretreatment at a ratio of 0.3 ml per g of biomass and the flask was filled with distilled water to 1,000 ml volume. Hydrolysis lasted 24 hours at a temperature of 50 °C under constant stirring in rotating shaker/incubator (Unimax 1010, Heidolph Instruments GmbH & Co.KG). After the hydrolysis, the glucose concentration in all the samples was measured.

Fermentation

Dry yeast *Saccharomyces cerevisiae* in ratio of 25 g of yeast per kg of biomass was added to all samples to start the fermentation process. Fermentation process was carried out at room temperature under low oxygen conditions in 1,000 mL glass bottles, sealed with a fermentation tube. Fermentation lasted for 7 days after which, the ethanol concentration in the mixture was measured.

Chemical analysis

Dry matter content was analyzed with a moisture analyzer Ohaus MB 45. The percentage of lignin, Acid Detergent Fiber (ADF), and Neutral Detergent Fiber (NDF) in the dry mass (DM) of the biomass samples was determined at the Plant Biochemistry Laboratory of Estonian University of Life Sciences (Tecator ASN 3430) (AOAC, 1990; Van Soest et al., 1991). The glucose and ethanol concentrations in the mixture were determined using Analox GL6 analyzer (Analox instruments Ltd.).

Averaged results of at least three parallel measurements are used in figures and corresponding standard deviations are shown by vertical lines.

RESULTS AND DISCUSSION

Biomass analysis

Barley straw was used as a sample biomass to investigate the effect of the explosive decompression pretreatment method on the bioethanol production process. A biomass can be characterized on the basis of its relative proportion of cellulose, hemicellulose, and lignin (Table 1). Previous research has shown that energy crops for ethanol production should be selected based on their cellulose content since ethanol yield per kg of biomass was directly proportional to the cellulose content in the energy crop (Kikas et al., 2016). As seen in Table 1, the barley straw used in these experiments as a sample biomass contained 45.73% of cellulose. Relatively high cellulose content makes it a suitable biomass for bioethanol production.

Table 1. Results of the biomass analysis (n = 3)

Component	Content (%) [1]
Hemicellulose	32.61 ± 0.53
Cellulose	45.73 ± 0.21
Lignin	5.25 ± 0.00
Ash	3.86 ± 0.06
Dry matter	n.a.

[1] Determined at the Plant Biochemistry Laboratory of Estonian University of Life Sciences.

Hydrolysis of biomass

The Fig. 2 illustrates the change in glucose yield at different temperatures when N_2 gas or compressed air was used to increase the pretreatment pressure. The glucose yield was the lowest when no additional pressure was used in pretreatment and only increase in temperature affected the biomass structure. Approximately the same glucose yields were gained when the compressed air was used to increase pressure in the pressure reactor. Using compressed air for pretreatment, a 68% increase in glucose yield can be seen in Fig. 2 when the temperature was increased from 100 °C to 150 °C. The increase in glucose yield was gained due to the autohydrolysis of biomass caused by the elevated temperature. The autohydrolysis leads to the hydrolysis of hemicelluloses and the lignin disruption, resulting in increase in cellulose reactivity with cellulose in the following enzymatic hydrolysis process (Samuel et al., 2013). The explosive pretreatment with compressed air had little to no effect on the glucose yield, which was approximately the same as with autohydrolysis.

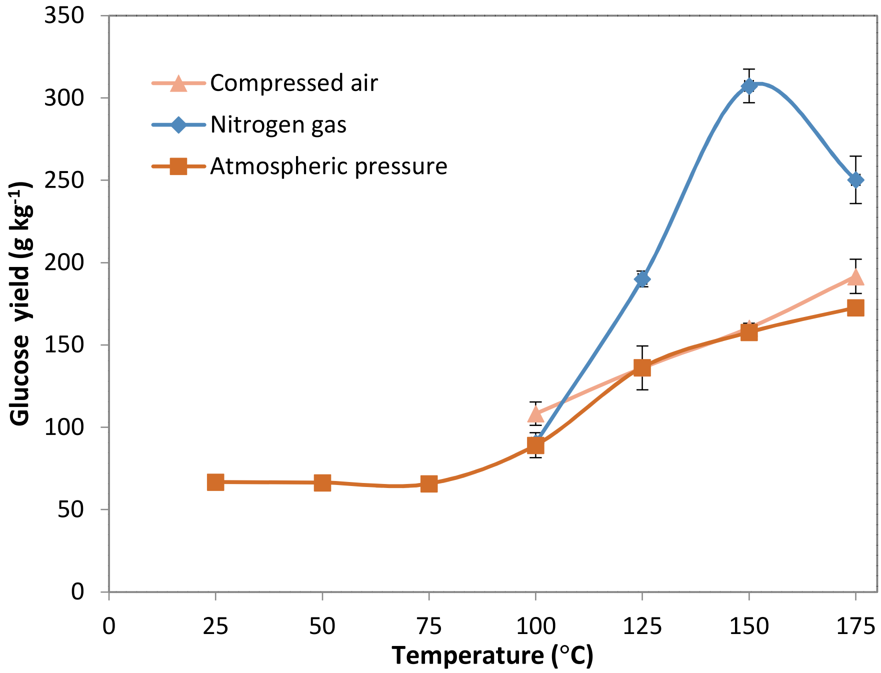

Figure 2. Comparison of glucose yields gained at pressure of 30 bars with different pretreatment methods when the pretreatment temperature was gradually increased.

However, in case of explosive decompression with N_2 gas, a sharp – 218% increase in glucose yield was noted when the pretreatment temperature was increased from 100 °C to 150 °C. At 150 °C explosive decompression with N_2 gas enabled to gain 95% higher glucose yield than when using explosive decompression with compressed air or autohydrolysis at higher temperatures.

During the pretreatment the small N_2 molecules penetrate more efficiently into the biomass fibres and cells than gases found in compressed air. When the pressure is suddenly decreased, the dissolved gas expands and opens the cellulosic structure of biomass and thereby, increases the accessible surface area of biomass for further enzymatic hydrolysis. Although the pressurized air contains 78% of N_2, it does not effectively penetrate into the biomass cells and therefore, it is not as effective for use in explosive pretreatment of biomass as nitrogen gas.

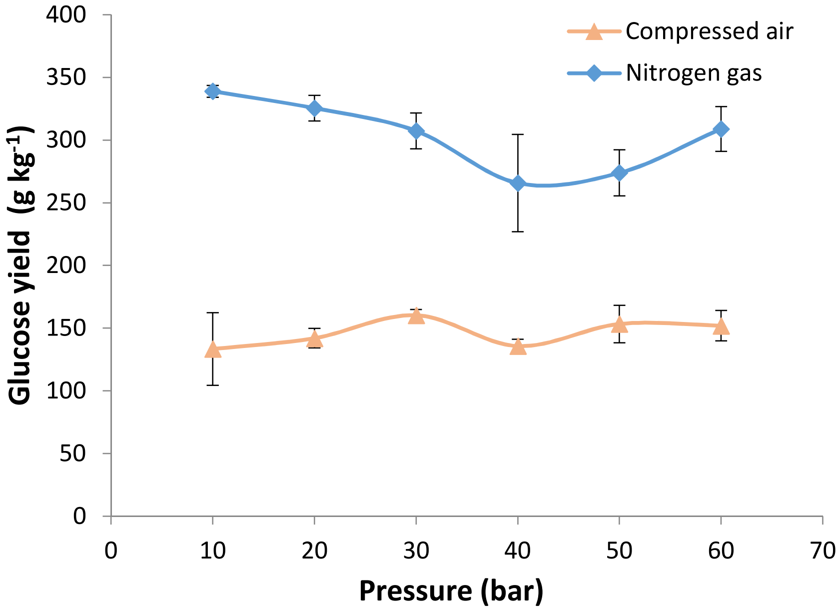

Figure 3. Comparison of glucose yields gained with different pretreatment methods at 150 °C when the pretreatment pressure was gradually increased.

Fig. 3 illustrates the effect of pretreatment pressure to the glucose yield of biomass at 150 °C. As can be seen, the pretreatment pressure has little effect on the glucose yield of biomass. When compressed air was used to generate pressure, the glucose yield changed only to a small degree. On the other hand, pretreatment with nitrogen gas resulted in higher results but the glucose yield had a U-shaped dependence where the minimum glucose yield was gained at the pressure of 40 to 50 bars. In addition, depending on the temperature, the pretreatment with N_2 gas enabled to gain 90–150% higher glucose yield than when compressed air was used for pretreatment. This shows that even though the presence of pressure and its explosive release has effect on the biomass, the extent of pressure has negligible effect on the pretreatment process. However, choosing the suitable gas for pressure elevation and temperature combination enables to gain considerably higher glucose yields.

Fermentation

After hydrolysis, the fermentation with yeast *Saccharomyces cerevisiae* was used to convert the glucose into ethanol. Compressed air or nitrogen gas were used to reach pressure of 30 bars inside the pressure reactor. Comparison experiments were conducted at near atmospheric pressure with no gas-added pressure. Based on gained results the ethanol yield was calculated and used to estimate the effect of different pretreatment conditions to ethanol production process (Fig. 4).

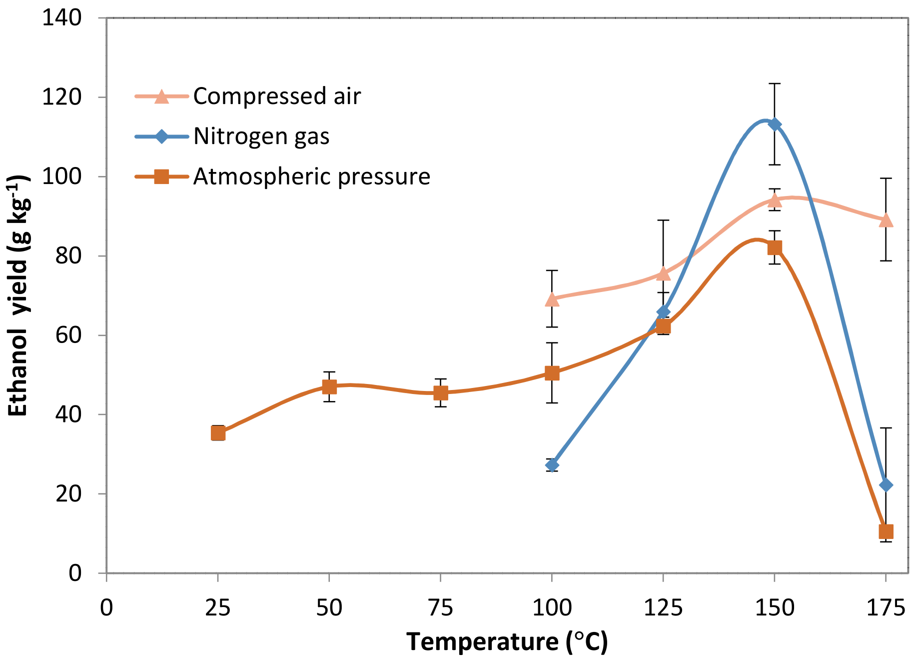

Figure 4. Comparison of ethanol yields gained with different pretreatment methods at 30 bars and at near atmospheric pressure when the pretreatment temperature was gradually increased.

The ethanol yields increased as the pretreatment temperature was increased. Lower ethanol yields were gained at temperatures below 125 °C and at 175 °C. The highest ethanol yields were gained with all pretreatment methods at 150 °C. At these conditions, 82 g ethanol per kg of biomass was gained when no pressure was applied during pretreatment. However, when compressed air was used to elevate the pressure to 30 bars during pretreatment a 14.2% higher ethanol yield was gained. Even higher ethanol yield – 113 g per kg of biomass was gained when explosive decompression pretreatment was used with nitrogen gas.

The increased ethanol yields gained with nitrogen gas as operative gas in pretreatment was expected since the glucose yields at these conditions were more than two times higher. On the other hand, while the glucose yields of pretreatment with compressed air as operative gas and near atmospheric pressure pretreatment were very similar, ethanol yields gained with compressed air pretreatment were considerably higher than those gained with autohydrolysis.

The ethanol yields, in case of nitrogen explosion pretreatment and autohydrolysis methods, decreased significantly when temperature above 150 °C was used while in case of compressed air explosion pretreatment the decrease was insignificant. The sharp decrease in ethanol yield can be attributed to formation of inhibiting compounds at higher pretreatment temperatures. The pretreatment temperatures above 150 °C probably result in formation of compounds that inhibit the fermentation process, which leads to lower ethanol yields. The explosive decompression pretreatment with decompressed air enabled to gain higher ethanol yield at 175° than with nitrogen gas of pretreating at atmospheric pressure at this temperature, however it still remained lower than pretreating with nitrogen gas at 150 °C. In addition, it is not reasonable to use too high temperatures due to high energy cost associated with this.

Furthermore, Fig. 5 shows that in case of autohydrolysis and compressed air explosion pretreatments the fermentation efficiency exceeds 100% at majority of pretreatment temperatures. This suggests that these pretreatments were not efficient enough in opening the biomass structure and thus, the enzymatic hydrolysis continued during the fermentation period. Extremely low fermentation efficiencies at temperatures above 150 °C confirm that at higher temperatures compounds are formed that inhibit the yeast.

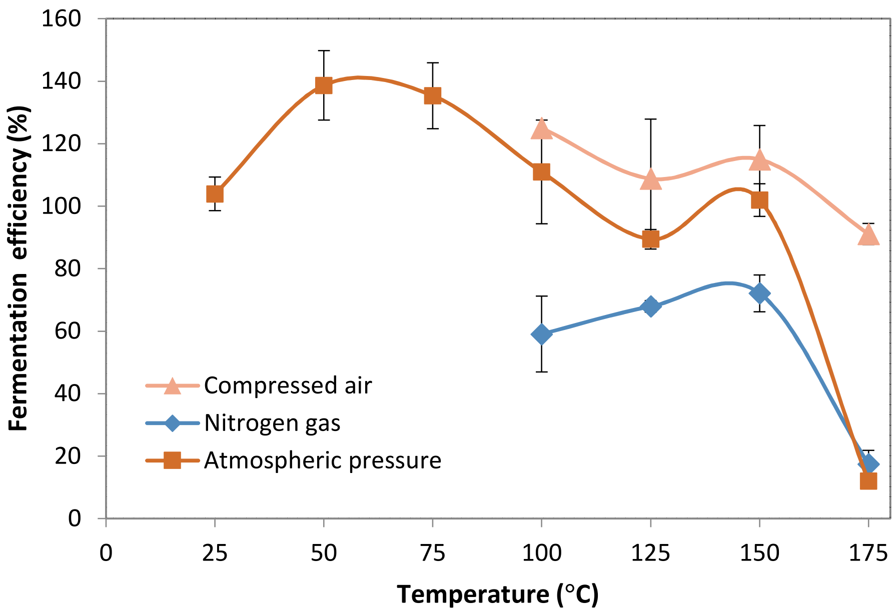

Figure 5. Comparison of fermentation efficiencies gained with different pretreatment methods at 30 bars or at atmospheric pressure when the pretreatment temperature was gradually increased.

CONCLUSIONS

In order to evaluate the effect of explosive decompression pretreatment method, two different gases were used as operative gas in explosion at different temperature and pressure combinations and the results were compared to those of autohydrolysis using barley hay as a sample biomass. Resulting pretreated biomass was used in the standard three step lignocellulosic bioethanol production process, where the glucose and ethanol concentrations of the samples were measured in order to quantify the effect of different pretreatment methods.

The results show that nitrogen is most suitable operative gas for explosive decompression pretreatment giving the highest glucose yield at 150 °C and at pressure of 30 bars. Although major component in compressed air is also nitrogen, considerably lower glucose yields were gained using explosive decompression pretreatment with compressed air as operative gas. The results with compressed air were almost the same as those gained in autohydrolysis pretreatment, where no added pressure was used in addition to elevated temperature. This shows that compressed air, although consisting for the most part of nitrogen, is not as effective in explosive decompression pretreatment as nitrogen. As the explosive decompression pretreatment with nitrogen as operative gas enabled to gain the highest glucose yields, the highest ethanol yields where gained with this pretreatment method in the next stage of the process as well.

REFERENCES

Agbor, V.B., Cicek, N., Sparling, R., Berlin, A. & Levin, D.B. 2011. Biomass pretreatment: Fundamentals toward application. *Biotechnology Advances* **29**, 675–685.

Alvira, P., Tomás-Pejó, E., Ballesteros, M. & Negro, M.J. 2010. Pretreatment technologies for an efficient bioethanol production process based on enzymatic hydrolysis: A review. *Bioresource Technology* **101**, 4851–4861.

AOAC (1990). 'Official methods of analysis of the Association of Official Analytical Chemists'.

Chiaramonti, D., Prussi, M., Ferrero, S., Oriani, L., Ottonello, P., Torre, P. & Cherchi, F. 2012. Review of pretreatment processes for lignocellulosic ethanol production, and development of an innovative method. *Biomass and Bioenergy* **46**, 25–35.

Commission, E. Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC.

Conde-Mejía, C., Jiménez-Gutiérrez, A. & El-Halwagi, M. 2012. A comparison of pretreatment methods for bioethanol production from lignocellulosic materials. *Process Safety and Environmental Protection* **90**, 189–202.

Demirbas, A. 2011. Competitive liquid biofuels from biomass. *Applied Energy* **88**, 17–28.

Haghighi Mood, S., Hossein Golfeshan, A., Tabatabaei, M., Salehi Jouzani, G., Najafi, G.H., Gholami, M. & Ardjmand, M. 2013. Lignocellulosic biomass to bioethanol, a comprehensive review with a focus on pretreatment. *Renewable and Sustainable Energy Reviews* **27**, 77–93.

Kikas, T., Tutt, M., Raud, M., Alaru, M., Lauk, R. & Olt, J. 2016. Basis of Energy Crop Selection for Biofuel Production: Cellulose vs. Lignin. *International Journal of Green Energy* **13**, 49–54.

Min, D., Yang, C., Shi, R., Jameel, H., Chiang, V. & Chang, H. 2013. The elucidation of the lignin structure effect on the cellulase-mediated saccharification by genetic engineering poplars (Populus nigra L. × Populus maximowiczii A.). *Biomass and Bioenergy* **58**, 52–57.

Phitsuwan, P., Sakka, K. & Ratanakhanokchai, K. 2013. Improvement of lignocellulosic biomass in planta: A review of feedstocks, biomass recalcitrance, and strategic manipulation of ideal plants designed for ethanol production and processability. *Biomass and Bioenergy* **58**, 390–405.

Raud, M., Kesperi, R., Oja, T., Olt, J. & Kikas, T. 2014. Utilization of urban waste in bioethanol production: Potential and technical solutions. *Agronomy Research* **12**, 397–406.
Raud, M., Olt, J. & Kikas, T. 2016. N2 explosive decompression pretreatment of biomass for lignocellulosic ethanol production. *Biomass and Bioenergy* **90**, 1–6.
Raud, M., Tutt, M., Olt, J. & Kikas, T. 2015. Effect of lignin content of lignocellulosic material on hydrolysis efficiency. *Agronomy Research* **13**, 405–412.
Samuel, R., Cao, S., Das, B.K., Hu, F., Pu, Y. & Ragauskas, A.J. 2013. Investigation of the fate of poplar lignin during autohydrolysis pretreatment to understand the biomass recalcitrance. *RSC Advances* **3**, 5305–5309.
Tutt, M., Kikas, T. & Olt, J. 2012. Influence of different pretreatment methods on bioethanol production from wheat straw, *Agronomy Research* **10**, 269–276.
Tutt, M., Kikas, T. & Olt, J. 2013. Influence of harvesting time on biochemical composition and glucose yield from hemp, *Agronomy Research* **11**, 215–220.
Tutt, M., Kikas, T., Kahr, H., Pointner, M., Kuttner, P. & Olt, J. 2014. Using steam explosion pretreatment method for bioethanol production from floodplain meadow hay, *Agronomy Research*, **12**(2), 417–424.
Shirkavand, E., Baroutian, S., Gapes, D.J. & Young, B.R. 2016. Combination of fungal and physicochemical processes for lignocellulosic biomass pretreatment – A review. *Renewable and Sustainable Energy Reviews* **54**, 217–234.
Van Soest, P.J., Robertson, J.B. & Lewis, B.A. 1991. Methods for Dietary Fiber, Neutral Detergent Fiber, and Nonstarch Polysaccharides in Relation to Animal Nutrition. *Journal of Dairy Science* **74**, 3583–3597.

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Productivity and cost of biofuel in ditch cleaning operations using tracked excavator based harvester

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Abstract. Forest ditches is one of the poorly utilized sources of biomass for energy production and timber industry. Increase of productivity and reduction of cost of extraction of biomass from the ditches, retaining at the same time high quality standards, are the key issues of mechanization of harvesting operations in this area. The scope of the study was to evaluate productivity and cost of biomass delivered from forest ditches, when tracked excavator based harvester and different work methods are used. New Holland 215B excavator with Ponsse H7 felling head was used in trials. The machine was operated by experienced operators. The study was implemented in drainage systems managed by Joint stock company „Latvia state forests". Total extracted area 12 ha, extracted biomass – 734 m^3. Duration of the study including harvesting and forwarding – 4 months. Average cost of roundwood production including road transport to 50 km distance in the trials was 27 EUR m^{-3}, average cost of biofuel – 11 EUR m^{-3} (4.5 EUR LV m^{-3}). The study approved advantages of excavators in ditch cleaning operations; however, several improvements are possible. The machine should be equipped with smaller accumulating felling head, delimbing and bucking should be done in parallel to a ditch direction, number of assortments should be reduced, as well as extraction of trees with diameter below 6 cm should be avoided.

Key words: excavator, ditch cleaning, productivity, biofuel, prime cost.

INTRODUCTION

Drainage is one of the most important forest management measure in Latvia contributing to increase of economic value of forests, sequestration of carbon from atmosphere and implementation of social functions of forests. In Latvia 32% of forests grows on drained organic or mineral soils and the improvement of soil water regime in combination of use of improved (bred) plant material, had notably and significantly improved forest productivity and financial value (Jansons et al., 2015; 2011). Forest drainage ditches may become a considerable source of solid biofuel in Latvia. According to results of the study implemented in cooperation with the Joint stock company 'Latvia state forests' (LVM) in 2012 total area of drainage ditches in fertile forest stand types in the state forests is 23 kha. The average above ground biomass of trees on drainage ditches in the fertile forest stand types is 46 tonnes ha^{-1}, and the total stock corresponds to 1.1 mill. tonnes of biomass or 5.4 mill. LV m^3 (LV – loose volume) of chips. If the extraction is repeated every 30 years the annual production capacity is 0.2 mill. LV m^3

of chips or 0.07 mill. m^3 of roundwood. Biofuel (firewood and tops) is about 23 % of the output of roundwood, respectively annual production of wood chips is 0.04 mill. LV m^3, which is about 10 % of chips delivered by the LVM directly from forest operations (Lazdiņš & Zimelis, 2012).

