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Web and android applications for district level nutrient management planning

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Abstract. Livestock manure, often perceived as a waste problem, is in fact a valuable nutrient source for plants. Besides, it does not only provide nutrients to plants, also improves soil structure, aeration properties and water retention capacity. A district level manure management study was conducted in Çanakkale/Turkey for developing a web based application for animal manure application rates. The procedure and the outcomes of the study were made available for better use of producers. Therefore, a web and an android based application was developed using java programming language coupled with android job package that accessed database for interaction and presentations of the results. The database was created with PHP scripting language to provide soil analysis results (electrical conductivity, pH, lime, organic matter, nitrogen, phosphorus, potassium, iron, manganese, copper and zinc) and manure application rates for major cultivars (paddy rice, maize, wheat, processing and table tomato) within the Gümüşçay district of Çanakkale and uploaded on a server. Then, a browser access interface to specific web page built up with Massachusetts Institute of Technology (MIT) app inventor 2 for android devices and published on official android market.

Key words: GIS, nutrient management, soil mapping, android application.

INTRODUCTION

Land application of animal manure is a widely accepted mothed of manure disposal and a valuable nutrient source for plants. Animal manure rather than saying waste, supplies a complete band of nutrients (nitrogen-N, phosphorus-P_2O_5, potassium-K_2O, etc.) and organic matter required for crop growth and improvement of soil properties (Kessel et al., 1999). Accurate application can improve the soil texture, aeration and hydration capacity in conjunction with enrichment of nutrients (Hillel, 1980). On the other hand, excessive applications may cause yield limitations, waste of nutrients, and impair ground and surface water as well (Kızıl & Lindley, 2001; Sradnick et al., 2014).

Fertilizers are likely preferred by the producers because of their plant available mineral forms. Therefore, limited use of manure compared that generated from animal breeding program may create a huge waste management challenge over time. Consequently, the producer may get rid of this nuisance by quick dumping off the manure in the land leading to an over fertilization or dispose to surface waters. Over fertilization leads to accumulation of immobile nutrients which are transform plant unavailable forms over long-term (KeDong et al., 2013). Likewise, mobile nutrient (primarily nitrate) leakage to groundwater impairs the water quality (Gerhart, 1986) and runoff through surface waters cause eutrophication which leads to a decrease on biodiversity (Hodgkin & Hamilton, 1993).

Determination of manure application quantity requires a delicate and multi-staged calculation. Otherwise, variable nutrient inclusive of manure affects yield negatively and unfavourable environmental impacts can be observed in the vicinity of land application via runoff, leakage and capillary migration (NRCS, 2005). Existing available nutrient content of soil to be fertilized with, nutrient requirements of the crop to be planted for expected yield, and nutrient content of the manure to be applied must be known to calculate optimum manure application rate. Producers are lean to spread manure over the close range fields (Sharpley et al., 1994; Defra, 2004) and as a result of considering only nitrogen content for determination of application quantity, densely accumulated phosphorus in soil texture can be observed (Haygarth et al., 1998).

Crop nutrient cycle is a natural mechanism which operates according to the conservation of energy law. As illustrated in Fig , nutrients transferred from soil to forage crops via vegetative production, then goes to the livestock as feed, and finally return to soil when manure spread over it. Some of the nutrients leave the cycle in different phases as they turn into biomass or under effect of environmental factors. Aim of nutrient recycle program is to sustain the cycle with least loss and nutrient management programs has been designed to achieve.

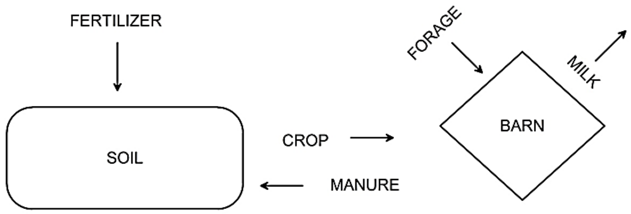

Figure 1. Crop nutrient cycle for dairy farming.

Convenient planning model is applicable to district scale for the territories where livestock and plant production businesses are separated. Fulfilment of nutrient needs in crop production via local livestock production businesses can be sustain within the study areas where regional boundaries were specified for the ease of transportation.

Manure management planning requires to be known the amount of nutrient in soil, depending on location. However, study area must be handled as a whole by the accurate estimations (Basnet et al., 2002). Geographical Information Systems (GIS) can be used for this purpose. GIS, expresses a system which can store and process many qualifier and quantifier data as layers (ESRI, 2010). Also, enables the Cartesian geometry explanations on a geographic position data.

The information, provided from field, has transferred to GIS layers via embedded tools to use as algebraic and statistical calculation inputs. In addition, the visual exposition required to be constituted. However, the complexity originated from third party licensed software has limited the use of knowledge by producers.

Access to internet ratio increases as the increasing use of personal computers and smartphones. Almost every agricultural producer has internet access nowadays. Therefore, producer can have their nutrient application rate in their fingertips if manure management data are available over internet. Therefore, the objective was to develop and test a web based android applications for planning nutrient management.

MATERIALS AND METHODS

This study was conducted in a chosen district to identify potential manure usage on crop fields and provide scientific data to producers over internet. A web page was created using PHP scripting language and all calculations involved with fertilization dose estimation were written in an android programing environment.

Study Area

Gümüşçay District is located 8 km away from the Biga Town, Çanakkale, Turkey (Fig. 2). District has 29,000,000 m^2 agricultural land (TÜİK, 2011).

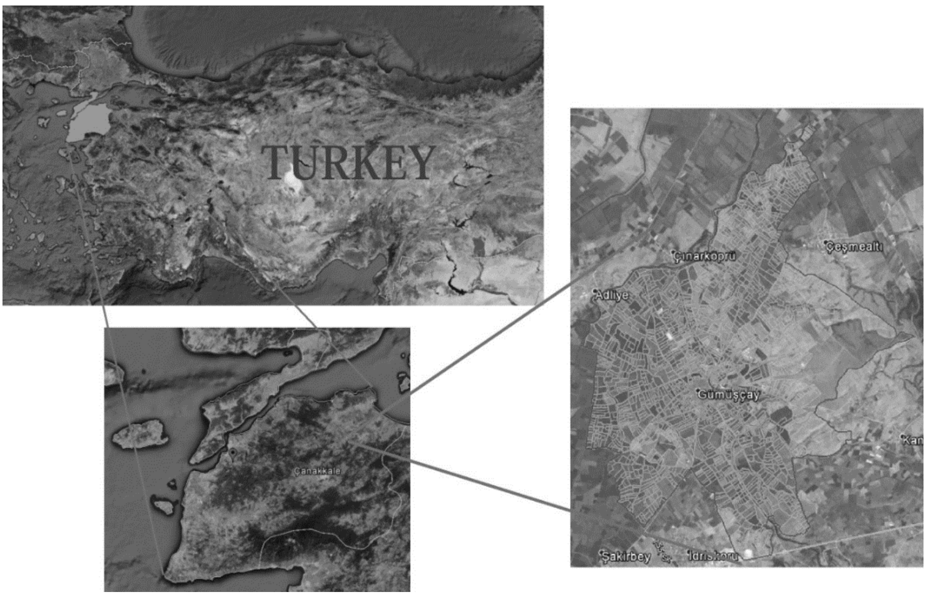

Figure 2. Study area.

According to district directorate of agriculture inventory sheet, there are total 773 milking and 739 heifer cow breeds in this district. Besides, there are 3 different broiler production facilities (poultry) which have a total 250,000 birds. Ovine shelters are located in pasturelands and herd grazing around. Hence, there are no piles of manure exist. Similarly, there is no stored poultry manure accordingly to company contracts. Manure must be stored until its use in a suitable period for a particular plant (crop or forage) production season (Beegle et al., 2000). Therefore, manure amount calculations for the district manure management planning based on bovine.

Quantity of existing nutrients in soil and manure are essential for determining the dosage of animal manure and chemical fertilizer application. Existing digital soil inventory data was obtained from a previous study (Aksu & Kızıl, 2015) and integrated with the animal manure dose estimation algorithm in accordance with the purpose of this research. Quantity of nutrients in animal manure right before application is an another factor to be considered for sound manure management planning (Chescheir et al., 1985). Total amount of nutrients in manure which produced within the district must be accurately determined. In this research, animal manure samples collected from commercial barns were analyzed before estimating application dose. Later on, manure nutrients data was uploaded to a particular location (Web Address) to be integrated with fertilizer dose calculation tools (algorithm) develpped in this research.