Excavator based harvester is not a common phenomenon in forest management in Latvia in spite this type of machines is well known in forestry since several decades, for instance John Deere produces heavy duty harvesters on tracks. Usually these harvesters are heavy (above 25 tonnes) and are more adapted to extraction of large dimension trees, which is not a case in Nordic and Baltic states (Bergroth et al., 2006). Cranes of tracked harvesters are usually massive and short (7–8 m) to demonstrate the best performance in regenerative felling. In Finland there are studies approving suitability of excavators in thinning of forests on organic soils (Väätäinen et al., 2004); however, excavators are more common in stump extraction and forest regeneration, where tracked excavators approved their reputation of durability and cost effectiveness (Laine & Rantala, 2013; Persson, 2012). Theoretically this type of the machines can be utilized also in ditch cleaning, but they are too costly to operate in conditions, where the most of output is low grade biomass and cost efficiency of the machine is critical (Lazdiņš et al., 2014).

An alternative to the expensive tracked harvester is rebuilding of standard tracked excavator into forest harvester by replacing or extending the crane, installation of a felling head and harvester control system, as well as by adding an external frame around cabin and other safety equipment. This solution costs half of a standard harvester price, but it is not commonly used in harvesting practice due to insufficient durability of standard excavators and worse working environment (mainly vibration) in the tracked machines. Ditch cleaning provides completely different working conditions in comparison to a regenerative felling or thinning – flat landscape, no large stumps, no accessibility issues. These conditions are native to excavators and to their operators providing significant advantages for broader utilization of excavators in forest operations. Smaller excavators (10–15 tonnes) with smaller felling heads can be selected for ditch cleaning; however, the reach length of the crane is still important in the ditch cleaning operations. A standard crane with extension rod (increases reach length up to 11 m) can be used instead of complete replacement of the crane. In this case the excavator can be easily adopted for different operations – digging, harvesting, soil scarification and stump extraction (Lazdiņš & Thor, 2009; Lazdiņš et al., 2014; Zimelis et al., 2015).

According to Finnish studies utilization of tracked excavators instead of standard harvesters is more beneficial than the use of standard middle size wheeled harvesters mainly due to smaller investments and operational costs. The main drawbacks are low clearance, large dimensions of machines and short crane (Väätäinen et al., 2004). The questionnaire of Finnish entrepreneurs using excavators in forest harvesting, constructing companies and producers of the equipment for harvesters resulted with the conclusion that the most important drawbacks are small driving speed (and restrictions to access certain types of roads) and problems to operate in rocky areas. However, constructing companies in Finland proposed interest about utilization of their machines in forest harvesting in winter season (Bergroth et al., 2006).

The clearance and size of the machine have no critical technical value in the ditch cleaning operations, and accessibility of the felling sites can be solved by temporal bridges from low grade roundwood assortments. The most significant benefits of excavators in the ditch cleaning operations are smaller investments and ability to use a machine for different purposes. Reduced environmental impact due to smaller pressure on a ground can be of importance; however, this issue is more related to machines utilized in forwarding of roundwood and biofuel. Ditches usually characterizes with low visibility during harvesting, which is one of the most often mentioned problem in small tree harvesting (Lazdiņa et al., 2012) and there is another benefit of excavators, because the crane is mounted beside a cabin and operator is always looking to the same direction where an operation takes place and there are no obstacles between the cabin and the felling head. Excavators are usually heavier than standard harvesters and the additional weight is another benefit, because it allows to use a crane to the maximum reach length, as well as to use accumulating function for bigger trees and in a larger distance from the machine (Zimelis & Lazdiņš, 2015).

MATERIALS AND METHODS

New Holland 215B excavator (total weight 26 tonnes) with Ponsse H7 felling head was used in trials. Accumulating function was secured by feed rollers. The machine was operated by experienced operators; however, they didn't used accumulating function before the trials. A training period of 3 days was used to adopt to the work methods. The study was implemented in drainage systems managed by Joint stock company „Latvia state forests" nearby Glāzšķūnis and Lēdmane villages. Off-road transport of roundwood was done by John Deere 810D forwarder; harvesting residues were transported by Logset F5 forwarder (no tracks was used during transportation). Forwarder operators were less experienced and demonstrated lower productivity than average in a specific conditions (Lazdiņš et al., 2014; Zimelis et al., 2015). Total extracted area 12 ha, extracted biomass – 734 m^3. Duration of the study – 4 months (May to August, 2015).

Four harvesting methods were compared in the study:

5. **full tree biofuel method** – production of standard set of roundwood assortments, harvesting residues and non-delimbed undergrowth trees (up to 6 m long) in one pile nearby or across a ditch, accumulating unit utilized for undergrowth trees not suitable for standard assortments;

6. **partly delimbed biofuel method** – production of standard set of roundwood assortments, harvesting residues and partly-delimbed undergrowth trees; harvesting residues and partly delimbed trees (up to 3 m long) in separate piles nearby or across a ditch, accumulating unit utilized for undergrowth trees not suitable for standard assortments;

7. **merged firewood and partly delimbed biofuel method** – production of standard set of roundwood assortments (excluding firewood), partly-delimbed undergrowth trees with firewood (up to 3 m long) in one pile and harvesting residues in separate pile; roundwood and biofuel is piled nearby or across a ditch, accumulating unit utilized for undergrowth trees and trees suitable for firewood production;

8. **partly delimbed firewood and undergrowth tree method** – production of standard set of roundwood assortments, harvesting residues, partly delimbed firewood, partly-delimbed undergrowth trees and harvesting residues; firewood (2.7–3.3 m long),

undergrowth trees (up to 3 m long) and harvesting residues in separate piles nearby or across a ditch, accumulating unit utilized for undergrowth trees not suitable for standard assortments and trees suitable for firewood production.

Schematic structure of the work methods is provided in Fig. 1. Assortments specific for certain method are highlighted with darker lines.

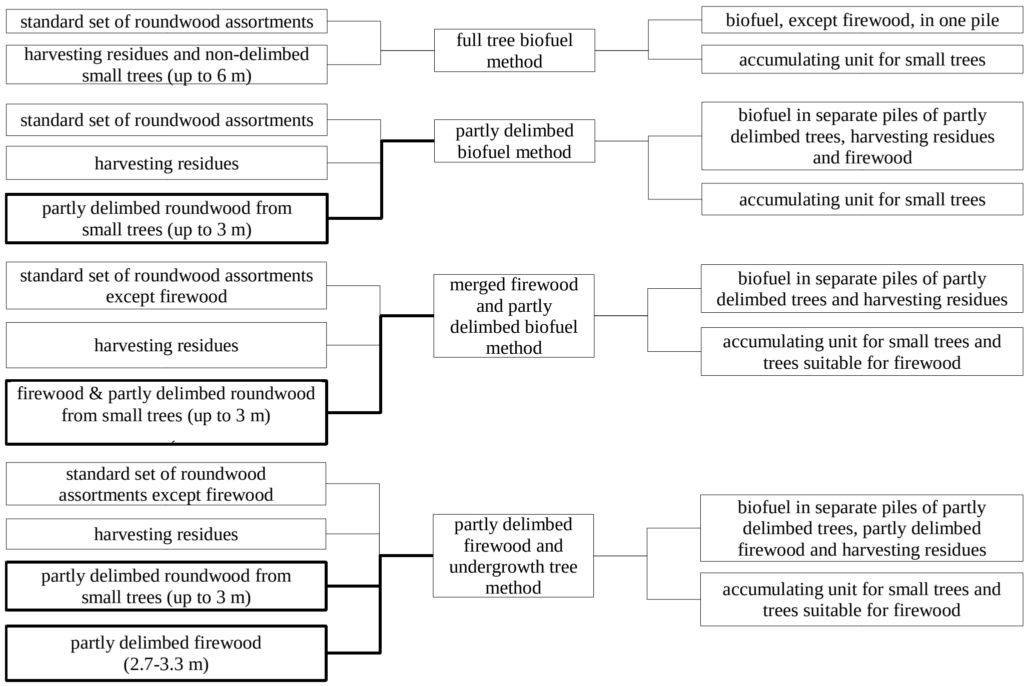

Figure 1. Schematic structure of work methods.

The 4th method is separated to utilize to a maximum extend capacity of the harvester and the accumulating unit while working with large dimension trees.

Time studies of all operations were done by the LSFRI Silava team. Calculation of prime cost was based on information delivered by dealers of New Holland, John Deere and Logset in Latvia.

Calculation of productivity and cost of biofuel is based on time studies of the harvesting and forwarding (roundwood and harvesting residues separately). Figures on productivity and cost of chipping and road transport of roundwood was borrowed from earlier studies (Zimelis and Lazdiņš, 2015).

The work time was accounted using shock- and humidity-resistant field computer Allegro CX with time tracking software SDI. During hauling, the driving speed of the forwarder was determined using GPS measurements within the SDI software. The time studies of the excavator included automated accounting of fuel consumption using an AIC-904 VERITAS unit. For other machines average values provided by the contractors were used. The work time of the machines was matched with accounting of the engine hours, i.e. the time study was stopped when the engine was switched off and resumed when the engine was started again.

The work time elements are shown in Table 1. Volume of every load forwarded to roadside were estimated by operators and verified by the harvester accounting system for every ditch.

Table 1. Work time elements in harvesting and forwarding

Harvesting		Forwarding	
Category	Explanation	Category	Explanation
Informative fields	work cycle number	Informative fields	various notes on breaks, passages, change of ditches etc.
	average diameter of gripped trees D1.3, mm	Productive work time	driving to stand
	qty. of gripped trees		reaching logs or branches when loading
	felled half-trunks		gripping logs or branches when loading
	various notes, especially on manipulations with chain or chain bar		loading logs or branches in the bunk
Productive work time	reaching tree		arranging logs or branches in bunk
	time for gripping tree		driving during loading
	cutting tree		putting logs or branches into strip-road
	drawing the trunk and placing in the assortment stack		driving out of stand
	clearing the undergrowth		reaching log or branches when unloading
	bucking the tree		
	time consumed to enter the stand		unloading logs or branches (from gripping till releasing in the yard)
	time consumed to exit the stand		gripping logs or branches when unloading
	other non-standard operations, inter alia clearing the undergrowth and machine service		moving when unloading
Non-productive time	activities not related to work		other work-related operations
		Non-productive time	activities not related to work

The ditches were surveyed before and after the operations and surrounding stands were surveyed after the operations to estimate rate of damages. Square sample plots (20 m long with a ditch dependant width, average area 400 m^2) were equally distributed across the ditch and at least 100 trees per ha were measured (species, diameter and height of about 10% of the measured trees) in the sample plots. Damages of trees were accounted in all stands across the ditches in a 20 m wide band after harvesting and forwarding of roundwood and harvesting residues.

RESULTS AND DISCUSSION

Duration of harvesting time studies was 174 hours, average productivity of harvester was 6.2 m^3 per efficient hour at the average tree volume of 0.28 m^3. The most of the produced assortments was firewood and pulp-wood (78 % in total, Fig. 2). A share of high grade logs produced in the trials was only 13 %; the most of them only 1 % from the total stock (0.6 m^3 ha^{-1}). The efficient work time (work cycles resulting with logs) was 76 % of the planned work time. The most important issue was regular problems with the chain due to lack of automatic tensioning system in the felling head.

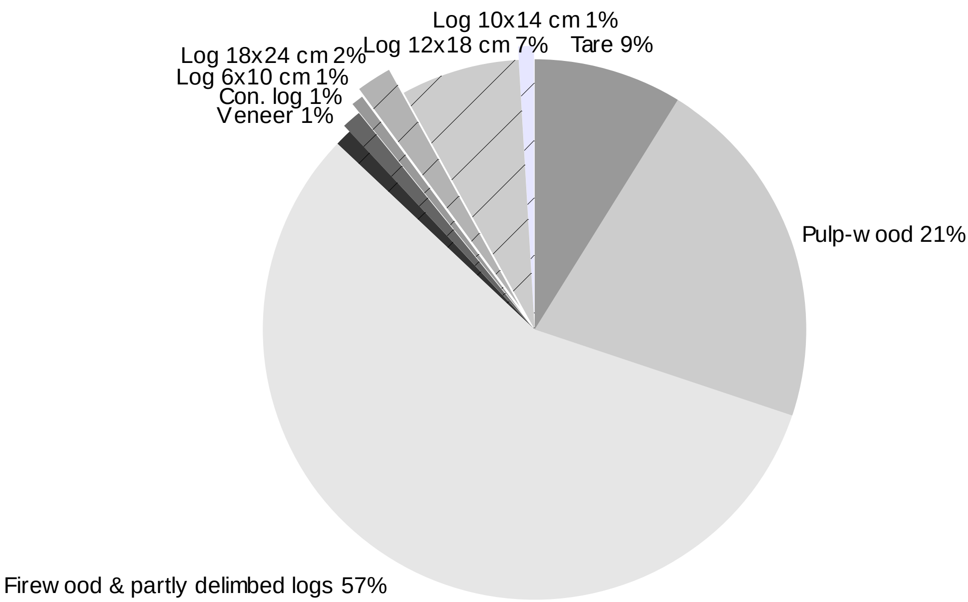

Figure 2. Structure of roundwood assortments (numbers in labels, for instance 18x24 cm, means minimum top and bottom diameter, con. log means other coniferous logs).

Productivity of harvesting depending from a diameter of extrated tree follows to a power regression (Fig. 3). Accumulating function was used mostly for trees with diameter at 1.3 m height below 8 cm; however, accumulating was used rarely.

Fig. 4 demonstrates the reason for comparably low productivity of the harvester – the most of the productive time was spent to cut undergrowth trees with diameter below 8 cm contributing to less than 10% of the produced assortments. Small trees was cut to free up space for the assortment piles and to improve visibility conditions during harvesting. Considerable improvement of the productivity, especially during forwarding, was reached when operators put logs and residues into ditches and left undergrowth trees untouched.

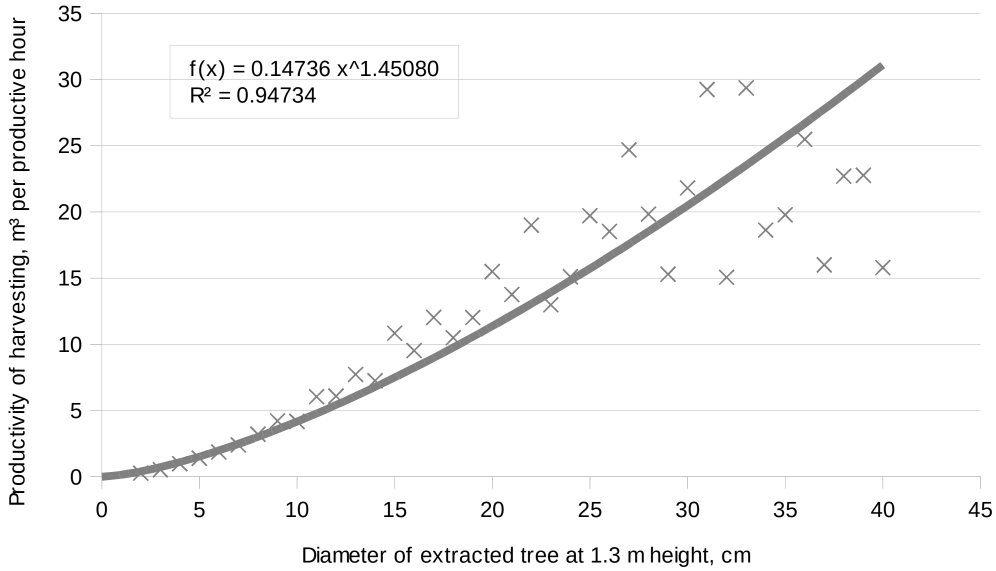

Figure 3. Average productivity of harvester.

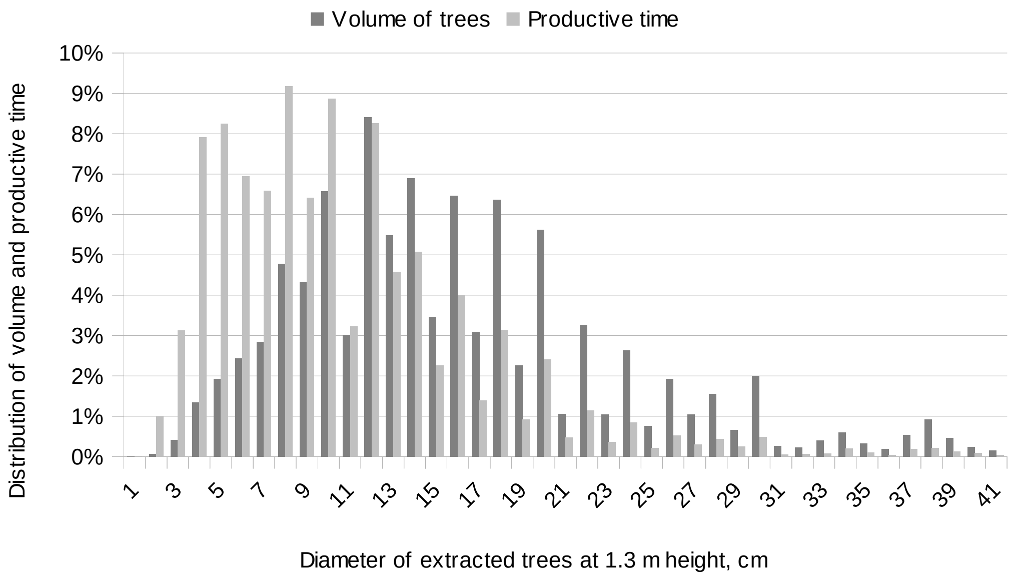

Figure 4. Distribution of productive harvesting time and volume of extracted trees.

Average fuel consumption of the harvester was 15.2 L per hour and it was not significantly affected by the work method. Higher fuel consumption in comparison to a wheeled harvester can be explained by less adaptive regulation of the engine RPM (it works with constant RPM), higher total mass of the machine and higher engine power of the excavator.

The best results were obtained using the 1st work method (full tree biofuel method); however, weighing of the results by diameter of the extracted trees approved that 3rd method (merging of firewood and partly delimbed logs) demonstrates the best performance (Fig. 5).

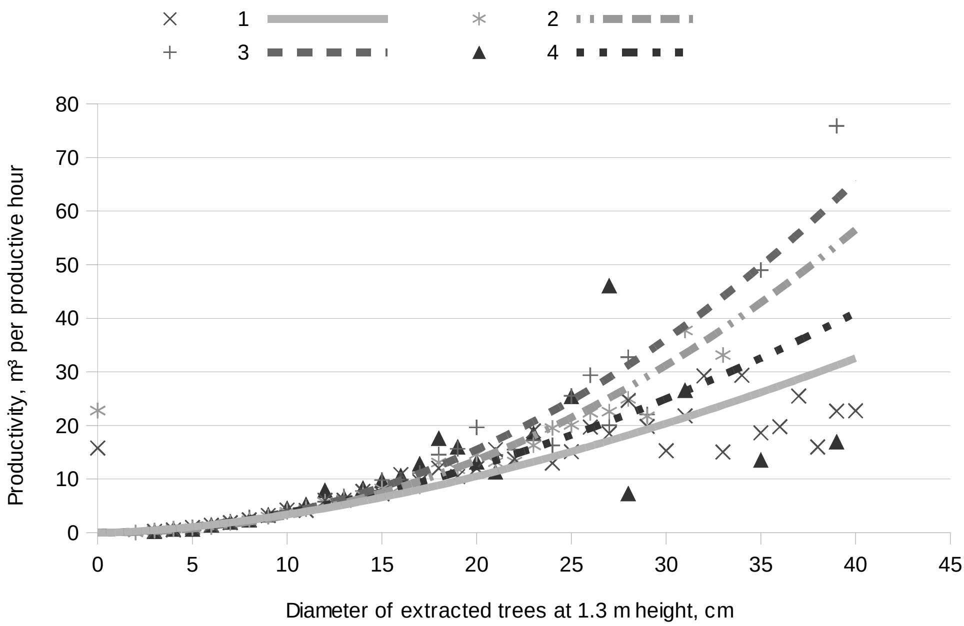

Figure 5. Harvesting productivity (m3 per direct work hour) depending from diameter of tree and work method.

During the time studies species (pine, spruce, deciduous) and dimensions of extracted trees were noted; however no statistically significant difference were found in productivity of extraction of the deciduous and coniferous trees.

Average load of roundwood in the trials was 6.9 m^3; loading took in average 49 minutes, unloading – 16 minutes, which is about twice more than in earlier trials (Lazdiņš et al., 2012). Forwarder driving speed due to excellent conditions was 175 m $min.^{-1}$, which is close to a maximum speed of the machine. The worse performance of the roundwood forwarder can be explained by lack of experience (all operations were slower) and by inappropriate work method – operators tried to make a single assortment loads instead of mixing assortiments. As a result of this approach the total driven distance was at least twice longer than it should be. Productivity of forwarding significantly decreased if 4th method was applied; however, this result is less related to the method than to other factors (dimensions of trees and driving conditions, location of assortments piles).

Average load of harvesting residues was 13 m^3 LV (loose volume), loading time 12 minutes, unloading time – 3 minutes per load. Average load of partly delimbed logs was 16 m^3 LV, loading time 20 minutes, unloading – 5 minutes per load. Operators were experienced and reduced driving distance considerably in comparison to the roundwood forwarding. Average driving speed with harvesting residues was 156 m min. and with partly delimbed logs – 188 m min.

The quality requirements in state forests proposes that the whole ditch channel should be cleaned from woody vegetation, and in our trials it was done using chainsaw. Extracted trees and bushes were piled above the harvesting residues. Time consumption to clean the whole channel was 12 hours ha^{-1} and to clean roadside only – 6 hours.

The cost and income analysis demonstrated that cash flow of mechanized ditch cleaning using the 3rd method can be positive if average extracted tree is at least 8.6 cm in diameter and the areas harvested during the study are close to this threshold (Fig. 6). Avoiding of cutting of trees with diameter below 6 or even 8 cm would increase net income considerably having at the same time negligible impact of the output of roundwood and biofuel.

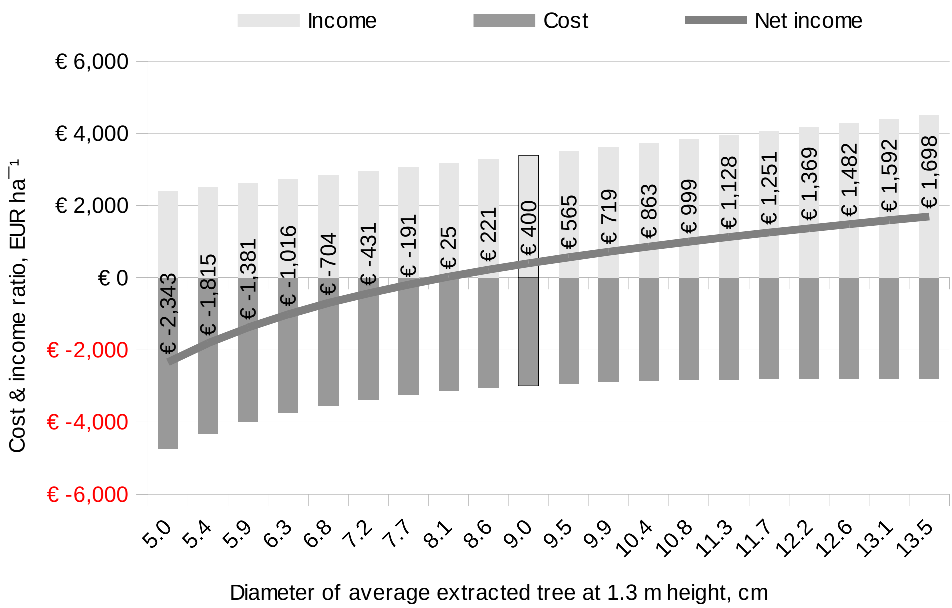

Figure 6. Ratio of harvesting cost and income.