Coding Software

Internet based application was chosen because of its easy access, which facilitates user friendly web development and database processing tasks. Simple C# and C++ codes were used to create Hypertext Pre-processor (PHP) web development project. This project was the core of web based applications that linked and processed databases. Project database allows uploading of updated soil inventory, manure application rates, maps as images, and filtering attribute table. On the other hand, android applications are written in java programing language which utilize android job packages. Another method to create android applications is combining logical blocks (Fig. 3) with help of MIT App Inventor 2 (Massachusetts Institute of Technology, Massachusetts, USA). This engine has few benefits namely, it is free of charge, fast response on emulators, and easy online library access. Hence, it eases coding for java and chosen to create android application. Both of the applications connects nutrient management database to retrieve requested info.

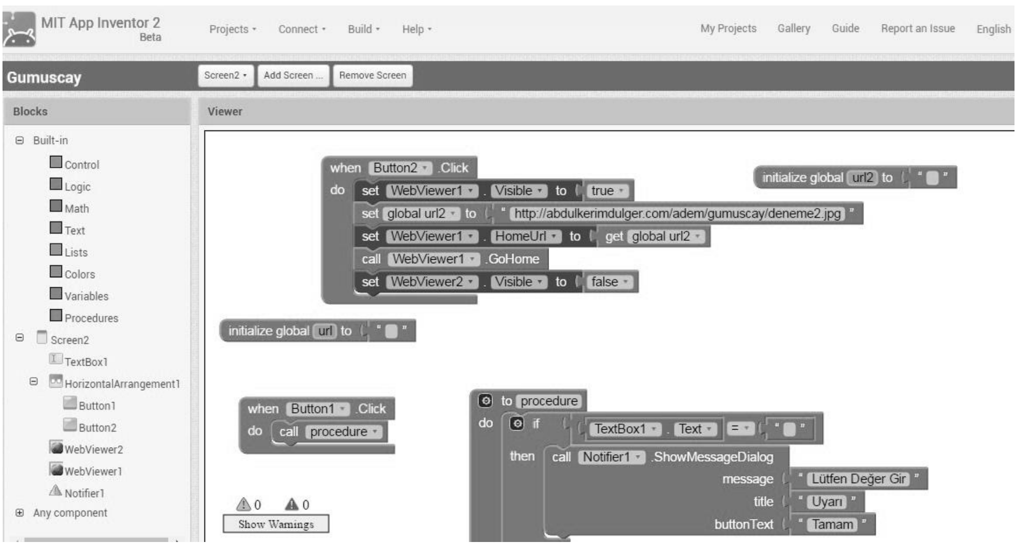

Figure 3. MIT App Inventor logic blocks design.

Method

High definition satellite image covering the target district was clipped from an open source map application. A parcel border layer was added to image and labelled according to parcel numbers that obtained from the Gümüşçay Municipality Civil Works Department. Visualisation of application has prepared by this manner.

Soil nitrogen content of district, nutrients content of the manure and chemical fertilizer, and nitrogen requirement of a crop were used according to the Eq. 1 (MWPS, 1993).

$$N = \frac{\mathrm{N}_{need} - N_{soil}}{[\mathrm{N}_{\mathrm{total}} - (N_{ammonium} + N_{nitrate})] * 0.3 + N_{ammonium} + N_{nitrate}} \quad (1)$$

where: N – nitrogen application; N_{need} – cultivars nitrogen need; N_{soil} – soil nitrogen content, N_{total} – manure total nitrogen content; $N_{ammonium}$ – manure ammonium nitrogen content; $N_{nitrate}$ – manure nitrate nitrogen content.

Soil inventory data and manure application rates for manure and mineral fertilizer were combined into one MS Excel file and organized according to parcel numbers. That was how this manure nutrients database was created, uploaded, and integrated with web based application for determining manure application rates.

RESULTS AND DISCUSSION

All collected and created data uploaded to web server to publish. The web page can be reached at 'http://abdulkerimdulger.com/adem/gumuscay/exread.php'. Users can search the parcels either enlarging the map on the screen or typing parcel number. Application shows the physical characteristics, soil inventory data and manure application rate (according to major cultivars) when 'bring values' button pushed (Fig. 4).