According to the study results biofuel, including firewood, harvesting residues and undrgrowth trees contributes to 67% of the potential income if the produced biomass is sold according to the market price. Inrease of the diameter of the average extracted tree would increase the share of biofuel in the income according to the average conditions in different ditches extracted during trials; however this assumption can be wrong if the species composition is changing, for instance, if share of birch and spruce is increasing.

CONCLUSIONS

1. The study results approves hypothesis that excavator, euqipped with accumulating felling head and long crane is efficient solution for extraction of biomass from the forest drainage ditches. It is important to prioritize biofuel production in extreme harvesting conditions to secure efficient and continuous utilization of the machine, because, in contrast to other roundwood assortments, biofuel can wait in a stand for favourable forwarding conditions. In a good conditions it is reasonable to produce more valuable assortments and biofuel.

2. To reduce fuel consumption and to improve quality of the operations it is reasonably to equip the excavator with smaller felling head (Ponsse H5, Moipu 500 or similar). Significant benefit would be additional guillotine unit below the chain bar to be able to cut trees close to water level or in bad visibility conditions.

3. The fuel consumption of the excavator used in the trials was considerably higher than of the conventional wheeled harvesters (respectively, 15.2 L per hour and 9–12 L per hour); however, the impact of fuel consumption on prime cost of the production is smaller than the potential impact of work method improvements.

4. The most beneficial work method in the trials was production of the standard set of roundwood assortments, harvesting residues and merged assortment of partly delimbed logs and firewood. The whole tree harvesting method do not inceases productivity, mostly because of the tree lenght restrictions requiring to pull through the feed rollers the most of the trees.

5. Considerable increase of productivity can be reached by more intensive use of accumulating unit – for pulp wood, firewood and partly delimbed logs, and by avoiding extraction and processing of small trees and bushes (diameter below 6–8 cm). These improvement requires different bucking instructions (reduced number of assortments) and reconsidering of quality requirements for firewood, pulp-wood and tare (longer branches allowed, less restrictive rules for lenght and top diameter of logs). The changes in work method will also improve performance of roundwood forwarding.

6. It is also reasonably to reconsider quality requirements for ditch cleaning, because cutting of undergrowth trees before or after mechanized harvesting usually have no practical reasons behing. Remaining trees and bushes will hamper development of the ground-floor vegetation in ditches and will use nutriets leaching out of the surrrounding stands. The silvicultural and environmental aspests of the ditch cleaning should be evaluated further.

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REFERENCES

Bergroth, J., Palander, T. & Kärhä, K. 2006. Excavator-based harvesters in wood cutting operations in Finland. *Forestry Studies|Metsanduslikud Uurimused* **45**, 74–88.

Jansons, A., Donis, J., Danusevičius, D. & Baumanis, I. 2015. Differential Analysis for Next Breeding Cycle for Norway Spruce in Latvia. *Baltic Forestry* 21, 285–297.

Jansons, A., Gailis, A., Donis, J. 2011. Profitability of silver birch (Betula pendula Roth.) breeding in Latvia. In: *Annual 17th International Scientific Conference Research for Rural Development Proceedings*. 2, Jelgava, Latvia, pp. 33–38.

Laine, T., Rantala, J. 2013. Mechanized tree planting with an excavator-mounted M-Planter planting device. *International Journal of Forest Engineering* **2**4, 183–193.

Lazdiņa, D., Lazdiņš, A. & Zimelis, A., Lazdāns, V. 2012. Productivity of tending depending on intensity of overgrowth. In: *Mežzinātne. Special Issue. Abstracts for International Conferences Organized by LSFRI Silava in Cooperation with SNS and IUFRO*. LSFRI Silava, Riga, Latvia, pp. 134–136.

Lazdiņš, A., Kalēja, S. & Zimelis, A., 2014. Factors affecting productivity and cost of solid biofuel in mechanized forest ditch cleaning. In: *Annual 20th International Scientific Conference Research for Rural Development Proceedings* **2**, Jelgava, Latvia, pp. 90–96.

Lazdiņš, A., Lazdāns, V. & Zimelis, A. 2012. *Enerģētiskās koksnes sagatavošanas tehnoloģijas kopšanas cirtēs, galvenās izmantošanas cirtēs un meža infrastruktūras objektos* (Research report No. 3. 5.5-5.1-000p-101-12-8, Technologies for production of biofuel in thinning, regenerative felling and forest infrastructure harvesting operations). LSFRI Silava, Salaspils, 143 pp. (in Latvian).

Lazdiņš, A. & Thor, M. 2009. Bioenergy from pre-commercial thinning, forest infrastructure and undergrowth – resources, productivity and costs. In: *Annual 15th International Scientific Conference Research for Rural Development Proceedings.* Jelgava, Latvia, pp. 147–154.

Lazdiņš, A. & Zimelis, A. 2012. *Biokurināmā sagatavošanas darba ražīgumu un izmaksas ietekmējošo faktoru izpēte meža infrastruktūras objektu apaugumā* (Research report No. 3. 5.5-5.1-000p-101-12-8, Evaluation of factors affecting productivity and cost of biofue; production in forest ditch cleaning). LSFRI Silava, Salaspils, 93 pp. (in Latvian).

Persson, T. 2012. Tree stumps for bioenergy – harvesting techniques and environmental consequences. *Scandinavian Journal of Forest Research* **27**, 705–708.

Väätäinen, K., Sikanen, L. & Asikainen, A. 2004. Feasibility of Excavator-Based Harvester in Thinnings of Peatland Forests. *International Journal of Forest Engineering* **15**, 103–111.

Zimelis, A. & Lazdiņš, A. 2015. *Biokurināmā un apaļo kokmateriālu sagatavošana grāvju trašu apaugumā ar mežizstrādes darbiem aprīkotu ekskavatoru* (Research report No. 2015/16, Production of biofuel and roundwood assortments with excavator adopted for the forest operations). LSFRI Silava, Salaspils, 78 pp. (in Latvian).

Zimelis, A., Lazdiņš, A., Spalva, G. & Saule, G. 2015. Results of evaluation of different methods and technologies of solid biofuel production in ditch cleaning harvesting operations. In: *Proceedings the International Scientific Conference Knowledge based forest sector*, Riga, Latvia, p. 29.

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Determination of the physical properties of different types of milk claws and air leaks in the claw according to rotameter-milk bucket methods

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Abstract. In this study, physical properties (internal volumes, weight and the diameters of the hole in the milk and pulse tubes) of eighteen different types of milk claws which are one of the significant components of milking machine and the amount of air leaks in the claws were examined according to the flow meter (rotameter) and milk bucket experiment methods. 'L' type milking claw was 70 ml in volume which was lower than the standard minimum volume of 80 ml, however, others were higher. Five of the claws ('C', 'D', 'E', 'H' and 'Q' types of claws) were lower than 500 g, the minimum recommended standard for weight. Internal diameters of the short milk tube of the claws were between 5.5 and 10.8 mm. Internal diameters of all but one of the claws' main milk output tubes (with a diameter of 11. 9 mm in 'L' type) were under the minimum diameter (12.5 mm).

In experiments conducted with rotameter, the values of the leaking of the claw tap were between 0.0 and 11.0 l min^{-1}. Air leakages of twelve claws ('A', 'C', 'E', 'F', 'H', 'I', 'J', 'K', 'L', 'N', 'P' and 'R' types of claws) were below the standard maximum level of 2 l min^{-1}. The amounts of leaks in the tap of claws were between 0.0 and +14 l min^{-1}. Ten milk claws in here ('A', 'B', 'C', 'D', 'F', 'G', 'M', 'O', 'P' and 'R' types of claws) did not meet the minimum and maximum flow rates. The total amounts of air leak in the claws in the experiments performed with a milk bucket were between 4.1 and 33.9 l min^{-1}. Although the calculated amount of total air leak in all the claws was above the recommended minimum amount (4 l min^{-1}), eight claws ('B', 'C', 'D', 'E', 'H', 'J', 'K', and 'O' types of claws) exceeded the maximum limit (12 l min^{-1}).

Key words: Milking machine, milk claw, claw physical properties, rotameter, milk bucket, claw air leak, free air intake hole leakage.

INTRODUCTION

Milk claw is an element that ensures the collection of the milk in milking machines coming from milking cluster to milk bucket or milk pipeline. Claw generally consists of a vacuum inlet coming from the pulsator, the section that transmits the vacuum to teatcup, the inlet of the milk coming from the teatcupliner, the output that ensures the transmission of the milk to the milk bucket or pipeline, and the claw valve that is used in order to stop the flow of the milk when necessary. The body of the milking claw generally consists of plastic and stainless material, and the upper part is made of transparent plastic. The short milk and pulse tubes between the milking claw and teatcup liner are made of rubber, and the tubes between the milking claw and the main milking tube are made of PVC. Today, the volume of the milking claw may be of different capacities depending on milk yield. While the claw capacity depends on the milk yield of the animal, tube with a small volume are preferred in bucket milking machines, and tube with a large volume are preferred in pipeline milking machines (Akam et al., 1990; Mein, 1992; Unal, 2013).

Commercially, the weight of the existing milking cluster varies between 1.6 and 3.5 kg. The weight of the milking clusters used in New Zealand may usually be between 2.2 and 2.6 kg. The real benefit of the milking cluster is that it ensures that the milk is discharged in a short time with the pressure effect it applies on the teat of the animal. However, the increase in the weight of the milking cluster has disadvantages such as the tiredness of the milker, slipping of the teatcup liners, falling off the teat-end, and damaging the teat-end. The optimum weight selection is generally determined by the type of teatcup liner used and the vacuum setting preferred (Dairynz, 2015).

According to ISO 5707, the total air inlet per each milking cluster is suggested as at least 4 l min^{-1} in order to allow effective milk transmission through the claw and prevent the additional mixing of the milk in the claw. This value should not exceed 12 l min^{-1} for cows and buffalos, and 8 l min^{-1} for sheep and goats in a nominal working vacuum. When the vacuum closing valve of the milking claw is in off position, the free air flow into the long milk tube should not be higher than 2 l min^{-1}. The leaktightness of the vacuum closing valve of claw is important when removing the milking cluster. If the claw valve is not or cannot be closed well when the milking ends, the milking clusters are removed by pulling manually as its vacuum effect on cluster will continue (as the valve fails to cut the vacuum completely). This is an unwanted situation for the milking technique. Furthermore, the free air flowing from the valve leads to the failure to obtain enough vacuum in the claw and teat-end. Thus, all air holes leakages on the claw should be positioned so as to prevent unnecessary turbulence in the milk in order to prevent free fatty acid formation during milking. There is an air inlet hole with a diameter of approximately 0.8 mm on the claw in order to facilitate that milk is transmitted to the bucket or pipeline from the long milk tube. Constant air inlet is ensured from this hole on the claw (ISO 3918, 1996; Bilgen & Oz, 2006; Unal 2013; TS ISO 5707, 2014; TS ISO 6690, 2014; Dairynz, 2015).

In the research conducted, no comprehensive study was encountered on the air leakage amounts of the claws both by physical properties and flow meter (rotameter) and bucket experiment methods of different types of milk claws in our country and the world.

The objective of this study was to determine certain physical properties (internal volumes, weights, milk and pulse tubes hole diameters) that are accepted as effective elements on the milking performance and milk quality of eighteen different types of milk claws that are locally produced and used all around the world and the air leakage amounts of the claws by rotameter–bucket methods (claw valve leaktightness, amount of claw valve leakage, total amount of air leakage passing through the claw and the amount of air entering the claw free inlet hole).

MATERIALS AND METHODS

Eighteen different types of milking claws used in bucket and pipeline milking machines and facilities were investigated in this study (Fig. 1).

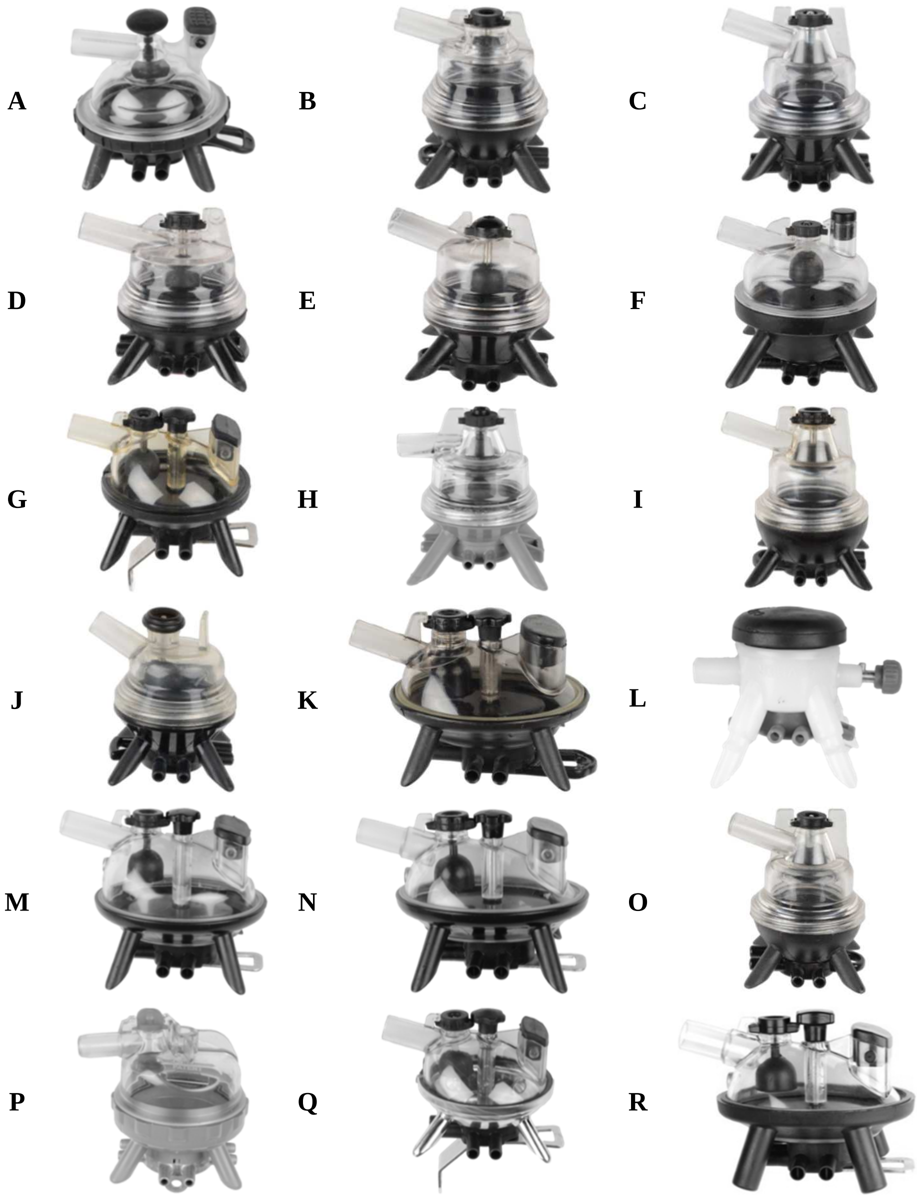

Figure 1. Eighteen different types of milking claws used in the research.

The internal volumes, weights (milking claw and milking cluster as a whole), the internal diameters of short milk inlet and main milk output tubes and the internal diameters of short and long pulse tubes were measured respectively in order to reveal the physical properties of the milking claws. The capacities of the claws were determined in accordance with the amount of water filled into their internal volume. For this, the openings of four short milk inlet tubes of the milking claw were closed hermetically, and water was filled in the claw from the opening of the main milk output. At that moment, the claw valve was kept in the open position and the rubber tab was kept on the claw at a tight contact. The water that was filled at claw capacity was then poured into a container with levels with a capacity of 500 ml, and the volume of the claw was found in millilitres (ml). The weights of the claws were weighed using scales with a sensitivity of 1 g (Baster B 150, Capacity: 15 kg, İzmir, Turkey) as a milking cluster only on the claw and the whole claw. The milk and pulse tubes internal diameters of the claws were measured with a digital calliper (Mitutoyo, CD-15CP, USA) with a sensitivity of 0.01 mm.

In this research, a vacuum pump with an air capacity of 200 l min^{-1} (1,425 rpm and 50 kPa working vacuum) with a direct connection to the electricity motor of 0.55 kW for the vacuum production necessary for the measurement of milking claw air leakage was used. The vacuum pump was adjusted to nominal vacuum pressure (50 kPa) throughout the works.

Flow meter and a stainless steel milk bucket with a volume of 20 l were used for the leaktightness of the claw valve, and the leakage amount measurements of free air inlet hole in this study. The rotameter (Flowmeter, AGL 19, Medition,Spain) has a flow measurement interval between 0.0–14.0 l min^{-1} and a measurement sensitivity of 1.0 l min^{-1}. The vacuum changes in the measurements made with the bucket were monitored with a digital vacuum meter (DVPM-01 Digital Vacuum Pressure Meter, Medition, Vacuum and Pressure Range 0–100 kPa) with the sensitivity of 0.1 kPa, and the pressure change periods were monitored on digital chronometer.

The claw vacuum closing valve leaktightness is the unwanted air leakage entering from the claw valve. This leakage measurement is determined only through the rotameter (Bilgen & Oz, 2006). For the measurement, the rotameter device was connected to the milking claw with the long milk tube on the one side, and to the vacuum line with a secondary tube on the other side. The claw vacuum closing valve leaktightness was measured when the milk inlets of the claw were open, and the claw valve was in the closed position (Fig. 2). The free air inlet from the claw valve in off position to the long milk tube should not be higher than 2 l min^{-1} (Bilgen & Oz, 2006; ISO5707, 2014; ISO6690, 2014).

The free air inlet in the claw is defined as the amount of air entering through the constant air inlet hole on the claw when the claw valve is in on position. Two methods for the measurement of the amount of air inlet in standards and researches are as follows (Bilgen & Oz, 2006; TS ISO 5707, 2014; TS ISO 6690, 2014). The first method is the measurement using rotameter, and the second is the measurement using bucket. According to the first method, the rotameter is connected to the milking claw with the long milk tube from its bottom end, and tothevacuumline with a second milk tube on the upper end. In the experiments, the teatcup liners of milking claws were removed and milk tubes each cut in 10 cm height were placed there. Air leaktightness was ensured by covering one side of milk tubes with silicone (Figs 2, 3). An operation vacuum was formed in the system by operating the vacuum pump, and the claw valve was opened. Meanwhile, the amount of air passing through the rotameter was observed. This value was recorded as '*the total amount of air leakage (l min^{-1})*' entering the claw. Then the value read in the rotameter by closing the free air inlethole on the milking claw was recorded as '*the claw valve leakage amount (l min^{-1})*'. The difference between the two measurements gave '*the amount of air leakage entering the free air hole (l min^{-1})*'.The pulsation was deactivated when applying these measurements.For this, long binary pulse tubes connected to the milking claw were removed. There are no free air inletholes on eight milking claws ('B', 'C', 'E', 'F', 'I', 'J', 'L' and 'O' type claws) within the scope of the research.

The second method is the measurement made using the milk bucket. According to this method, stainless steel milk bucket with a volume of 20 l with air leaktightness was used. The cover of the milk bucket is again made of stainless steel, and it has three milk–air output tubes. One of the output tubes was connected to the vacuum line with the long milk tube. A ball valve was placed on vacuum line connection. And the connection was made to the milking claw with a second milk tube. The third output tube on the bucket cover was additionally connected to the vacuum meter with an air tube (Fig. 3). After achieving the system operation vacuum pressure in the system, the ball valve was closed, and the chronometer was operated at the same time. The period that passes for the vacuum reduction of 10 kPa was detected. The time that passes for the vacuum change of 10 kPa was measured according to the following parameters:

1. The total amount of air leakage entering the claw (milk inlets are in off, and free air inlethole and claw vacuum closing valve are in on position),
2. The amount of air leakage entering the claw valve (milk inlets and free air inlethole are in off, and the claw vacuum closing valve is in on position),
3. The amount of air leakage entering the free air hole (found using the difference between the first and second measurements).

The following equation was used in order to calculate the amount of air leakage in the claw by the time measurements obtained (Bilgen & Oz, 2006):

$$q = \frac{6V}{T} \tag{1}$$

where: q – air leakage amount in the claw, l min^{-1}; V – Bucket volume, l; T – the time, that passes for a vacuum decrease of 10 kPa, s.

The measurement parameters obtained from rotameter and bucket methods were applied in three repetitions for each milking claw.

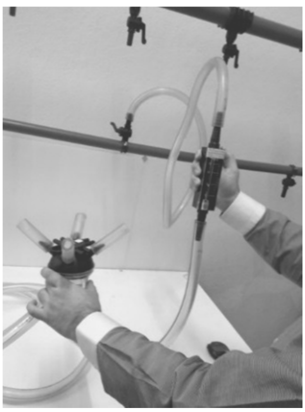

Figure 2. Experimental look made with the rotameter.

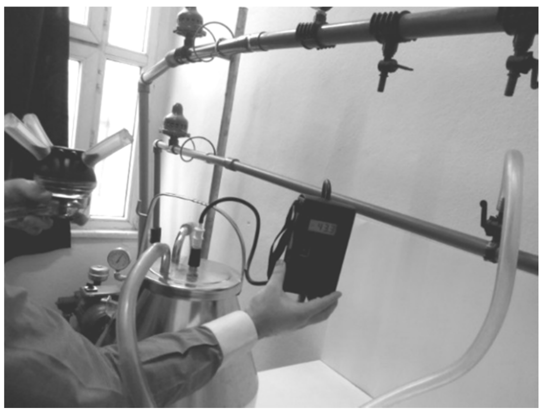

Figure 3. Experimental look made with the milk bucket.

In the experiments conducted with rotameter and bucket, the total amount of free air flow that enters through the free air inlethole and claw valve by air leakage should not be over 12 l min^{-1}. On the other hand, the free air inlet in total should be at least 4 l min^{-1} at nominal vacuum pressure. Otherwise, when the vacuum closing valve of the milking claw is off position, the free air flow into the long milk tube should not be higher than 2 l min^{-1} (Akam et al., 1990; ASAE Standards, 1998; Bilgen & Oz, 2006; TS ISO 5707, 2014; TS ISO 6690, 2014).

RESULTS AND DISCUSSION

Physical measurement results of milking claws

The measurement results regarding the capacities (internal volumes), weights and internal diameters of milk and pulse tubes of milking claws are given in Table 1. Examining the capacities of milking claws in Table 1, it has been determined that the milking claw of 'L' type has the lowest capacity of 70 ml and the milking claw of 'P' type has the highest capacity of 475 ml. With its volume, the milking claw of 'L' type has been found to be fewer than 80 ml, which is the minimum recommended capacity in the literature (Akam et al., 1990). On the other hand, in another study, it is suggested that the volume of a claw should be at least 150 ml (Dairynz, 2015). According to Dairynz (2015), it has been stated that the capacity of a milking claw should be at least 150 ml in order to keep animal teat-end under stable vacuum, prevent cross-flow in the claw and, contamination and liner slip between quarter milk entries in the claw. In accordance with the quantity stated, the milking claw of 'J' type has been identified to have a volume, which is close to this limit. All of the claws, except the claw of 'L' type, have provided the minimum amount required.

When the weights of the milking claws were measured, it was determined that 'H' type claw has the lowest weight with 237 g, and 'P' type claw has the highest weight with 729 g (Table 1). Although no weight limit is specified in TS ISO 5707 (2014) and TS ISO 6690 (2014) standards for the weight of the milking claw alone, it was reported by Akam et al. (1990) that the milking claws should be at least 0.5 kg and the milking cluster should be approximately 2.5 kg. In another study, it was reported that the weights of milking cluster as a whole may vary between 1.6 and 3.5 kg (Dairynz, 2015). According to Dairynz (2015), it was reported that commercial milking cluster in New Zealand is frequently between 2.2 and 2.6 kg. The weights of type 'C', 'D', 'E', 'H' and 'Q' milking claws within the scope of this research were found fewer than 0.5 kg, which is supposed to be, and the other claws are above this amount. And in the milking cluster weight measurements, it was found that the milking claw of 'H' type has the lowest weight with 1,730 g, and 'P' type claw has the highest weight with 2241 g. As it is seen in Table 1, 'C', 'D', 'E', 'H' and 'Q' type milking claws remained below 2 kg. Although these weights are within the limits of 1.6 and 3.5 kg specified in Dairynz (2015), all milking claws other than 'P' type milking claw were found fewer than the 2.2–2.6 kg values given in New Zealand example of the same literature. Furthermore, the weight of approximately 2.5 kg reported by Akam et al. (1990) was not ensured by any milking cluster within the scope of this research. The weight of the milking cluster is important, and the requested weight is directly related to the design of teatcup liner and milking claw. A too light milking cluster may lead to incomplete milking as it will create pressure on the teat-end of the animal, and too heavy milking cluster may lead to the fall off from the teat-end of the animal during milking (Akam et al., 1990).

Table 1. Some physical properties of eighteen different types of milking claws used in the research

Claw type	Claw volume, ml	Claw weight, g	Milking cluster weight, g	Short milk tube internal diameter, mm	Main milk tube internal diameter, mm	Pulse tube internal diameter, mm
A	225	531	2,081	10.8	15.7	8.0
B	170	578	2,090	7.7	12.6	6.9
C	175	404	1,916	7.0	12.7	8.4
D	170	478	1,976	7.5	13.6	5.7
E	185	423	1,935	8.8	13.1	5.7
F	320	514	2,000	7.9	15.7	6.3
G	235	564	2,076	8.6	16.3	7.4
H	180	237	1,731	5.5	13.0	5.5
I	185	551	2,162	7.4	13.7	6.3
J	155	507	2,019	7.5	13.5	6.5
K	215	588	2,100	7.7	13.9	7.6
L	70	531	2,106	7.3	11.9	5.5
M	350	556	2,068	8.4	15.9	7.6
N	240	554	2,066	8.4	14.0	7.9
O	160	582	2,094	7.6	13.3	6.9
P	475	729	2,241	5.5	13.5	5.5
Q	250	447	1,959	7.5	16.0	8.0
R	240	550	2,088	7.8	16.5	7.8

The minimum measures for the internal diameters of short milk, main milk, short pulse and long pulse tubes are specified in standards and different sources (Akam et al., 1990; TS ISO 5707, 2014). Accordingly, it is required that the internal diameter of short pulse tube should not be lower than 6 mm (5 mm according to Akam et al., 1990), and the internal diameter of the long pulse tube should not be lower than 6 mm in bucket milking machines and 7 mm in pipeline milking systems. Starting from the principle that the internal diameter values specified should also be the same in milking claws, the assessments were made in accordance with this principle.

The internal diameters of the short milk tubes of only five milking claws ('A', 'E', 'G', 'M', and 'N' type claws) fit the rule of being at least 8 mm. The internal diameters of the short milk tubes in these claws vary between 8.4 and 10.8 mm. The internal diameters of short milk tubes in 'H' and 'P' type claws were found to have quite a low value of 5.5 mm. The other eleven milking claws remained below the value indicated in the literature with the internal diameter values between 7.0 and 7.9 mm (Table 1).

The main milk tube internal diameter measures of the claws were found to be between 11.9 and 16.5 mm (Table 1). As it is seen in the Table, the internal diameters of all the claws except for the 'L' type claw were measured below the minimum limit of 12.5 mm that is requested.

The short pulse and long pulse tube of all claws in our study were made of the same measures. Thus, the assessments were made in accordance with the common values. The internal diameters of the pulse tubes of the claws were detected to be between 5.5 and

8.0 mm (Table 1). As it is seen in the Table, the pulse tube internal diameters of type 'D', 'E', 'H', 'L', and 'P' milking claws were found below the internal diameter value of minimum 6 mm specified in the standards (TS ISO 5707, 2014). On the other hand, it was determined that the short pulse tube diameter of the claws is above the limit of 5 mm, which is reported by Akam et al. (1990).

Rotameter measurement results

Claw closing valve leakage amounts

Claw valve leaktightness results measured with rotameter are shown in Fig. 4. As it is seen in the figure, air leakage between 0.0 and 2.0 l min^{-1} was measured in the on position of the milk inlets in the claw and off position of the vacuum plug in twelve milking claws ('A', 'C', 'E', 'F', 'H', 'I', 'J', 'K', 'L', 'N', 'P', and 'R' type claws). According to the principle of '*the free air entry from the claw valve in off position to the long milk tube side should not be higher than 2 l min^{-1} value*' reported by Bilgen & Oz (2006), claw valve leakage above the permissible limit occurred in six milking claws ('B', 'D', 'G', 'M', 'O' and 'Q' type claws). The amount of air leakage measured in the vacuum closing valve of these valves was found between 2.3 and 11.0 l min^{-1}.

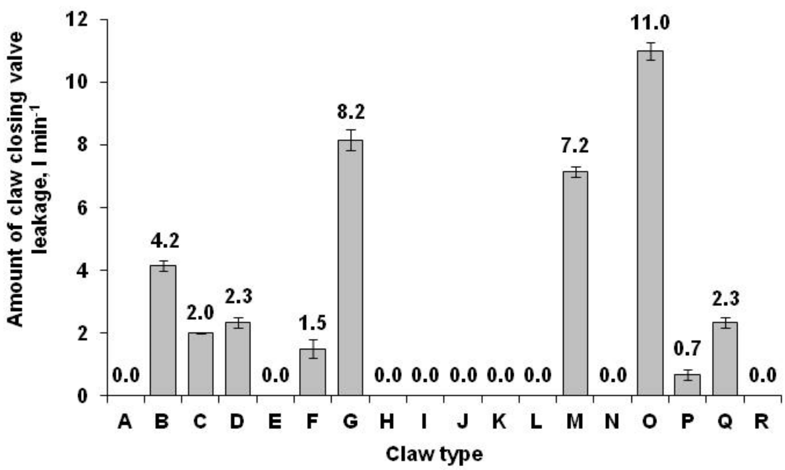

Figure 4. Amount of claw closing valve leakage measured with rotameter in different types of milking claws (claw milk inlets are open, and claw vacuum closing valve is in off position).

Total amount of air leakage entering the claw

The total amount of air leakage measured in the rotameter when claw milk inlets are in off and the claw valve and free air inlethole are in on position is shown in Fig. 5. As it is seen in the figure, it was determined that there is air leakage above 12 l min^{-1}, which is the maximum limit in three claws ('B', 'C', and 'H' type claws). On the other hand, 'F', 'G', and 'N' type milking claws were also found lower than the lower limit (4 l min^{-1}) withthe values between 1.8 and 3.8 l min^{-1}. The other twelve milking claws gave air leakage between minimum and maximum limits.

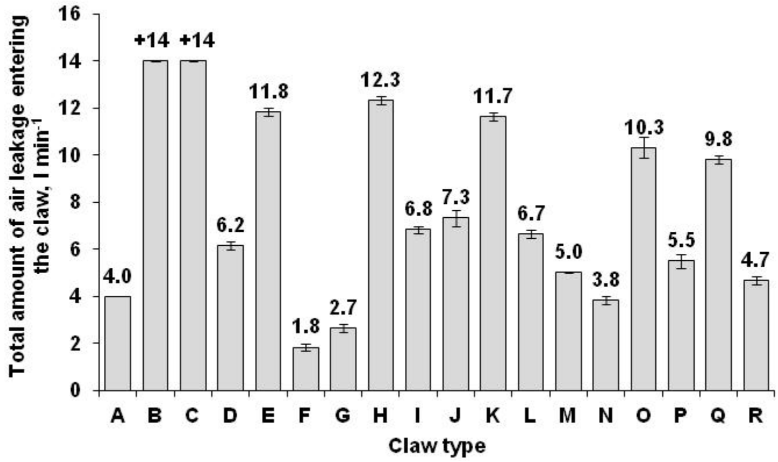

Figure 5. Total amount of air leakage entering the claw that is measured with rotameter in different types of milking claws (claw milk inlets are in off, and free air inlethole and claw valve are in on position).

Claw leakage amounts when the free air hole of the claw is in off, and the claw valve is in on position

Claw valve leakage amounts measured from the rotameter when claw milk inlets and free air inletholes are in off and the claw valve is in on position are shown in Fig. 6. As it is seen in the figure, the values measured from two claws ('B' and 'C' type claws) rose to 14 l min^{-1}, which is the maximum measurement limit of the rotameter. It was seen that the leakage amount of these two claws highly exceeded the upper limit of 12 l min^{-1} that is required.

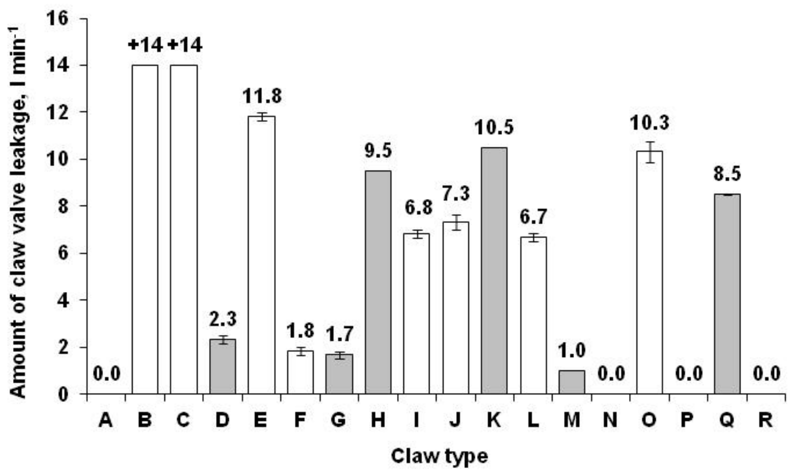

Figure 6. Amount of claw valve leakage measured with the rotameter in different types of milking claws (claw milk inlets and free air inlet hole are in off, and the claw valve is in on position).

Furthermore, the minimum air leakage amount that must be given by eight milking claws ('A', 'D', 'F', 'G', 'M', 'O', 'P', and 'R' type claws) was also found lower than the lower limit of 4 $lmin^{-1}$. Here, it is understood that in case ten free air inletholes mentioned above become congested or do not exist at all, the permissible amount of air leakage cannot be fulfilled. Thus, whether the claw free air holes are open should be checked before each milking. As it is explained in the method section, it was seen that eight milking claws ('B', 'C', 'E', 'F', 'I', 'J', 'L', and 'O' type claws) were produced without free air inlet hole. As it is seen in the figure, 'B', 'C', and 'F' type claws could not fulfill the minimum and maximum conditions.

Amounts of air leakage entering the claw free air inlethole

The amount of free air leakage allowed by ten different types of milking claws with claw free air inletholes is shown in Fig. 7. As it is seen in the figure, the amount of air passing through the free air hole of ten claws varies between 1.0 and 5.5 l min^{-1}. These values are the difference of the values in Figs 5, 6. The amount of air that constantly passes through the free air hole is important as it affects the minimum and maximumamount of air that must pass through the claw in total. When the figure is examined, only four ('A', 'M', 'P', and 'R' type claws) among ten claws allowed the leakage above the minimum limit. The amount of air passing through the free air holes of these claws was found between 4.0 and 5.5 l min^{-1}. The amount of air leakage of the remaining six claws was found to be lower than 4 l min^{-1}, which is the lower limit. These claws failed to fulfill the minimum amount of free air.

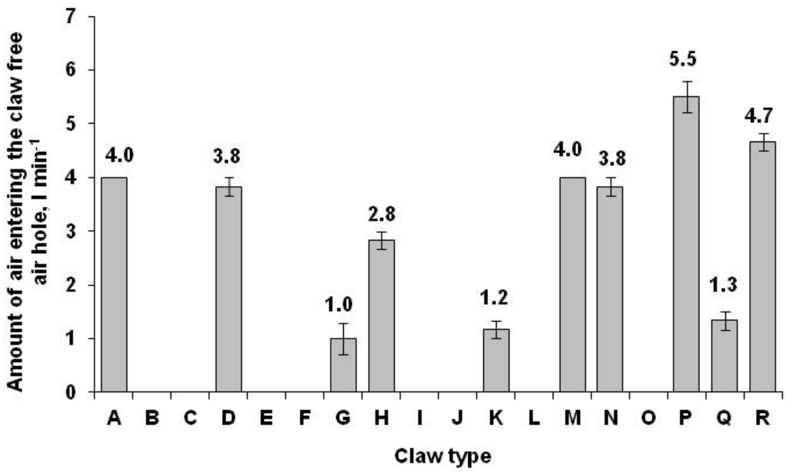

Figure 7. Amount of air entering the claw free air hole measured with rotameter in different types of milking claws (claw milk inlets and free air inlethole are in off, and the claw valve is in on position).

Bucketmeasurement results

A study was carried out with milk bucket as an alternative to claw air leakage measurements performed with a rotameter. According to the parameters given in the method section, the period measured for a vacuum change of 10 kPa in a bucket with a volume of 20 l is shown in Table 2. As it is seen in the table, the least duration for a vacuum change of 10 kPa in the 1st measurement parameter was measured (3.54 s) in 'K' type claw, while the longest duration was measured (29.50 s) in 'G' type claw. On the other hand, the shortest duration for a vacuum change of 10 kPa in the second measurement parameter was again measured (4.21 s) in 'K' type claw, while the longest duration was measured (70.11 s) in 'Q' type claw. The first and second measurement periods obtained from milking claws were put in their place in Equation [1] and given in Figs 8–10 by converting them to the amount of air leakage.

Table 2. The duration that passes for 10 kPa vacuum change according to the bucket experiment

Claw type	Measurement parameters	
	Time of first parameter[1], s	Time of second parameter[2], s
A	10.50 ± 0.40	20.29 ± 1.48
B	5.77 ± 0.36	~[3]
C	7.38 ± 0.33	~
D	9.12 ± 0.36	15.38 ± 0.63
E	7.93 ± 0.43	~
F	23.11 ± 1.29	~
G	29.50 ± 0.97	39.26 ± 1.54
H	5.85 ± 0.24	7.00 ± 0.21
I	14.13 ± 1.05	~
J	8.01 ± 0.56	~
K	3.54 ± 0.05	4.21 ± 0.25
L	22.56 ± 0.59	~
M	11.25 ± 0.19	22.37 ± 0.42
N	20.14 ± 2.02	65.61 ± 2.86
O	7.32 ± 0.17	~
P	25.77 ± 1.85	47.94 ± 7.30
Q	15.21 ± 0.54	70.11 ± 0.69
R	11.32 ± 0.50	19.32 ± 0.24

[1]First parameter: Claw milk inlets are in off, and the free air inlethole and claw valve are in on position; [2]Second parameter: Claw milk inlets and free air inlethole are in off, and claw valve is in on position; [3]No free air inlet hole; ± Standard deviation.

Total amount of air leakage entering through the claw

The total amount of air leakage passing through the claw for a vacuum change of 10 kPa when claw milk inlets were in off and the free air inlethole and claw valve were in on position in bucket experiment is shown in Fig. 8. As it is seen in the figure, the total amount of air leakage entering eight claws ('B', 'C', 'D', 'E', 'H', 'J', 'K', and 'O' type claws) exceeded the maximum limit value (12 l min^{-1}). Nevertheless, the total amount of air that should pass through all claws as a minimum was determined above 4 l min^{-1} that is provided for the lower limit. Here, it was concluded that eight claws gave leakage above the upper limit although the minimum amount of air that should pass through all claws is sufficient.

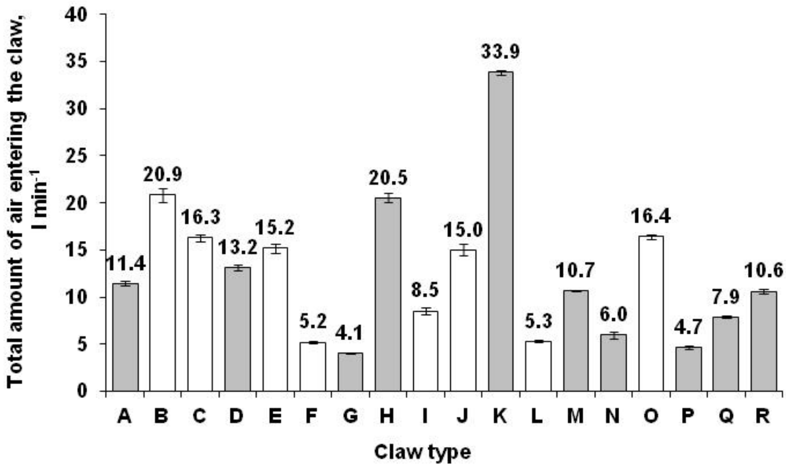

Figure 8. Total amount of air entering the claw that is measured with bucket in different types of milking claws (claw milk inlets are in off, and free air inlethole and claw valve are in on position).

Amount of claw leakage when the claw free air hole and claw valve are in on position

Claw valve leakage amounts calculated from bucket measurement when the milking claw is on and free air inlethole is in off position are shown in Fig. 9. As it is seen in the figure, data obtained from seven claws ('B', 'C', 'E', 'H', 'J', 'K', and 'O' type claws) exceeded the maximum air limit (12 l min^{-1}). On the other hand, four claws ('G', 'N', 'P', and 'Q' type claws) gave leakage below the minimum limit that must be with values between 1.7 and 3.1 l min^{-1}. As it is seen in the figure, five of eight different milking claws ('B', 'C', 'E', 'J' and 'O' type claws) with no free air inlethole (claws with white columns) gave leakage above 12 l min^{-1}.

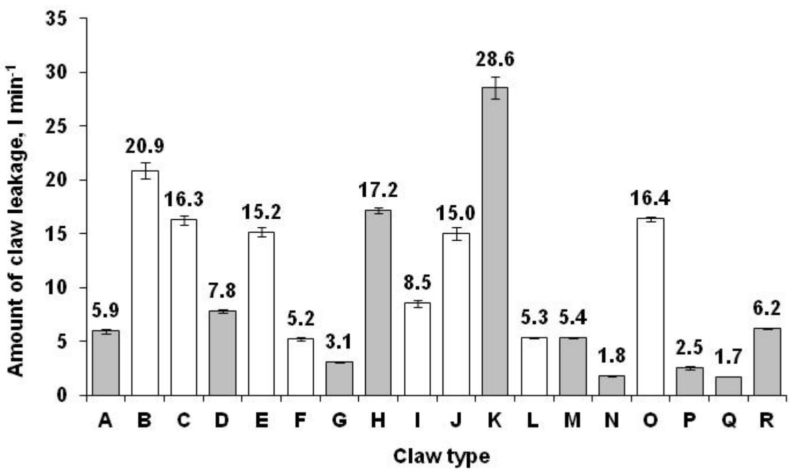

Figure 9. Amount of claw leakage measured with bucket in different types of milking claws (claw milk inlets and free air inlethole are in off, and the claw valve is in on position).

Amount of air leakage entering the free air hole of the claw

The amount of free air leakage allowed by ten different types of milking claws with free air inletholes is shown in Fig. 10. As it is seen in the figure, the amount of air passing through the claws with free air holes varies between 1.0 and 6.2 l min^{-1}. These values are the difference of the values calculated in Figs 8, 9. As it is also specified in the sectionof measurement with rotameter, the minimum and maximum limits of the amount of air that must pass through the free air inlethole are not specified in standards and other studies. However, the amount of air passing through the free air hole is important as it affects the minimum and maximum amount of air that must pass through the claw in total. Upon examining Fig. 10, the amount passing through the free air hole of 'G', 'H' and 'P' claws was found in the values of 1.0, 3.4 and 2.1 l min^{-1}, respectively. These values were found to be lower than the total amount of minimum 4 l min^{-1} that should pass through the claw. Here, it was seen that 'G', 'H' and 'P' type claws did not fulfill the minimum amount of air.

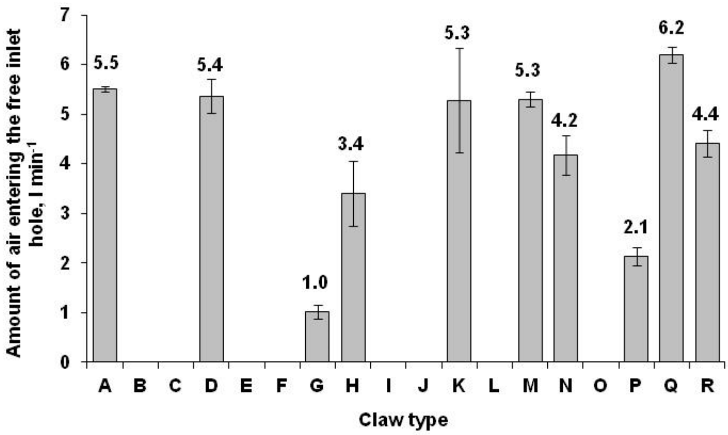

Figure 10. Amount of air entering the free air inlethole measured with bucket in different types of milking claws (claw milk inlets and free air inlethole are in off, and the claw valve is in on position).

CONCLUSIONS

Claw air leakage results are summarized below by the physical properties applied to eighteen different types of milking claws within the scope of the research, the methods of rotameter and bucket:

- Only the 'L' type claw among the milking claws was found below the minimum volume limit (80 ml) with 70 ml.
- It was determined that the weight of five of the milking claws ('C', 'D', 'E', 'H', and 'Q' type claws) was found below 0.5 kg, which is the minimum limit, and other claws are above this amount.
- The internal diameters of the short milk tube of only five of the claws ('A', 'E', 'G', 'M', and 'N' type claws) fulfilled the minimum 8 mm rule.

- The internal diameters of the pulse tube of 'D', 'E', 'H', 'L' and 'P' type claws were found below the internal diameter value of minimum 6 mm specified in the standards.
- In the claw valve leaktightness experiment carried out with rotameter, the claw closing valve leakage amounts of twelve claws were measured between 0.0 and 2.0lmin^{-1}, and it was determined that six claws exceeded the limit of 2.0 lmin^{-1}.
- In the experiments conducted usingrotameter, it was observed that the total amount of air leakage of six claws ('B', 'C', 'F', 'G', 'H', and 'N' type claws) remains outside the lower limit (4 l min^{-1}) and upper limit (12 l min^{-1}).
- According to the rotameter experiment, it was seen that only four of ten claws ('A', 'M', 'P', and 'R' type claws) with free air inletholes fulfilled the minimum amount of air leakage.
- In the experiments conductedwith the bucket, it was determined that the total amount of air leakage of eight of the milking claws ('B', 'C', 'D', 'E', 'H', 'J', 'K', and 'O' type claws) exceeds upper limit (12 l min^{-1}). On the other hand, it was determined that the minimum total amount of air leakage of all of the milking claws exceeds 4 l min^{-1}, which is provided for the lower limit.
- According to the bucket experiment, only three of ten claws ('G', 'H', and 'P' type claws) with free air inletholes have a minimum amount of air leakage below the lower limit of 4 l min^{-1}.

These results have shown that the quality and sensitivity required in the design and production of the milking claws used in bucket and pipeline milking machines has not yet been achieved.

REFERENCES

Akam, D.N., Dodd, F.H. & Quick, A.J. 1990. Milking, milk production hygiene and udder health (Milking machines and equipments). Food & Agriculture Organization of the United Nations, *FAO Animal Production and Health Paper* **78**, 125 p.

ASAE Standards, 1998. Terminology for milking machines, milk cooling, and bulk milk handling equipment. *ASAE S300.3*, Jul 96, 121-128.

Bilgen, H. & Oz, H. 2006.Controls according to standards milking machines and installations. Ege University, Agriculture Faculty, Dept. of Agricultural Machinery Publications, *Ege University Publisher,* **10**, 77 p., İzmir, Turkey (in Turkish).

Dairynz, 2015. Milking clusters. DairyNZ Milk Smart. *http://www.dairynz.co.nz/media/214306/ Milking-cluster.pdf.* Accessed 15.10.2015.

Mein, G.A. 1992. Simple checks of a milking system. National Mastitis Council Annual 1992 Meeting, NMC-Global Milk Quality, *http://www.nmconline.org/articles/simplechks. html.* Accessed 17.10.2015.

ISO 3918, 1996. Milking machine installations–Vocabulary. *International Organization for Standards,* Geneva, Switzerland, 39 p.

TS ISO 5707, 2014. Milking machine installations–Construction and performance. *Turkish Standards Institute*, 47 p.

TS ISO 6690, 2014. Milking machine installations – Mechanical tests. *Turkish Standards Institute*, 34 p.

Unal, H. 2013. Mechanization of dairy farming. *SÜTAŞ Publications of Dairy Farming Training Centre,* ISBN: 97-975-93554-4-9, **9**, 77 p. Bursa, Turkey (in Turkish).

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Aquaculture: problems and modern perspective on topical solution

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Abstract. In this article describes the current problems of aquaculture. As a new material for feeding fish pond serves biocomposite based on protein hydrolysates and natural polymers. Also disclosed is a method of forming the proposed mother. Studies have been conducted biocomposite molecular weight and amino acid composition of the initial protein products.

Key words: fish feed, biocomposition, protein hydrolysate, aquaculture.

INTRODUCTION

The usage of the North-West region for the cold-water fishing based on the natural lake of the Velino, Samolovskoy region of the Pskovsky district seem quite promising.

The Veline Lake as well as the following lake Dolgoe is located in the Zhelch river Valley are now considered as natural monument of the Pskovsky district. Lakes play an important part in supporting the fish stocks of the Chudskoye water body.

The area of the Velino lake is 1.6 km^2. Maximum depth is identified near the shoreline of the river Zhelch and reaches 16.7 m. In 50 meters away from the water edge continental slope from 4 to 6 meters. The average depth of the water body is 5.7 meters. Velino lake basin is 1,089 km 22 with water exchange from 25 to 26 times a year what causes a volatility of hydro chemical regime and 2–3 times changes of such indicators as pH, mineralization and containment of organic and bioorganic substances, during the year.

The feature of the hydrological regime is in high amounts of oxygen that doesn't fall below 8.6 mg l^{-1} even in the bottom waters of gulf. Salmonid fish farming in the fish tanks located on the Velino Lake is closely linked to the balanced feed production issues. Fish food for salmonids produce from more than 40 components, and consists mainly of protein, fat and carbohydrate fractions. Many manufacturers in accordance with Directive 2000/766/EU, banning the use of 'animal proteins' in the form mix of muscle-connective-bone tissue for animals destined for fattening food production, replacing animal protein in feed on vegetation, usually soybean meal. C.K. Fæste et al. (2015) have shown that since fishmeal produced from marine pelagic fish is an important feed component in the culture of Atlantic salmon and in the poultry industry, it should be considered as a source of potentially allergenic peptides in the final products.

However, in the case of feed based on soybean meal in farming fish - fodder factor has a low figure. Based on the analysis of energies in the structures of collagen on the scientific site of the ITMO University were developed technologies for processing of by-products from meat-, poultry-, and fish production by chemical hydrolysis in the presence of catalysts of trace. ‘Kuprina et al. (2013; 2015) have shown that nowadays little high-quality and feature-rich feedstuffs, which are so necessary today’.

Creation of new protein-containing products generated on the base of collagen containing muscle or their compositions with the necessary structural and mechanical, physic-chemical and technological properties, with a significant content of nanoparticles offers great prospects not only in food but also in feed production. The main technological process for trout farming is feedings in which regular quality control of feed mixtures will help gain the economic benefits for growing trout.

When formulating diets not only the quantitative composition of protein should be taken into account, because of its lack of retards the growth of the fish, and the surplus increases energy metabolism and leads to an inefficient waste of this valuable product, but also its qualitative composition. The ratio of amino acids in the diet that changes due to the stage of fish progress circle which will have high biological value in case if ideal protein is approximated. ‘Henry et al. (2015) have shown that the decrease in the availability and the increase in the prices of fishmeal and fish oil have prompted the search for sustainable alternatives for aquaculture feeds’.

To compose feed salmonids used hydrolysates and protein ingredients, received them the following by-products processing industries: collagen tissue of beef, mix of muscle-connective-bone tissue of birds and fish, egg white (a by-product of the production of mayonnaise), egg shells and spongy mushrooms that are not used in the production of high quality of quick-frozen products. ‘Eric Leclercq et al. (2015) have shown that the possibility of using collagen tissue of beef’.

Usually hydrolysates are used to create compositions of the salmonids feed and protein ingredients, received from the following by-products processing industries: collagen tissue of beef, mix of muscle-connective-bone tissue of birds and fish, egg white (a by-product of the production of mayonnaise), egg shells and spongy mushrooms that are not used in high quality of quick-frozen products. The holding of the hydrolysis of these products and the compilation of composition of them will make a start, production and feed for feeding early juveniles, and fish producers. Multifunctional fodder mixture includes not only necessary for salmon amino acids-arginine, lysine, phenylalanine (in case of absence of tyrosine), valine, Leucine, isoleucine, threonine, Histidine, methionine (in case of lack of cysteine), tryptophan, but minerals (calcium, phosphorus, sodium). Digestibility protein ingredients ranging from 92 to 98%. ‘Mohamed S. Hassaan et al. 2015) have shown that Yeast fermentation increased the protein content by 13.65%, increased the total of hydrolyzed amino acids by 16.27% and decreased phytic acid and tripsin inhibitor’.

Feature of fish feed is high value proteins and fats, which account for 46 and 20%, respectively. Technology of obtaining protein ingredients allows you to get fat from mix of muscle-connective-bone tissue of trout, including Omega-3 fatty acids: linolenic acid, arachidonic acid and also eicosapentaenoic acid and Docosahexaenoic acid (DHA). Creating a feed for salmonids is considered one of the most complicated processes in the industrial relation throughout the livestock sector due to the high fat content. We have developed polymer biocomposites with different content of pectin’s that that allows you to retain fat in finished food to Trout Pellet. Thus, protein-containing composites from new products and developed technology of encapsulation allowed to create a perspective on the composition and the form feed for growing salmonids.

Artificial cultivation of fish in terms of unique flow reservoir ice age Lake Velino appears to be rational in terms of geographical location, the hydrological regime and the characteristic of the coastal zone rich in water plants, working as a spawning substrate for spring-spawning fish phytophilous fish. It should also be noted the great importance of Lakes Velino and long in maintaining fish stocks of Chuskogo reservoir.

Due to the reduction of natural catch fish the development of aquaculture may be associated with modern solutions to the tasks in creating compositions of the starting feeds. One of the strategic action lines in the field of artificial fish breeding is to create new kinds of forages on the basis of protein containing components of by-products from organic raw materials.

Freshwater trout in cages in the conditions of Northwest of Russian Federation appears to be cost effective in the case of the introduction at enterprises of the region integrated processing of various types of by-products of animal and vegetable origin for the creation, including animal feed, high quality. Expansion of assortment policy in the segment of balanced composition of protein, fats, carbohydrates, vitamins, macro-and microelements feed at the moment is not possible without the development of resource-saving technologies.

Traditionally, the main raw material in the production of animal feed was the flour reached from animal products. However, modern requirements for the composition of the ingredients of all types of animal feed, including aquaculture production, involve the development of technologies for producing insoluble (protein products) or functional properties of hydrolysates defined by their molecular mass (MM) 'Kutsakova et al. (2009) have shown that hydrolyzate properties depend on catalyst concentration'.

Creating technology of hydrolysis collagen containing raw materials by chemical hydrolysis to obtain protein products with desired pre-defined properties is related to the need to reduce the activation energy of the process and an increase in the energy system.

These conditions can be fulfilled through the action of catalysts (often HCl, NaOH) and temperature growth. Given the strong covalent bond in primary and quaternary, and, consequently, weak hydrogen and ionic bonds in the secondary and tertiary structures of collagen, as well as certain combinations of modal parameters of the process, it is possible to obtain the hydrolyzed product with the desired molecular weight, which provides specific properties 'Kuprina et al. (2002; 2003), Nyanikova et al. (2002; 2003), have shown hydrolysis method of protein'.

MATERIALS AND METHODS

In process of creating of biopolymerical material were used various protein. materials such as mix of muscle-connective-bone tissue of trout, egg white, mushroom mixture, pork skin, collagen tissue of beef. 'Kuprina et al. (2002), Sáez et al. (2015), have shown that Encapsulation efficiency of protein in alginate or a combination of alginate and chitosan hydrogels was studied with the aim of ascertaining the adequacy of these carriers to deliver exogenous protein to fish orally'. When conducting the hydrolysis of the basic materials used were sodium hydroxide and hydrochloric acid. Research on distribution function of molecular mass protein products and hydrolyzed proteins derived from collagen tissue of beef of cattle hides at temperatures of 92–95 and 130 °C respectively, in the presence of chemical catalysts, concentration from 0.05 to 3% it have been conducted with method of gel chromatography. Columns filled with gels sefadeks G–50 (mm = 1–30 kDa), G-75 (mm = 3–70 kDa) and G–200 (mm = 5–800 kDa). 0.15 M. NaCl solution was used as the eluent, elution speed was 20 ml h^{-1} detection conducted by the Spectrophotometric method with 230 nm wavelength. To determine MM took 5 mg of the substance in 1 ml of 0.15 m NaCl solution. All chemicals were analytical grade.

Dynamic viscosity is defined with Ostwald viscometer while the modulus of elasticity- is defined with consistometr.

During the process of organization of the feed production and transportation of the protein products for the implement over long distances, it is advisable to conduct their drying. Drying is conducted in the laboratory of the ITMO University in semi-industrial unit with back-to-back twirled air flow and the temperature of drying agent at the inlet to the unit equal 140 °C while the temperature of leaving the unit is 90 °C. Industrial production of the drying unit carries out the company Poly NOM. Study of dry protein products were held jointly with Leningrad interregional veterinary laboratory.

Amino acid composition of modified protein products were determined by the method of ion exchange chromatography on the automatic amino acid Analyzer (Japan). The research results are presented in the Table 1.

Polymer biocomposites consisting of insoluble protein (46%) and the fat fraction (20%), and granulation molding method for making synthesized material specified dimensions used acrylic leaf shape with a specified thickness and diameters of the holes corresponding to the desirable size of the pellets. A mixture of bio-polymers such as gelatin and pectin is used as a binder. 'De Cruz et al. (2015) have shown that significant effects on the physical properties of the extruded pellets during the increase of die temperature and also change of starch source from taro to broken rice'. Polymerization of finished material was carried out from the aquatic environment granulation molding method methodology includes the following phases: preparation of primary nutrient material cooking the binder, mixing aqueous biopolymer composites and binder, molding pellets, polymerization received composition and its drying. Formation of liquid feed pellets is the final step in creating a feed of polymeric bio compositions. Preparation of the primary nutrient material was deleting the water parts of polymeric biocomposites at temperatures temperature 60 °C for 180 minutes. Preparation of binder is based on getting the dry mixes biopolymers with content (50–60–70–80–90–100) % pectin, which were flooded with water when liquid ratio equal to 3, and maintained for the swelling within 120 minutes.

Mixing prepared biopolymer composites and binder were conducted dosed at constant hashing with at least 700 rpm and temperature 60 °C before reception of homogeneous weight. Molding pellets from mixed solution biocompositions conducted in previously chilled to a temperature of 4 °C cleaning method sheets (you can use as a method of granulating extrusion mechanism). Polymerization of granules were done in oven with forced convection at a temperature of 40 °C, after which they removed from the forming of sheets and dried at a temperature of 60 °C to specified moisture content.

Table 1. Amino acid composition of modified products of animal and vegetable origin

Name of amino acids	The content of amino acid in 100 g protein, %						
	recommended for starting trout feed	mix of muscle-connective-bone tissue of trout	egg protein	fungi Boletus edulis+ Leccinum scabrum= 1 : 1	mix of muscle-connective-bone tissue of bird	pork skin	collagen tissue of beef
valine	9.4	9.5	7.4	7.55	3.89	1.83	2.36
isoleucine	7.4	7.8	6.3	11.83	3.42	0.97	2.01
lecithine	15.8	14.9	9.2		6.60	2.30	3.99
lysine	14.7	15.8	6.8	7.43	6.35	2.60	3.52
methionin*	4.9	5.5	4.1	2.79	2.23	0.61	0.80
threonin	8.9	9.1	4.8		5.28	1.25	2.06
tryptophan	1.6	1.6	1.7	1.12			0.50
phenylalanine**	8.9	8.1	6.7	4.67	4.48	1.54	1.75
arginine	11.5	12.2	6.2	10.22	18.24	5.67	4.19
histidine	7.5	5.9	2.5	4.82	10.28	0.76	0.81
glutamic acid		31	15.1	12.12	15.58	6.42	8.09
proline			4.0		21.26	8.49	9.89
tyrosine	6.8	6.5		3.00	1.77	0.83	0.98
cysteine			2.8	1.42		0.43	0.82
cystine	2.8	3.1			0.33		
alanine		14	6.9	8.39	16.58	5.37	10.35
aspartic acid		20	10.1	10.37	9.95	3.93	5.62
asparagine					2.18		
glycine		9.5	3.9	5.33		14.06	31.87
serin			7.6	4.35		2.28	3.44
oxyproline						7.24	1.93
ornithine				1.20			0.59

* in the absence of cysteine
** in the absence of tyrosine

RESULTS AND DISCUSSION

NaCl solution was used as the eluent, elution speed was 20 ml h^{-1} detection conducted by the Spectrophotometric method with 230 nm wavelength. To determine MM took 5 mg of the substance in 1 ml of 0.15 m NaCl solution. Chromatograms, reflecting the values of the distribution functions of molecular masses collagen containing insoluble hydrolysates obtained in the presence of a chemical catalyst concentration of 0.05, 0.3 and 3% are presented in Figs 1, 2 and 3.

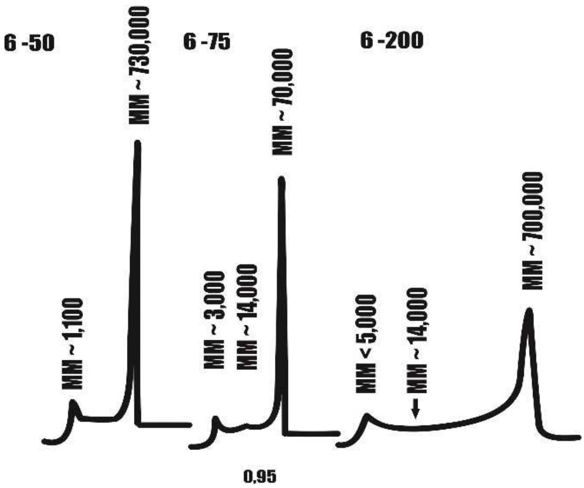

Figure 1. Chromatogram of distribution function of molecular masses of collagen hydrolysate obtained in the presence of a catalyst, a concentration of 0.05%.

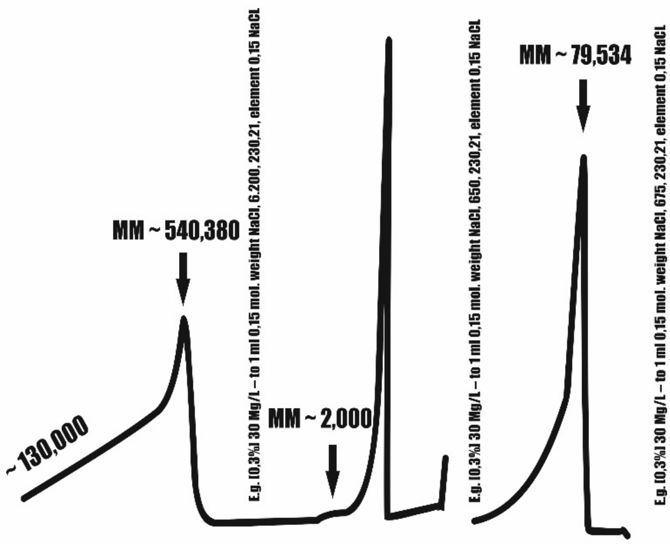

Figure 2. Chromatogram of distribution function of molecular masses of collagen hydrolysate obtained in the presence of a catalyst, a concentration of 0.3%.

From the analysis of the distribution functions of molecular masses and structurally-mechanical properties of protein products for border concentration we can match the following: The mean values of the molecular masses of protein products obtained in the presence of catalyst concentration from 0.05 to 0.3%, are identical (Fig. 1) and were 700 kDa.

The obtained substances have high values of viscosity (of 3086.9 to 10^{-6} • 56281 Pa •) and strength (modulus of elasticity of the gel at a temperature of t = 4 °C is E = 29.54-51.06 kPa). The results of processing the chromatograms, presented in Fig. 2 showed that 40% of the substance has the molecular mass of 540, and 60%–130 kDa. The average value of such a product will be protein MM 300 kDa.

Functional and technological properties of the protein product hydrolyzed in the presence of 0.3% chemical catalyst protein product are completely different. Viscosity was 1109.2 • 10^{-6} Pa • and protein product had the consistency of weak jelly, which elasticity is impossible to determine.

The average value of the molecular masses of protein product obtained when processing catalyst 3% concentration (Fig. 3) stood at 6.7 kDa. Protein collagen containing product is a combination of amino acids, with a maximum content of glycine. Using similar modal parameters modificates and hydrolysates of the by-products of meat, poultry and fish processing equipment-pork skins, mix of muscle-connective-bone tissue of birds and fish, egg whites, as well as raw materials of mushroom were obtained. ‘Pat. 2303881 (2006) showed the use of this method’. In order to obtain the protein product from muscle tissue meat and bone remnants of raw, processing raw materials carried out in the presence of catalyst concentration 0.4%. ‘Kutsakova et al. (2013) have shown that way catalyst concentration was chosen’.

Functional and technological properties of powders has high water-binding capability (1:18 the best for mince systems), solubility of not less than 95% and digestibility 96.9% minimum (pork skin).

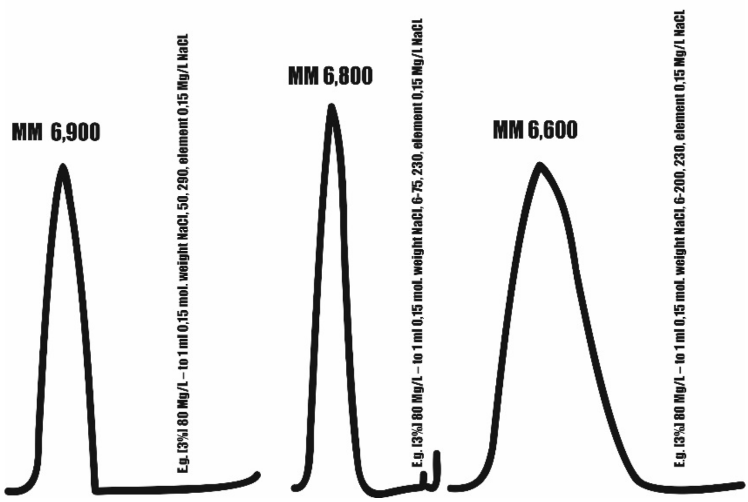

Figure 3. Distribution function of molecular masses of collagen hydrolysate obtained in the presence of a catalyst, with a concentration of 3%.

As it is clear from the presented data, amino acid composition of new modified products allows you to create a wide range of balanced feed for the desired protein composition variation.

In fish cultivation wet forage is also used. For small farmers that organize production for their own needs, the use of drying is quite expensive. Studies have shown that cold storage jelly modificates at a temperature 4 °C enables you to use the product within 14 days of elaborate, without altering the physico-chemical and microbiological indicators.

The Starter feed feature is regulation not only protein content (46%) but also fat (up to 20%). Developed technologies include the generation and collection of fat by-products that allows almost completely compensate for feeding component through the processing of by-products from meat bone residue and pig skins.

When creating a moist feed from the proposed modified protein the development of additional products such as glue from cover or bone tissues is not required. Since the rheological characteristics of protein products are high, their introduction to recipes as moisture binding component will have a positive impact and on the structure of the feed.

Introduction to compounding forage mushroom modification draws an attention, from the point of view that the presence of chitin-glucan complex in the cell wall of fungi can be regarded as a substitute for expensive chitin component of crustaceans, used to improve the process during the period osmosis regulation smoltification of salmon and enhance the sustainability of the fish to skin diseases and stressful situations. Toxicological characteristics of fungal product conducted with express-method using infusoria Tetrahymena pyriformis.

The conducted contents of toxic elements and residual pesticides are (mg kg^{-1}): lead (15.8), cadmium (2.15), copper (90.0), zinc (335.0), mercury (0.15), arsenic (less than 0.2), aldrin (not detected), heptachlor (not detected), hexachlorocyclohexane (total isomers of less than 0.001), DDT and its metabolites (less than 0.002).

CONCLUSIONS

Thus, expanding the range of supply trout fish species can be achieved by solving the problem of aquaculture, including in the field of creation of forages during artificial cultivation.

Thus, expanding the range of trout fish nutrition can be achieved through the introduction of advanced new solutions to the problem of aquaculture in creating quality forages during artificial rearing of fish. 'Mukhina & Pestrikova (2012), James et al. (2013) have shown prospects of Aquaculture development'. Organization and implementation of resource-saving technologies of the by-products of animal and vegetable origin can produce with minimal competitive feed polymer bio composition.

The usage of 'animal proteins' is limited by the rules of the European Union which leads to the development of a new protein containing products used in the fattening of livestock. One of the directions for obtaining such products may be a hydrolysis of the collagen containing by-product in the presence of chemical catalysts micro concentration. Through this process it is possible to gain trace ingredients with specified composition and properties.

Analysis of the binding energy in collagen structures revealed that the hydrolysis process required energy can be transferred to the system either by increasing the kinetic energy associated with an increase in temperature or by lowering the activation energy by the action of catalysts. Depending on the required properties of the obtained ingredients defined by molecular weight (from 6.7 to 700 kDa) modal parameters of hydrolysis are specified. Analysis of the collagen hydrolysis mechanism allows predicting the process parameters of hydrolysis and concentration of catalyst, providing the relevant mechanical and technological properties of functional protein ingredients.

Amino acid composition of all the studied protein ingredients recommended for compiling starting feed salmonids recipes, allows noticing the high quality of the designed product.

Addition of non-toxic chitin glucan complexes made of the plant component to the feed formula will not only advantageously replace the expensive equivalent, derived from crustaceans but can be used to regulate critical physiological and biochemical processes of restructuring the body of salmonids, preceding and accompanying migration from the freshwater reservoirs.

The recommended granulation method for molding forage caps with bio-composite material composed of protein and fat ingredient faction, allowed to keep such a complex system with a combination of acrylic sheet forms and bounded gelatin-pectin mixtures.

These drying modes in aggregates with back-to-back twirled the air flows also allows to receive powdered protein ingredients with preservation of functionally-technological properties in organizing large productions.

REFERENCES

De Cruz, C.R. Kamarudin, M.S. Saad, C.R. & Ramezani-Fard, E. 2015. Effects of extruder die temperature on the physical properties of extruded fish pellets containing taro and broken rice starch. *Animal Feed Science and Technology* **199**, 137–145.

Henry, M., Gasco, L., Piccolo, G. & Fountoulaki, E. 2015. Review on the use of insects in the diet of farmed fish: Past and future. *Animal Feed Science and Technology* **203**, 1–22.

Fæste, C.K., Levsen, A., Lin, A.H., Larsen, N., Plassen, C., Moen, A., Van Do, T. & Egaas, E. 2015. Fish feed as source of potentially allergenic peptides from the fish parasite Anisakis simplex (s.l.). *Animal Feed Science and Technology* **202**, 52–61.

James, P., Siikavuopio, S., Samuelsen, T.A., Mundheim, H., Carlehög, M., Vasilyev, R. & Kovatcheva, N. 2013. The effects of varying the percentage of herring versus salmon protein in manufactured diets on the survival, meat content, hepatosomatic index and meat sensory quality of adult red king crab paralithodes camtschaticus held in captivity. *Aquaculture* 416–417, 390–395.

Kanyılmaz, M., Tekelioglu, N., Sevgili, H., Uysal, R. & Aksoya, A. 2015. Effects of dietary zeolite (clinoptilolite) levels on growth performance, feed utilization and waste excretions by gilthead sea bream juveniles (Sparus aurata). *Animal Feed Science and Technology* **200**, 66–75.

Korneev, A.A. & Luzhnyak, V.A. 2012. Biological peculiarities of the industrially bred juvenile Russian sturgeon acipenser gueldenstaedtii (acipenseridae, acipenseriformes) in the don. *Journal of Ichthyology* **52**(4), 268–276.

Kuprina, E.E., Bobylev, V.S. & Kirillov, A.I. 2013. *Electrochemical methods for the preservation of crustaceous wastes from shellfish processing*. Progress on Chemistry and Application of Chitin and its Derivatives, **18**, 5–12.

Kuprina, E.E., Kirillov A.I., Ishevski A.L. & Myrashev S.V. 2015. *Food supplement based on chitin with enhanced lipid-lowering and sorption properties.* Progress on Chemistry and Application of Chitin and Its Derivatives, 156–161.

Kutsakova, V.E., Kremenevskaya, M.I., Pogonyaeva, A.J. & Kalmikova, T.S. 2013. Development of technology of hydrolysis of muscle tissue of poultry meat and bone residue. *Meat Industry* **4**, 65–66. (in Russian)

Kuprina, E.E., Timofeeva, K.G. & Vodolazhskaya, S.V. 2002. Electrochemical preparation of chitin materials. *Russian Journal of Applied Chemistry* **75**(5), 822–828.

Kuprina, E.E., Vodolazhskaya, S.V. & Nyanikova, G.G. 2003. Destruction and hydrolysis of proteins in their electrochemical extraction. *Russian Journal of Applied Chemistry,* **76**(4), 639–642.

Kutsakova, V.E., Frolov, S.V., Kremenevskaya, M.I. & Moskvicheva, E.V. 2009. *The dependence of the technological properties of collagen hydrolyzate on the concentration of the catalyst*. Storage and processing of agricultural raw materials **12**, 20–22. (in Russian)

Leclercq, E, Graham, P. & Migaud, H. 2015. Development of a water-stable agar-based diet for the supplementary feeding of cleaner fish ballan wrasse (Labrus bergylta) deployed within commercial Atlantic salmon (Salmon salar) net-pens. *Animal Feed Science and Technology* **208**, 98–106.

Li Xu, Chao Ran, Suxu, He, Jianli Zhang, Jun Hu, Yalin Yang, Zhenyu Du, Yanou Yang, Zhigang Zhou. 2015. Effects of dietary yeast nucleotides on growth, non-specific immunity, intestine growth and intestinal microbiota of juvenile hybrid tilapia Oreochromis niloticus + Oreochromis aureus. *Animal Nutrition* **1**, 244–251.

Mohamed, S. Hassaan, M.S., Soltan, M.A. & Abdel-Moez, A.M. 2015. Nutritive value of soybean meal after solid state fermentation with Saccharomyces cerevisiae for Nile tilapia, Oreochromis niloticus. *Animal Feed Science and Techn*ology **201**, 89–98.

Mukhina, I.N. & Pestrikova, L.I. 2012. Research PINRO of. N.M. Knipovich in forage production and cultivation of aquaculture promising Arctic. *Herald Bauman*, **15**(4), 810–817. (in Russian)

Nyanikova, G.G., Kuprina, E.E. & Vodolazhskaya, S.V. 2003. Protein hydrolysates extracted electrochemically from crustaceans as major components of nutrient media. *Applied Biochemistry and Microbiology* **39**(4), 431–434.

Nyanikova, G.G., Kuprina, E.E., Pestova, O.V. & Vodolazhskaya, S.V. 2002. Immobilization of bacillus mucilaginosus, a producer of exopolysaccharides, on chitin. *Applied Biochemistry and Microbiology* **38**(3), 259–262.

Pat. 2303881 RF A 23 L 1/31 A 23 J 1/10. *A method of manufacturing a meat product with the use of meat and bone residue hydrolyzate* / Kutsakova, V.E., Frolov, S.V., Kremenevskaya, M.I., Marchenko, V.I., Golovantseva, O.V., Moskvichev, A.S., Struzhenko, I.Y. – № 2005111315/13; appl. 18.04.05; publ. 27.10.06. - Bull. **22**, pp. 5. (in Russian)

Sáez, M.I., Barros, A.M. Vizcaíno, A.J., López, G., Alarcón, F.J. & Martínez, T.F. 2015. Effect of alginate and chitosan encapsulation on the fate of BSA protein delivered orally to gilthead sea bream (Sparus aurata). *Animal Feed Science and Technology* **210**, 114–124.

Zaki Sharawy, Ashraf M.A.-S. Goda & Mohamed Hassaan, S. 2016. Partial or total replacement of fish meal by solid state fermented soybean meal with Saccharomyces cerevisiae in diets for Indian prawn shrimp, Fenneropenaeus indicus, Postlarvae. *Animal Feed Science and Technology* **212**, 90–99.

Taida Juliana Adorian, Patrícia Inês Mombach, Fernanda Rodrigues Goulart, Bruno Bianch Loureiro, Dirleise Pianesso & Leila Picolli da Silva. 2015. Dietary fiber in the nutrition of silver catfish: Prebiotic or antinutrient? *Animal Feed Science and Technology* **209**, 167–173.

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Mass and energetic yields of hydrochar from brewer's spent grain

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Abstract: Brewer's spent grain (BSG) was hydrothermally carbonized at combinations of three temperatures (180 °C, 215 °C, 250 °C) and three reaction times (2 h, 5 h, 12 h). For comparison, the corresponding barley malt was also tested at the same conditions. Elemental composition, volatile matter, ash and heating values were determined for original biomasses as well as resulting hydrochars. The mass yield of dry BSG hydrochar ranged from 45 to 73%. The energetic yield defined as retention of total lower heating value in the hydrochar on dry basis ranged from 66 to 85%. Specific lower heating value of dry material rose from 20.6 MJ kg^{-1} to 30.3 MJ kg^{-1} at the most severe conditions. Nitrogen and sulphur content in hydrochar were not strongly dependent on reaction conditions.

Key words: hydrothermal carbonization, malt, calorific value, heating value, biochar, elemental composition.

INTRODUCTION

One of the main components for beer brewing is malt. That is germinated and then dried cereal, usually barley, which provides starch and sugars that can be later consumed by yeast. Brewer's spent grain (BSG) is then the main by-product (85% of all by-products by weight) of brewing beer which is collected after filtering the wort. It contains water insoluble malt remnants composing mainly of water insoluble proteins and cell wall residues of the husk, pericarp and seed coat within the spent grain (Mussatto et al., 2006). BSG is composed mainly of lignocellulosic fibres (cellulose, lignin and arabinoxylan might make up around 70% of dry weight of BSG). Another roughly 20% is taken up by proteins. The rest are lipids and starch remnants. The composition changes with barley variety and differences in the brewing process even within one brewery so the reported values vary significantly. (Santosa et al., 2003; Mussatto et al., 2006; Xiros & Christakopoulos, 2012)

Brewer's spent grain can be used traditionally for animal feeding. For its high content of fibre and protein it has been used largely for dairy cows to increase milk production, but its use for other animals, such as poultry, pigs or fish, has been also investigated. Human consumption is possible when adding moderately small quantities of BSG flour into bakery products, with reported health benefits. When converted to so-called germinated barley foodstuff it has been found to be beneficial to patients with ulcerative colitis (Mussatto et al., 2006; Steiner et al., 2015). If not used for nutrition

BSG may possibly serve in brick-making to increase porosity, in paper manufacture or after pyrolysis treatment as adsorbent. BSG can be used also in a number of biotechnological processes as substrate for cultivation of microorganisms or substrate from which enzymes or other biochemical products can be obtained. (Mussatto et al., 2006; Xiros & Christakopoulos, 2012)

Finally, when there is not sufficient demand for these uses it may be also utilized energetically. Since fresh BSG is usually a very wet substrate, biogas production in an agricultural biogas plant would omit the need to dry the material. (Malakhova et al., 2015) found methane yield of BSG in co-fermentation up to 58.7 l kg^{-1} of raw BSG. Different option may be hydrolysis treatment to produce liquid fuels (Raud et al., 2015). Another technique that can process wet material is hydrothermal carbonization (HTC). In general, hydrothermal treatment of biomass can lead to a variety of products depending on the substrate, reaction temperature and pressure etc. (Kruse & Dahmen, 2015). Hydrothermal carbonization occurs in water environment mainly in temperature range of ca. 180–250 °C. The reaction pressure corresponds to that of saturated water vapour or is increased by generated gases, which are mostly CO_2 (Poerschmann et al., 2014). The solid product is most often called biochar or hydrochar. Suitable substrates are generally all carbohydrates, while proteins and lipids do not usually turn into hydrochar by themselves, but may be adsorbed onto it or their change into hydrochar may be facilitated by other substrates (Heilmann et al., 2011; Kruse & Dahmen, 2015). Submersion of substrate in water is a crucial condition in HTC and other solvents do not produce the same effects (Heilmann et al., 2011).

The advantages of hydrothermal treatment are complete hygienization and to some extent also degradation of some pollutants (Weiner et al., 2013). Under hydrothermal conditions the structure of original material and its cells are destroyed to a high degree, so the resulting hydrochar can be more easily dewatered. This is useful mainly for highly moist waste biomass which would have to be disposed of possibly without energy gain, but with HTC the energy efficiency may become better (Malaťák & Dlabaja, 2015).

Several works focused on HTC of BSG have been already written mostly focusing on composition of hydrochar or process water (Poerschmann et al., 2014; Poerschmann et al., 2015; Riedel et al., 2015). In these works, BSG was seen as a suitable material for HTC. The aim of this work is to help evaluate the potential of BSG for energy utilization by following the energetic yield in HTC of BSG across three different carbonization temperatures (180 °C, 215 °C, 250 °C) and three different times (2 h, 5 h, 12 h). Since mass and energetic yields in hydrothermal carbonization are influenced by other parameters as well (reactor loading, mixing, etc.) it was deemed useful to compare BSG to a different biomass for better comparison with literature. The barley malt used for brewing was chosen.

MATERIALS AND METHODS

Materials and chemicals

Barley malt and corresponding brewer's spent grain (BSG) were supplied from a local brewery. The initial moisture of the BSG was 75% wt. To preserve it, it was dried in a fruit drier in flowing air at 60° until no moist patches could be seen. The material was then thoroughly mixed to ensure homogeneity. BSG was then stored in a refrigerator. The moisture of stored BSG was measured every time it was used for an experiment, the average value being 7.0% wt.

Malt was supplied as whole grains. It was stored in a closed container at 20 °C. Its moisture was measured when received and then every week to determine moisture content changes over time. To measure moisture a sample was always ground and immediately weighed.

For adjusting the acidity of reaction mixtures citric acid was used (analytical grade, Lach-Ner). For calibration of analysers, calibrating standards were supplied by LECO. For calibration of volatile matter (VM) in TGA 701 coal standard with 40.4% wt. VM was used. CHN module was calibrated with ethylenediaminetetraacetic acid. S module was calibrated using coal standard with 1.16% wt. sulphur. The calorimeter was calibrated with 1 g pellets of benzoic acid.

Experimental procedure

Mixtures for HTC experiments were composed of such an amount of substrate to achieve 25 g of dry matter (DM) with the last known moisture content. Tap water would then be added to achieve a total 200 g of mixture (laboratory scales A&D GF-3000, accuracy 0.01 g). The actual amount of DM in case of BSG would be calculated using moisture of a concurrently measured sample, for malt the weekly value would be used. The final mixture DM content in all experiments was 12.5 ± 0.2%. Citric acid would then be added to adjust the acidity of mixture to pH3 – pH4 (pH-meter Thermo Scientific Orion Star 111). Malt was not ground in the mixtures.

The HTC treatment took place in a laboratory reactor, a stainless steel pressure vessel, Berghof BR-300 with an internal volume of 400 ml. It was not filled completely to allow for the expansion of the mixture at higher temperatures. Inert atmosphere was not introduced. The reactor was heated on an electric heater (Heidolph MR Hei Standard) which was controlled by a regulator (Berghof BTC-3000). In all experiments the reactor would be heated to the target temperature and maintained on it for the chosen time. The reaction was not stirred. Heating up and cooling down phases took each approximately 40–50 minutes. The reaction time was determined as the time when the temperature stayed above target temperature minus 2 °C and it never went above the target temperature plus 5 °C. The only variables in the experiments were reaction temperature and time. All other parameters were maintained the same throughout all experiments. Three different temperatures and times were chosen: 180 °C, 215 °C and 250 °C and 2 h, 5 h and 12 h. Experiments with all combinations have been performed for both substrates.

Upon completing an experiment, remaining pressure would be released and reactor opened when it reached 40 °C. Liquid phase was filtered on a qualitative filter paper and hydrochar left in the reactor was completely taken out. The filtered liquid contained no visible hydrochar particles so all carbon unrecovered in hydrochar is considered to have been dissolved in the process water or has escaped in formed gases. All solid product was then dried until reaching a constant weight (Memmert UN 30) at 105 °C. The mass yield of the hydrochar was then calculated as percent ratio of dry mass of hydrochar to dry mass input in each particular experiment.

Analyses and calculations

After determination of mass yields of hydrochars, the samples were crushed to produce homogenous powder. Consequently they were analyzed for moisture, volatile matter, ash, elemental composition and heating value. The first three parameters were analyzed in a thermogravimetric analyser (LECO TGA 701). The temperature programme first dried samples at 107 °C to constant weight. Volatile matter was determined in nitrogen atmosphere at 900 °C for 7 minutes. Lastly the samples were burned in oxygen at 550 °C, again until constant weight, to find ash content. Each hydrochar was analyzed twice with 1 g per sample; the original materials, BSG and malt, were analysed three times.

Elemental composition was analysed in an instrument LECO CHN628+S with helium as carrier gas to find carbon (C), hydrogen (H), nitrogen (N) and sulphur (S) contents. The analyser operates by analysing the flue gases of samples burned in oxygen. C, H and S are measured in infrared absorption cells; N is measured in a thermal conductivity cell. For determination of C, H and N, 0.15 g of sample was wrapped into a tin foil and burned at 950 °C. Samples into the S module (0.2 g) were poured into a crucible and burned at 1,350 °C. Each sample was analysed to get at least three good measurements of each element.

Higher heating value was measured in a isoperibol calorimeter (LECO AC 600). The samples were pressed into pellets of around 0.7 g and analysed to obtain two reliable results; three for original biomasses. Higher heating value (HHV) was determined using its supplied software.

All reported values are averages for dry basis values. Results of analyses were converted to dry basis values according to ČSN ISO 29541. The elements C, N, S and ash were converted using formula:

$$w_{Xd} = w_{Xa} \times \frac{100}{100 - w_{Ma}} \quad (1)$$

where w_{Xd} – dry basis elemental contents in % wt.; w_{Xa} – values of analytical samples; w_{Ma} – the moisture in analytical samples.

Hydrogen was converted using:

$$w_{Hd} = \left(w_{Ha} - \frac{w_{Ma}}{8.937} \right) \times \frac{100}{100 - w_{Ma}} \quad (2)$$

Oxygen content was calculated by subtracting C, H, N and S elemental contents and ash content, all on dry basis, from 100%.

Lower heating value (LHV) was then calculated according to ČSN ISO 1928 using elemental analysis results:

$$LHV = \{HHV - 212 w_{Hd} - 0.8 \times (w_{Od} + w_{Nd})\} \times (1 - 0.01 M_T) - 24.43 M_T \quad (3)$$

where M_T – the converted moisture basis, for dry basis it is zero.

All yield values are calculated in the same way. They are defined as the mass yield, as defined in the previous section, multiplied by ratio of contents on dry matter basis of each particular substance in hydrochar to that in the original biomass. Energetic yield is the yield of LHV. Since carbonization decreases the content of H, the HHV yield would be always somewhat lower.

RESULTS AND DISCUSSION

Overall results and energetic yield

After carbonization all hydrochars were not completely homogenous. After carbonization of malt, relatively empty husks tended to gather towards the surface and hydrochar formed arguably mostly from the malt endosperm was found mostly in the bottom half of the reactor. BSG hydrochar was mostly homogenous with its original structure still recognizable. However at higher temperatures and long times of carbonization the hydrochar tended to form a lump of hydrochar toward the surface while a tarry residue formed at the bottom.

Tables 1 and 2 show mass yield and analysis results for hydrochars from BSG and malt, as well as the original biomasses. Values are sorted by reaction temperature and then by reaction time which seems to correspond to reaction severity as the values of carbon content and heating values rise in the same order while volatile matter content decreases. As not a high number of experiments have been made for each set of conditions, small differences cannot be judged as statistically significant. However general trends are clear. Work of Poerschmann et al. (2014) showed carbonized BSG with similar composition giving comparable values of mass yield and elemental contents while also following composition of process liquid and sorption capability of hydrochar. Ash composition is another important factor in energy utilization, however it was not analysed in this work. In literature (Poerschmann et al., 2014) it can be found that after HTC of BSG some elements had an increased content in hydrochar, especially calcium.

Table 1. BSG hydrochar: Mass yield and composition of original BSG and resulting hydrochars at all reaction conditions

Tempe-rature	Time	Mass yield	Carbon content	Hydrogen content	Nitrogen content	Sulphur content	Oxygen content	Volatile Matter	Ash	Higher Heating Value	Lower Heating Value
°C	h	%	% wt.	% wt.	% wt.	% wt.	% wt.	% wt.	% wt.	MJ kg^{-1}	MJ kg^{-1}
Original material			51.9	7.44	4.38	0.34	31.8	83.8	4.10	22.2	20.6
180	2	72.9	59.3	7.32	4.57	0.35	24.0	76.3	4.48	25.2	23.7
180	5	71.7	60.9	7.22	4.64	0.37	22.2	74.6	4.71	25.6	24.0
180	12	70.9	61.8	7.28	4.40	0.36	21.6	73.7	4.60	26.3	24.7
215	2	64.8	63.5	7.37	4.35	0.34	19.9	71.7	4.53	27.3	25.7
215	5	59.2	66.0	7.40	4.58	0.34	16.9	69.8	4.80	28.3	26.7
215	12	56.1	67.3	7.42	4.67	0.35	15.0	67.2	5.29	29.4	27.8
250	2	51.5	69.5	7.50	4.68	0.36	12.9	65.4	5.06	30.4	28.8
250	5	49.2	70.2	7.72	4.32	0.33	12.5	63.3	4.90	31.3	29.7
250	12	45.0	69.7	7.42	4.37	0.38	12.4	56.7	5.72	31.9	30.3

The pH of the final process liquid was between pH3 and pH4 for malt and between pH4 and pH5 for BSG. It was always at least the same or higher compared to starting conditions, but there was not a clear trend. The pH rise was always well within one pH unit, so it was not expected to have a considerable impact on mass yield or other measured parameters (Reza et al., 2015).

Table 2. Malt hydrochar: Mass yield and composition of original malt and resulting hydrochars at all reaction conditions

Tempe-rature	Time	Mass yield	Carbon content	Hydrogen content	Nitrogen content	Sulphur content	Oxygen content	Volatile Matter	Ash	Higher Heating Value	Lower Heating Value
°C	h	%	% wt.	% wt.	% wt.	% wt.	% wt.	% wt.	% wt.	MJ kg^{-1}	MJ kg^{-1}
Original material			46.3	7.01	1.61	0.16	43.0	88.6	1.93	18.6	17.1
180	2	36.7	58.9	5.36	2.99	0.25	30.5	69.3	1.99	24.0	22.9
180	5	47.2	64.8	6.01	2.78	0.22	24.7	63.3	1.52	25.8	24.5
180	12	55.6	67.3	5.53	2.59	0.21	22.9	57.4	1.41	26.8	25.6
215	2	51.9	67.6	5.66	2.69	0.20	22.4	55.8	1.52	27.1	25.9
215	5	52.6	65.9	5.45	2.57	0.19	24.5	54.2	1.39	26.9	25.7
215	12	52.7	68.7	5.51	2.69	0.19	21.2	53.2	1.72	27.2	26.0
250	2	49.4	65.6	5.51	2.71	0.22	24.3	52.3	1.65	28.4	27.2
250	5	48.3	66.0	5.39	2.66	0.20	24.2	49.6	1.55	28.7	27.6
250	12	47.5	66.4	5.46	2.74	0.20	23.4	47.8	1.73	29.3	28.1

Mass yield of hydrochar, see Table 3, from BSG was higher at milder conditions as was expected. BSG is made up mostly of fibres like cellulose which dissolve into solution or degrade only under more severe hydrothermal conditions (especially cellulose) (Heilmann et al., 2011; Reza et al., 2014; Reza et al., 2015). Mass yield of hydrochar decreased with temperature and time mostly due to decomposition of fibre. On the other hand, lower heating value increased from 23.7 MJ kg^{-1} up to 30.3 MJ kg^{-1} making it comparable to quality bituminous coal. The final energetic yield decreased overall, but not as sharply as the mass yield. For lower temperatures the mass and energy yields are relatively consistent with those for cellulose (Lu et al., 2013), but at 250 °C BSG yields are lower.

Table 3. Mass and energetic yield of BSG hydrochars

	Mass yield (%)			LHV (MJ kg^{-1})			Energetic yield (%)		
	2 h	5 h	12 h	2 h	5 h	12 h	2 h	5 h	12 h
180 °C	72.9	71.7	70.9	23.7	24.0	24.7	83.6	83.4	84.9
215 °C	64.8	59.2	56.1	25.7	26.7	27.8	80.7	76.6	75.7
250 °C	51.5	49.2	45.0	28.8	29.7	30.3	71.8	70.8	66.1

The situation was different for hydrochar from malt, see Table 4. Malt still contains starchy endosperm which makes up most of its weight. The mechanism of hydrochar formation is different here. Sugars quickly solubilise in water at hydrothermal condition and most of the hydrochar has to be formed by polymerization from the solution (Nagamori & Funazukuri, 2004). It can be seen that at the mildest conditions the overall reaction proceeds slowly and the yield is quite low. With increasing time the reaction becomes more complete and the yield rises or remains level. This trend, however, is reversed at the highest tested temperature (250 °C) which might be contributed either to decomposition of the husks or further carbonization and losing of H and O content. The latter, however, does not seem to be the case since elemental composition is very similar for the 2 h and 5 h samples at 250 °C. The general increase in mass yield with time or its stagnancy and increase of LHV with temperature resulted in similar energetic yields around 80% for all but two samples (2 h and 5 h at 180° C).

Table 4. Mass and energetic yield of malt hydrochars

	Mass yield (%)			LHV (MJ kg^{-1})			Energetic yield (%)		
	2 h	5 h	12 h	2 h	5 h	12 h	2 h	5 h	12 h
180 °C	36.7	47.2	55.6	22.9	24.5	25.6	49.0	67.8	83.2
215 °C	51.9	52.6	52.7	25.9	25.7	26.0	78.6	78.9	80.2
250 °C	49.4	48.3	47.5	27.2	27.6	28.1	78.5	77.8	78.0

Mass yields of selected elements

The carbon content in hydrochars is always increased relative to that in the original biomasses. It increases mainly with carbonization temperature. Except for malt hydrochars at 180 °C it does not seem to be strongly dependent on time. The yields of carbon, see Tables 5–6, follow relatively closely energetic yields at milder conditions, but drop off more quickly at 250 °C and longer times in the case of both substrates.

Table 5. C, N and S contents and their yields in BSG hydrochars

	C (% wt.)			N (% wt.)			S (% wt.)		
	2 h	5 h	12 h	2 h	5 h	12 h	2 h	5 h	12 h
180 °C	59.3	60.9	61.8	4.6	4.6	4.4	0.35	0.37	0.36
215 °C	63.5	66.0	67.3	4.4	4.6	4.7	0.34	0.34	0.35
250 °C	69.5	70.2	69.7	4.7	4.3	4.4	0.36	0.33	0.38

	C yield (%)			N yield (%)			S yield (%)		
	2 h	5 h	12 h	2 h	5 h	12 h	2 h	5 h	12 h
180 °C	83.2	84.1	84.4	76.0	76.0	71.1	74.4	78.3	75.6
215 °C	79.3	75.2	72.7	64.4	61.8	59.9	65.4	59.4	57.8
250 °C	69.0	66.6	60.4	55.0	48.5	44.8	54.6	48.0	50.4

Table 6. C, N and S contents and their yields in malt hydrochars

	C (% wt.)			N (% wt.)			S (% wt.)		
	2 h	5 h	12 h	2 h	5 h	12 h	2 h	5 h	12 h
180 °C	58.9	64.8	67.3	3.0	2.8	2.6	0.25	0.22	0.21
215 °C	67.6	65.9	68.7	2.7	2.6	2.7	0.20	0.19	0.19
250 °C	65.6	66.0	66.4	2.7	2.7	2.7	0.22	0.20	0.20

	C yield (%)			N yield (%)			S yield (%)		
	2 h	5 h	12 h	2 h	5 h	12 h	2 h	5 h	12 h
180 °C	46.7	66.1	80.9	68.0	81.4	89.4	58.5	67.3	74.8
215 °C	75.7	74.8	78.1	86.7	83.7	87.7	65.0	62.3	63.1
250 °C	70.0	68.8	68.1	83.0	79.6	80.6	70.4	60.3	62.0

The hydrochar contents of N and S are relatively unaffected by carbonization conditions. In BSG hydrochar the N and S content are very close to those in original biomass, in malt hydrochar they are somewhat higher (Tables 5–6). The relatively unchanged nitrogen content was probably due to denatured proteins immobilized in the hydrochars (Heilmann et al., 2011; Poerschmann et al., 2014). The yields of N and S are then depending on the overall mass yield of hydrochars.

Van Krevelen diagram

Hydrochar achieves higher heating values thanks to increasing its carbon content and lowering mainly its oxygen and also hydrogen content. This conversion can be seen in a van Krevelen diagram, which has molar ratios O/C on its horizontal axis and H/C on the vertical axis. In Fig. 1 van Krevelen diagram of hydrochars and original biomasses can be seen. BSG hydrochars are moving to the left of the diagram with reaction severity (mainly with temperature, then with time) and at 250 °C they reach nearly the same ratios for all times, however with a little higher H/C ratio than in (Poerschmann et al., 2014). The ratios seem to follow a nearly linear trend. This was also the case for poplar wood or wheat straw in (Reza et al., 2014). Our BSG achieved similar ratios as olive mill waste in (Benavente et al., 2015). Malt hydrochars have very similar ratios for all but two conditions (180 °C at 2 h and 5 h). Comparing these results with heating values, it implies that a formula to estimate the heating value of hydrochars would have to consider more parameters than just elemental composition, for example volatile matter content.

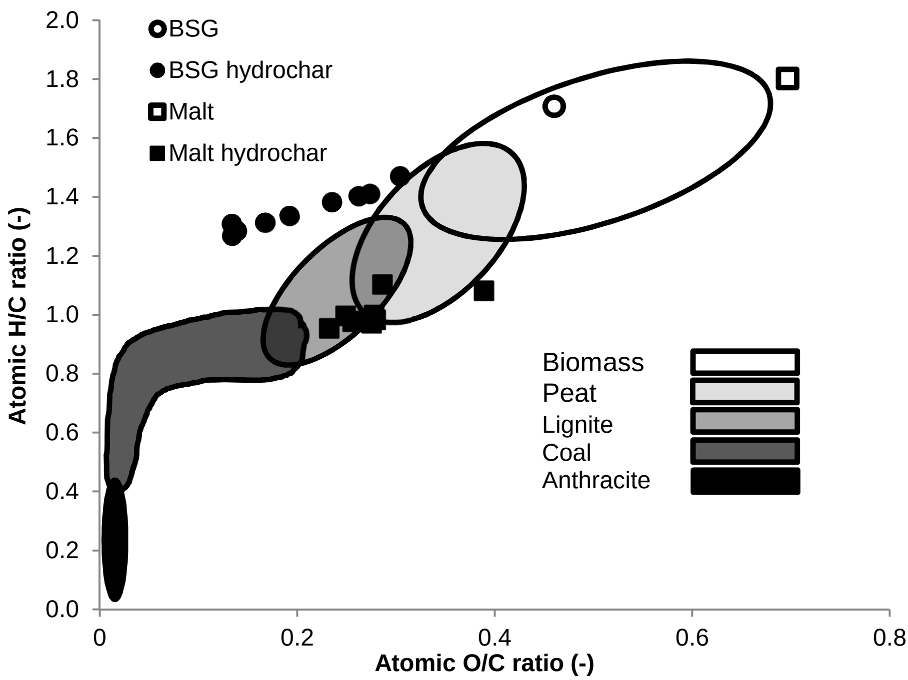

Figure 1. Van Krevelen diagram of BSG and malt hydrochar, areas of typical composition taken from (Van Loo & Koppejan, 2008).

CONCLUSIONS

The main aim of this work was to evaluate the possible energetic yield of hydrochar made by hydrothermal carbonization of brewer's spent grain. To compare it with a different biomass, the corresponding barley malt was also tested at the same carbonization conditions. On dry state basis the highest energetic yield (lower heating value returned in dry matter) was 84.9% at 180 °C and 12 h carbonization (but at shorter times it was almost as high). For malt nearly the same values were reached, but it took a time of at least 5 h or temperature 215 °C and higher to carbonize the most of dissolved sugars. In general, milder conditions produced hydrochar with lower specific heating values but with greater overall energy retention.

In practice other parameters will have to be accounted for to assess real efficiency of this process. Those are dewaterability of starting material versus that of hydrochar, the energy consumption to dry those materials or the energy consumption of hydrothermal conversion and others as well. The energy balance could be then calculated to see whether it is viable at all to hydrothermally convert this material from ecological, energetic or economical point of view. A life cycle assessment of environmental impact of hydrochar production has been performed in (Berge et al., 2015). It showed for example that the process water impact is not at all negligible. It contains still a large amount of dissolved organic carbon which would have to be removed, for example possibly by combining hydrothermal carbonization with wet oxidation (Riedel et al., 2015).

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REFERENCES

Benavente, V., Calabuig, E. & Fullana, A. 2015. Upgrading of moist agro-industrial wastes by hydrothermal carbonization. *Journal of Analytical and Applied Pyrolysis* **113**, 89–98.

Berge, N.D., Li, L., Flora, J.R.V. & Ro, K.S. 2015. Assessing the environmental impact of energy production from hydrochar generated via hydrothermal carbonization of food wastes. *Waste Management* **43**, 203–217.

ČSN ISO 1928 Solid mineral fuels – Determination of gross calorific value by the bomb calorimetric method, and calculation of net calorific value. 2010 (in Czech)

ČSN ISO 29541Solid mineral fuels – Determination of total carbon, hydrogen and nitrogen content – Instrumental method. 2012 (in Czech)

Heilmann, S.M., Jader, L.R., Sadowsky, M.J., Schendel, F.J., von Keitz, M.G. & Valentas, K.J. 2011. Hydrothermal carbonization of distiller's grains. *Biomass and Bioenergy* **35**(7), 2526–2533.

Kruse, A. & Dahmen, N. 2015. Water – A magic solvent for biomass conversion. *Journal of Supercritical Fluids* **96**, 36–45.

Lu, X., Pellechia, P.J., Flora, J.R.V. & Berge, N.D. 2013. Influence of reaction time and temperature on product formation and characteristics associated with the hydrothermal carbonization of cellulose. *Bioresource Technology* **138**, 180–190.

Malakhova, D.V., Egorova, M.A., Prokudina, L.I., Netrusov, A.I. & Tsavkelova, E.A. 2015. The biotransformation of brewer's spent grain into biogas by anaerobic microbial communities. *World Journal of Microbiology and Biotechnology* **31**(12), 2015–2023.

Malaťák, J. & Dlabaja, T. 2015. Hydrothermal carbonization of stabilized sludge and meat and bone meal. *Research in Agricultural Engineering* **61**(1), 21–28.

Mussatto, S.I., Dragone, G. & Roberto, I.C. 2006. Brewers' spent grain: Generation, characteristics and potential applications. *Journal of Cereal Science* **43**(1), 1–14.

Nagamori, M. & Funazukuri, T. 2004. Glucose production by hydrolysis of starch under hydrothermal conditions. *Journal of Chemical Technology and Biotechnology* **79**(3), 229–233.

Poerschmann, J., Weiner, B., Wedwitschka, H., Baskyr, I., Koehler, R. & Kopinke, F.-D. 2014. Characterization of biocoals and dissolved organic matter phases obtained upon hydrothermal carbonization of brewer's spent grain. *Bioresource Technology* **164**, 162–169.

Poerschmann, J., Weiner, B., Koehler, R. & Kopinke, F.-D. 2015. Organic breakdown products resulting from hydrothermal carbonization of brewer's spent grain. *Chemosphere* **131**, 71–77.

Raud, M., Tutt, M., Olt, J. & Kikas, T. 2015. Effect of lignin content of lignocellulosic material on hydrolysis efficiency. *Agronomy Research* **13** (2), 405–412.

Reza, M.T., Wirth, B., Lüder, U. & Werner, M. 2014. Behavior of selected hydrolyzed and dehydrated products during hydrothermal carbonization of biomass. *Bioresource Technology* **169**, 352–361.

Reza, M.T., Rottler, E., Herklotz, L. & Wirth, B. 2015: Hydrothermal carbonization (HTC) of wheat straw: Influence of feedwater pH prepared by acetic acid and potassium hydroxide. *Bioresource Technology* **182**, 336–344.

Riedel, G., Koehler, R., Poerschmann, J. & Kopinke, F.-D., Weiner, B. 2015. Combination of hydrothermal carbonization and wet oxidation of various biomasses. *Chemical Engineering Journal* **279**, 715–724.

Santos, M., Jiménez, J.J., Bartolomé, B., Gómez-Cordovés, C. & Del Nozal, M.J. 2003. Variability of brewer's spent grain within a brewery. *Food Chemistry* **80**(1), 17–21.

Steiner, J., Procopio, S. & Becker, T. 2015. Brewer's spent grain: source of value-added polysaccharides for the food industry in reference to the health claims. *European Food Research and Technology* **241**(3), 303–315.

Van Loo, S. & Koppejan, J. 2008. *The Handbook of Biomass Combustion and Co-firing*. Earthscan, London, 442 pp.

Weiner, B., Baskyr, I., Poerschmann, J. & Kopinke, F.-D. 2013. Potential of the hydrothermal carbonization process for the degradation of organic pollutants. *Chemosphere* **92**(6), 674–680.

Xiros, C. & Christakopoulos, P. 2012. Biotechnological potential of brewers spent grain and its recent applications. *Waste and Biomass Valorization* **3**(2), 213–232.

Agronomy Research **14**(2), 624–634, 2016

The relationship between precompression stress and rut depth of different soil types in Estonia

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Abstract. In agriculture as well for other purposes off-road vehicles have to move cross-country. Precompression stress is used to describe the load bearing capacity of different soils. The aim of the study is to investigate the relationship between precompression stress and rut depth for different Estonian soil types after 1 and 10 passes of a vehicle. Traffic experiments were conducted at eight experiment sites throughout Estonia using a 7 t truck and a 23 t wheeled vehicle. The experiment sites were selected based on the Estonian soil map. Rut depth was measured after the first pass and ten passes. Undisturbed soil samples were collected from topsoil and from subsoil right next to the track. Soil samples were compressed in an oedometer at stresses of 25, 50, 100, 200, 400 and 600 kPa. The Casagrande procedure was used to determine the precompression stresses. In topsoil, if the moisture content of a soil is high, then the differences in the precompression stress values of the various soil types disappears while in the subsoil layer the precompression stress is more dependent on the soil properties. The precompression stress cannot by itself be used as a threshold value to determine small and large sinkage. The choice of fitting methods for composing of stress compaction curve is critical and led to the preference of the logistic curve. The values of logistic functions at the points of their maximal curvature and calculation based on the area on stress-compaction graph can be used for prediction of rut depths.

Key words: soil bearing capacity, sinkage, soil compaction, logistic curve.

INTRODUCTION

In agriculture as well for other purposes off-road vehicles with different weights and contact pressure have to move cross-country. In many cases repeated passages over the same track is necessary. It is well known fact that the movement of vehicles over the landscape harms the soil environment by compacting it (Alakukku et al., 2003). Compaction of soils is induced by the stress that occurs from the contact between the vehicle and the soil. To stay mobile vehicles cannot cause deep sinkage and ruts. The compaction of agricultural soils can have an especially negative effect on the yield and growth of cereal grains. In Estonia the overall impact of soil compaction by vehicles was investigated by Kuht & Reintam (2004), Kuht et al. (2012). A study from Krebstein et al. (2014) revealed that soil compaction also occurs on cultivated grasslands. It was found that after these areas had been trafficked, the bulk density, as well as the precompression stress increased. Although natural grasslands are used for cross-country movement the compaction and bearing capacity behaviour of these areas has not been as thoroughly investigated.

The strength of soil is influenced by bulk density, moisture content, texture and organic matter content (Lal & Shukla, 2004). The most compressible soil type is peat (van Asselen et al., 2009). Mineral soils that have high organic material content can have a contradictory influence on the compressive properties of soil (Keller et al., 2011). Moist soils are more susceptible to compaction than dry soils. In addition to soil properties, the degree of vehicle sinkage into the soil is also dependent upon the wheel load, tire width, inflation pressure and the number of passes (Botta et al., 2006). According to Soane (1980) a wheel's first pass compacts the soil more than the second or subsequent passes. However, this is also related to the initial soil density level (Botta et al., 2009).

In agricultural studies precompression stress (also called pre-consolidation stress) is often used as a standard measure of compressive strength, or as an indicator of the bearing capacity of soil (Keller et al., 2012; Alakukku et al., 2003). The precompression stress value is acquired through analysis of the stress-strain curve, which is determined using a uniaxial compression apparatus (oedometer). Precompression stress is the stress value between the elastic and plastic regions of soil behaviour (Alakukku et al., 2003). If the stress level on soil surface is lower than precompression stress the soil deformation is elastic and small. Higher stress values would cause plastic and larger deformations of soil (Lebert & Horn, 1991). The standard procedure for obtaining precompression stress is done using the graphical procedure developed by Casagrande (1936). However there are also other methods for determining precompression stress as well (Arvidsson & Keller, 2004). Cavalieri et al. (2008) demonstrated that choice of methods for calculating precompression stress is critical, and has a significant influence on the determination of the precompression stress values.

There have been a limited number of investigations into the relation between precompression stress and rut depth. Hemmat et al. (2014) concluded that, according to tests done with 3.2 t and 5.8 t tractors on calcareous unstable soil, it would be insufficient to consider the precompression stress itself as a universal threshold stress value for high and low sinkage. Moreover, their experiments have revealed that if the ratio of precompression stress to nominal ground pressure is smaller than 1.6, then the soil sinkage is irreversible and significant.

Up to this point, little research has been conducted on the variability of precompression stress values of Estonian soils, or on the rut depth formations left by vehicles moving cross-country. The first purpose of this study is to determine the precompression stress values of selected Estonian soils. The other primary aim is to investigate the relationship between precompression stress, and other characteristics of the stress-strain curves, and rut depths after one or more passes of wheeled trucks on different soil and land use types in Estonia.

MATERIALS AND METHODS

Based on the large scale Estonian soil map (Maaamet.ee), eight experiment sites were selected in order to assess the varying texture and soil moisture regime types. The map defines the soil texture types according to Katshynsky's classification criteria. The physical properties of tested soils are presented in Table 1. Three of the sites were located in areas of agricultural use (Kesa, KaimiI, KaimiII) while the other five sites were located on natural grasslands (LaevaI, Laeva II, Ilmatsalu, Sirvaku, Saverna). The experiments were carried out in 2013 and again in 2014 during the autumn and the spring when the moisture content of the soils were high. The areas were trafficked with a 7 t 2-axle truck that had a wheel load of 18 kN for the first wheel. At the Saverna site a 23 t, 3-axle, wheeled vehicle with a wheel load of 38 kN was used. The tires were inflated to pressure of approximately 6 bars for both test vehicles. With the exception of the Saverna and the Sirvaku test sites, the trafficking was done one time and then ten times over the same rut. At Saverna and Sirvaku only the one pass tests were conducted. The path over which the vehicles travelled was approximately 50–100 m long. The rut depth was recorded after the first pass and again after ten passes after every 1 m, or 5 m at the deepest part. In order to determine the contact area for nominal ground pressure, measurement were done on hard ground.

Table 1. Physical properties of tested soils: soil texture, organic matter (SOM) and gravimetric water content (w)

Site	Depth, cm	Clay, %	Silt, %	Sand, %	SOM, %	w, %
Sirvaku	0	1.4	32.3	66.3	4.0	50.5
	30	7.3	35.7	57.0	0.2	14.0
Kesa	0	7.8	30.7	61.5	1.3	25.9
	40	3.6	21.4	74.9	0.2	16.8
KaimiI	0	18.0	43.3	38.7	4.1	28.3
	30	18.1	63.5	18.4	1.1	39.0
KaimiII	0	0.4	67.8	31.8	15.9	72.4
	30	19.9	53.0	27.1	2.4	49.3
Saverna	0	11.1	20.2	68.7	1.9	27.5
	40	10.8	28.9	60.3	1.5	24.5
LaevaI	0	30.4	37.5	32.1	2.9	30.0
	35	26.3	39.0	34.6	0.6	21.3
LaevaII	0	20.9	48.8	30.3	4.9	38.6
	35	20.0	46.4	33.6	1.2	22.1
Ilmatsalu,	0	-	-	-	40.7	101.3
peat	20	-	-	-	31.6	94.5

Sand (2–0.063 mm), silt (0.063–0.002mm), clay (< 0.002 mm).

The undisturbed soil samples with cylinders (height 3 cm, diameter 10 cm) were collected right next to the ruts from topsoil, i.e. at depth of 0 cm, and from the subsoil. The subsoil layer refers to soil that is found at depths of 30 to 40 cm. This soil layer contains less organic material. The only exception to this sampling protocol was at the Ilmatsalu experiment area where the peat soil samples were taken at 0 cm and at 20 cm. Soil samples were compressed in an oedometer at sequential stresses of 25, 50, 100, 200, 400, 600 kPa. The compression time step was set to 30 seconds in order to reproduce the sudden loading situation of the field. After every stress step the compaction was recorded.

The precompression stress was determined according to the Casagrande procedure (1936). For these purposes a graph showing the compaction versus the logarithm of the applied stress was compiled from the measured data. From stress-compaction curve the point of greatest curvature must be identified. A suitable fitting curve must be used to accomplish this. The measured points of a stress compaction curve were fit via a fourth-grade polynomial and a logistic curve as suggested by Gregory et al (2006). The stress-compaction curve fit results are presented on Fig. 1. A comparison of the two types of fitting curves indicates significant difference in the shape of the stress-compaction curve.

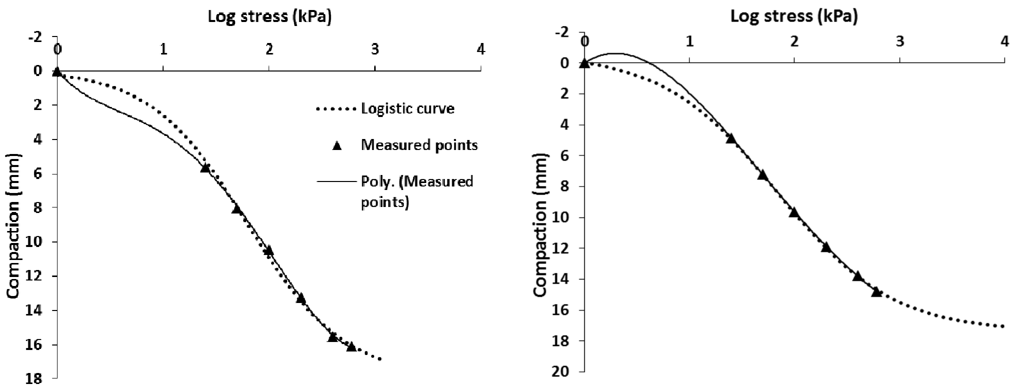

Figure 1. The logistic and fourth-grade polynomial fitting curves of the measured data.

The resulting fourth-grade polynomial curve is producing dependent upon the measured values underestimations or overestimations in compaction at lower stress levels (Fig. 1). It was found that the analytical calculation of the points of the greatest curvatures were in these cases outside the reasonable stress values (log stress from 0.8 to 3 kPa). For the present study 49 samples were measured and fitted with a fourth grade polynomial curve. In 27 of the cases the calculated points of the greatest curvatures were outside the reasonable region, or were even negative in some cases.

For the next step all of the measured stress-compaction curves were numerically fitted with a logistic function (1) and the parameters *a, b, c* and *m* were determined. For parameter *x*, a logarithm of pressure *p* in kPa units ($x = Logp$) and for a parameter *Y* compaction in millimetre units was used.

$$Y = a + \frac{c}{1 + \exp(b(x - m))} \tag{1}$$

The parameters of *a* and *c* of the logistic curve describe the extent of the curve in the direction of the compaction axis, with *m* determining the distance of the inflection point of the curve from the compaction axis, and the multiplication of *bc* determining the slope of the curve at the inflection point. The points of the logistic curve where its third derivate is zero determined the two points of its maximum curvature. The values of the pressure p_c and the logistic function Y_c at the point of the graph's maximum curvature can be calculated according to formulae (2) and (3) respectively:

$$Logp_c = m + \frac{1.317}{b} \quad (2)$$

$$Y_c = a + \frac{c}{4.732} \quad (3)$$

The measured experimental stress-compaction dependencies were fitted with logistic curves with a precision of R^2 that ranged from 0.97 to 0.99. The points of the maximum curvature were calculated according to the determined a, b, c and m values without any visual interpretation of curves. These points of maximum curvatures as distinctive analytically determined parameters of the measured soil samples were also applied towards the analysis of the experimentally measured rut depths of the same soils.

Two longitude values measured in centimetres were selected for the comparison of rut depths using logistic curve parameters that consisted of the values of logistic function Y_c at the point of its maximum curvature at the topsoil and subsoil layers. Two other logistic curve based parameters were also chosen in the units of longitude multiplied by pressure ($S = (Y_c p_c)/2$ and cm kPa units were used in calculations). These were also at the topsoil and subsoil layers. The latter unit is proportional to the work ($A = Fs$ or $A = p\Delta V$) done by the wheel in creating the ruts. On the stress-compaction graph this work is determined by the area between the logistic curve, the pressure axis and the perpendicular line from the pressure axis to the point of maximum curvature on the logistic curve. In order to simplify the calculations, this area was approximated by a triangle, and the logistic curve in the actual interval was replaced by a straight line. The area of this triangle is used as the parameter on the Fig. 3.

For the above described method the point of greatest curvature was calculated according the logistic curve parameters. This was also applied towards the determination of precompression stress. From the stress compaction curve, the point of greatest curvature is identified and at that point the tangent to the stress-strain curve was drawn. The bisector was plotted between the tangent and a horizontal line. Next, the virgin compression line (the straight portion of the stress-strain curve) was drawn. The point of intersection between the bisector and the virgin compression line determined the precompression stress value.

Microsoft Excel and the free software environment R (R Core Team, 2015) were used for the statistical analysis. The *t-test* was used to compare the difference between the precompression values.

RESULTS AND DISCUSSION

The measured rut depth values from the field and the precompression values are illustrated in Table 2.

After the initial passes of the main test vehicle the mean rut depths were similar for all of the tested sites, and ranged from 2.5–7.3 cm. Larger differences in depth occurred after repeated passages and averaged from 6.3 cm to 20 cm. The calculated nominal ground pressure values for the vehicles were 344 kPa for the 7 t truck, and 323 kPa for the 23 t vehicle. The 23 t vehicle produced remarkably deep ruts after first passage despite the fact that the nominal ground pressure and the inflation pressures of the tires were similar to the main test vehicle. This can be attributed to the higher wheel load of the second test vehicle. According to Arvidsson & Keller (2007) tire inflation pressure has a significant influence on soil stresses, as well as on the contact area and the topsoil, i.e. up to depths of 10 cm, wheel load plays a large role in subsoil stresses. As the first axle load of the 23 t vehicle was more than two times than that of the other test vehicle, it also sank more. Therefore, for further modelling of the relationship between rut depth and precompression stress the results from Saverna have been left out. This finding illustrates the importance of the bearing capacity of the subsoil layer.

Table 2. Measured rut depth values after 1 pass and 10 passes, and the calculated precompression values

Site	Rut depth, cm				Soil sampling depth, cm	Precompression stress, kPa	
	1 pass		10 passes			Repetitions	
	Mean	Max	Mean	Max		1.	2.
Sirvaku	4.4	8.0	-	-	0	13	20
					30	63	-
Kesa	3.0	3.3	8.4	11.0	0	14	20
					40	50	45
KaimiI	3.3	6.0	7.3	10.0	0	13	18
					30	63	79
KaimiII	2.5	6.3	6.3	12.3	0	18	8
					30	126	79
Saverna	15.6	21.2	-	-	0	13	13
					40	79	-
LaevaI	4.3	8.0	19.5	33.0	0	20	25
					35	178	199
LaevaII	6.7	10.0	20.0	24.0	0	10	8
					35	158	141
Ilmatsalu	7.3	18.0	13.4	28.0	0	20	18
					20	32	56

The comparison of precompression stress values from the subsoil and topsoil layers of all of the experiment sites indicate that statistically, the precompression stress was significantly ($P < 0.05$) higher for the subsoil layer. The precompression values for the topsoil layer are similar to all of the other measured soil and landuse types. The low variability of the precompression values of the topsoil layer can be associated with the high moisture content of the soils. It is apparent that if the majority of the soil pores are filled with water which is almost incompressible, then the soil texture and organic material content will not have a significant influence on the bearing capacity of the soil. For the subsoil layer the differences in precompression stress are higher and statistically significant ($P < 0.05$). The highest values were found in soils with very high clay contents, i.e. the soil of LaevaI. For the deeper layers the moisture content is lower and the properties of the soil particles have some influence on resistance to the stresses. The initial bearing capacity, however, decreases with repeated passes, especially for soils with higher clay contents and peat soils. The lowest precompression values for both layers of peat soil were found at the Ilmatsalu site.

The results from the experiments indicate that in moist soil the precompression value cannot be used as a predictor of rut depth. The contact stress of the test vehicles exceeded the precompression stress values of the tested soils by a huge margin, but the sinkage after the first pass was not large. As one pass rut depths depend on different soils, the precompression stress values of these soils ($R^2 = 0.002$) is less of a factor. The highest correlation ($R^2 = 0.402$) between the precompression stress of the subsoil layer and average rut depth occurred after ten passes. For this reason only the first parts of the logistic curves and linear model were used in following analysis. The following analysis was applied to the linear model, where a linear dependence between the two variables was assumed and afterwards analysed. The R^2 coefficient of determination was used as a tool to evaluate the proposed dependencies. In Fig. 2 the results show the dependence of the maximal and average rut depths after ten or one passes calculated according to the value of the logistic curve on its point of maximum curvature (Y_c).

A comparison of the R^2 values of the topsoil and subsoil layers from Fig. 2 indicates, that in every fourth case, the results are quite similar. In the graph that uses the subsoil data, the R^2 values for the average and maximal rut depths after one pass are about 30% higher than those of the topsoil data. Confluent ratio is also observable between R^2 values describing ruts depths after 10 passes, here the difference is less than 7% for average and 3% for maximal ruts depths. The highest value of the R^2 was 0.767 for the maximal rut depths after one pass. The R^2 value for average rut depths after ten passes had the smallest values. In both instances $R^2 = 0.2$. Equations for the trend lines in Fig. 2A and B are also rather similar. A comparison of the results presented in Fig. 2 allows us to conclude, that the calculated values of logistic functions at the points of their maximal curvature from the topsoil- or subsoil data may be used to predict one pass rut depths and the maximal depths after ten passes with equal success.

The results of the analysis based on the area on the stress-compaction graph are presented in Fig. 3.

Analysis, which was made on the basis of area, gives a different result based on the topsoil and subsoil data (Fig. 3A and B). Due to the large *m* values of the subsoils, there was a difference of ten times between the scale of the area on the stress-compaction graph and that of the topsoil data. The differences in the results of average rut depths after one pass ($R^2 = 0.221$ or 0.270) are not as striking, although in the case of the maximal rut depths of topsoil, the data showed a value of $R^2 = 0.444$ as opposed to the subsoil data which showed $R^2 = 0.135$ – a difference of more than three times. The significant difference is observable in the instance of average rut depths after ten passes: here the topsoil based data gives only $R^2 = 0.087$ while the subsoil data shows $R^2 = 0.746$, or approximately, an 8.5 times difference. The corresponding R^2 for the maximal values of the rut depths differ by about two times. Comparison of the R^2 values that are presented in Fig. 2 and Fig. 3 allows for the conclusion that in order to predict the rut depths after ten passes (either average or maximum) an area parameter from subsoil should be used.

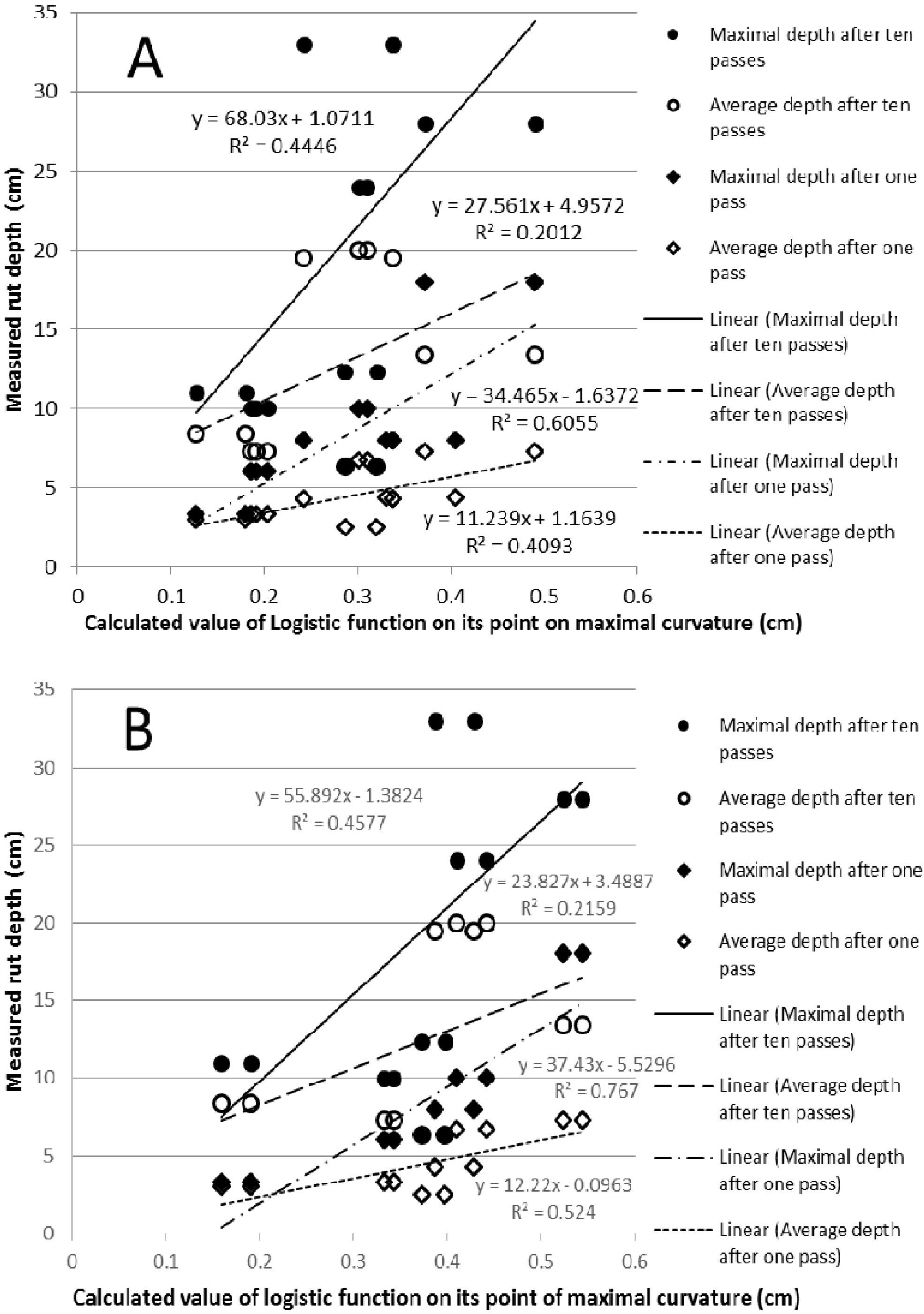

Figure 2. The dependence of the rut depths on the calculated values of the logistic function at the point of its maximal curvature according to the data from the topsoil layer (A) and the same dependence according to the data of the subsoil (B).

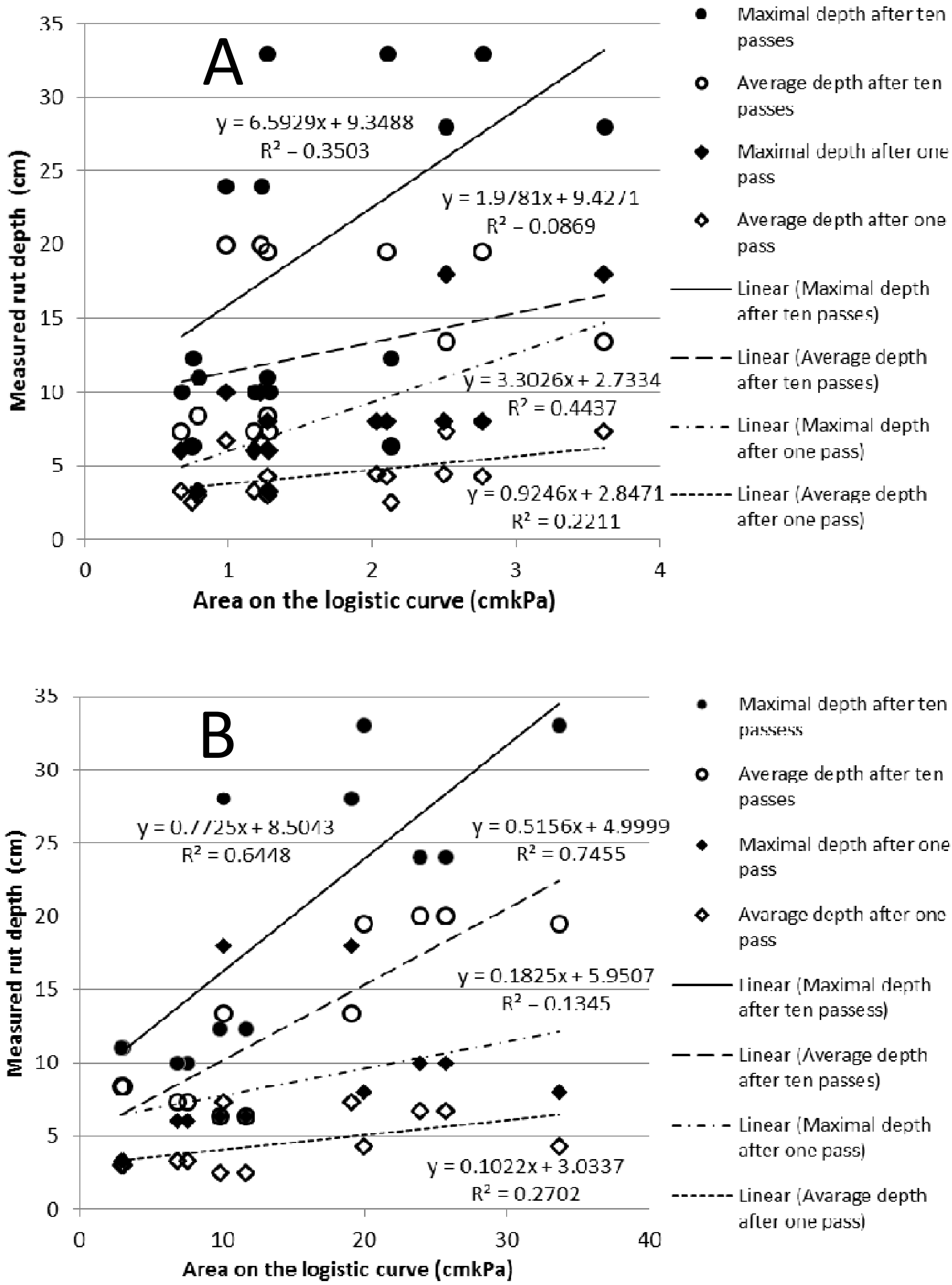

Figure 3. The dependence of the rut depths on an area on stress-compaction graph according to the data of the topsoil (A) and the subsoil (B) layers.

CONCLUSIONS

The precompression stress of topsoil at high moisture content in Estonia is more affected by water content than by other soil properties. In the subsoil layer the precompression stress is more dependent on the soil properties, but the initial high bearing capacity can decrease after repeated passes and deep ruts can form, such as is the case with soils with high clay contents. This study reveals that precompression stress cannot by itself be used as a threshold value to determine extent of sinkage.

Fitting experimental data to the stress-compaction graphs in order to determine the point of the maximum curvature led to the preference of the logistic curves. It was possible to calculate the points of maximum curvature analytically. The analysis allows to conclude that the calculated values of logistic functions at the points of their maximal curvature from the top- or subsoil data are equal in terms of predicting the average rut depths after one pass and the maximal depths after ten passes. For calculating rut depths for ten passes (average or maximal depths) subsoil data should be used with calculation based on the area on stress-compaction graph.

Nominal contact pressure is not the best indicator for determining vehicle sinkage. The results of this study indicate that the bearing capacity properties of the subsoil are more of a factor in rut depth formation than the topsoil properties are. Further investigation is needed to describe the relationship between precompression stress, and other characteristics of the stress-strain curves, and rut depth induced by vehicles with different weights.

REFERENCES

Alakukku, L., Weisskopf, P., Chamen, W.C.T., Tijink, F.G.J., van der Linden, J.P., Pires, S., Sommer, C & Spoor, G. 2003. Prevention strategies for field traffic-induced subsoil compaction: A review. Part 1. Machine/soil interactions. *Soil Tillage Res.* **73**, 145–160.

Arvidsson, J. & Keller, T. 2004. Soil compression stress I. A survey of Swedish arable soils. *Soil Tillage Res*. **77**, 85–95.

Arvidsson, J. & Keller, T., 2007. Soil stress as affected by wheel load and tyre inflation pressure. *Soil Tillage Res*. **96**, 284–291.

Botta, G.F., Jorajuria, D., Rosatto, H., Ferrero, C., 2006. Light tractor traffic frequency on soil compaction in the Rolling Pampa region of Argentina. *Soil Tillage Res*. **86**, 9–14.

Botta, G.F., Tolon Becerra, A., Bellora Tourn, F. 2009. Effect of the number of tractor passes on soil rut depth and compaction in two tillage regimes. *Soil Tillage Res*. **103**, 381–386.

Casagrande, A. 1936. The determination of the pre-consolidation load and its practical significance. In: *Proceedings of the International Conference on Soil Mech. and Found.* Eng. (ICSMFE), Cambridge, MA, 22–26 June 1936, vol. 3. Harvard University, Cambridge, MA, USA, pp. 60–64.

Cavalieri, K.M.V., Arvidsson, J., da Silva, A.P. & Keller, T. 2008. Determination of precomprression stress from uniaxial compression tests. *Soil Tillage Res*. **98**, 17–26.

Gregory, A.S., Whalley, W.R., Watts, C.W., Bird, N.R.A., Hallett, P.D. & Whitmore, A.P. 2006. Calculation of the compression index and precompression stress from soil compression test data. *Soil Tillage Res*. **89**, 45–57.

Hemmat, A., Yaghoubi-Taskoh, M., Masoumi, A. & Mosaddeghi, M.R. 2014. Relationship between rut depth and soil mechanical properties in a calcareous soil with unstable structure. *Biosystems Engineering* **118**, 147-155.

Keller, T., Arvidsson, J., Schjønning, P., Lamande, M., Settler, M. & Weisskopf, P. 2012. In Situ Subsoil Stress-Strain Behavior in Relation to Soil Precompression Stress. *Soil Science*, **177**(8), August 2012 pp 490–497.

Keller, T., Lamandé, M., Schjønning, P. & Dexter, A.R. 2011. Analysis of soil compression curves from uniaxial confined compression tests. *Geoderma* **163**, 13–23.

Krebstein, K., von Janowsky, K., Kuht, J. & Reintam, E. 2014. The effect of tractor wheeling on the soil properties and root growth of smooth brome. *Plant Soil Environ.* **60**(2), 74–79.

Kuht, J., Reintam, E., Edesi, L. & Nugis, E. 2012. Influence of subsoil compaction on soil physical properties and on growing conditions of barley. *Agronomy Research* **10**(1–2), 329–334.

Kuht, J. & Reintam, E. 2004. Soil compaction effect on soil physical properties and content of nutrients in spring barley (*Hordeum vulgare* L.) and spring wheat (Triticum aestivum). *Agronomy Research* **2**(2), 167–194.

Lal, R. & Shukla, M.K. 2004. *Principles of soils physics*. NY: Marcel Dekker Inc. 716 pp.

Lebert, M.& Horn, R. 1991. A method to predict the mechanical strength of agricultural soils. *Soil Tillage Res*. **19**, 275–286.

Maaamet.ee - http://geoportaal.maaamet.ee/eng/Maps-and-Data/Estonian-Soil-Map-p316.html

R Core Team. 2015. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/.

Soane, B.D. 1980. The role of field traffic studies in soil management research. *Soil Tillage Res.* **1**, 205–237.

Van Asselen, S., Stouthamer, E. & van Asch, Th.W.J. 2009. Effects of peat compaction on delta evolution: A review on processes, responses, measuring and modelling. *Earth-Science Reviews* **92**, 35–51.

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