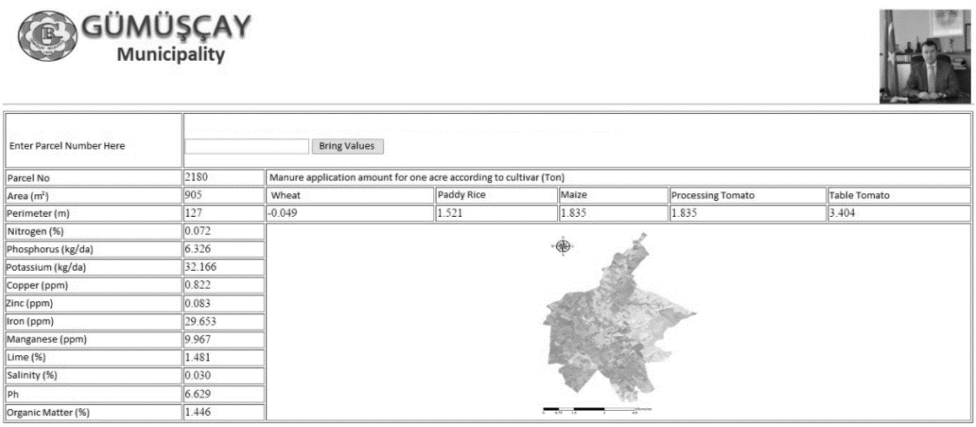

Figure 4. Web application user interface.

The main aim of the project is to serve producers. Therefore, this web based manure application tool was linked along with the description of applications to the official web page of Gümüşçay Municipality. Web based application can be used in mobile devices (smartphones, tablets, etc.) through embedded browsers. But some versions of browsers might encounter page resizing difficulties. Thus an android application has created and published on official Android Market (Fig. 5).

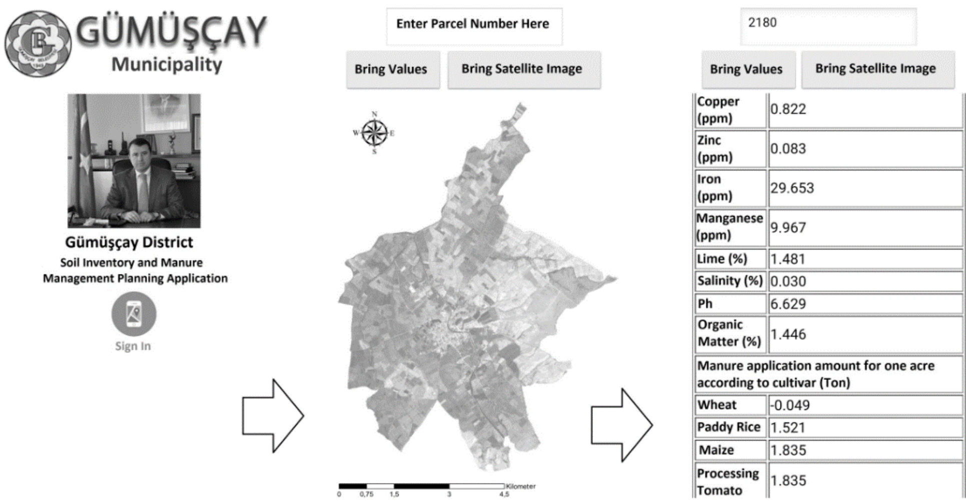

Figure 5. Android application user pages.

Android application is providing a secure path to web application database and the working procedure is the same way. The performance of this application is highly satisfactory and whole system worked without any problem, even if database was updated periodically. Especially soil inventory data varies under the influence of many factors like cultivar variety, tillage method, irrigation method, etc.

CONCLUSIONS

Use of smaller animal manure originated from stockbreeding has increased the use of mineral fertilizer for crop production. This situation has created a critical animal waste management problem for stockbreeders and thus a pollution thread to the environment. Within this context, animal waste management became an important issue, especially for big businesses. In addition, it will be inevitable to take precautions about manure originated environmental problems for Turkey through the European Union adjustment process. However, it was postulated that the lack of knowledge and experience about manure management in big businesses, not even exist for almost every small scale business. Study has conducted either to fulfil of knowledge lack about manure management or reveal an applicable model.

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REFERENCES

Aksu, S. & Kızıl, Ü. 2015. Developing a Town Based Soil Database to Assess the Sensitive Zones in Nutrient Management. *International Journal of Environmental, Chemical, Ecological, Geological and Geophysical Engineering* **9–8**, 818–823.

Basnet, B.B., Apan, A.A., Raine, S.R. 2002. Geographic Information System Based Manure Application Plan. *Journal of Environmental Management* **64**, 99–113.

Beegle, D.B., Carton, O.T., Bailey, J.S. 2000. Nutrient Management Planning: Justification, Theory, Practice. *Journal of Environmental Quality* **29**, 72–79.

Chescheir III, G.M., Westerman, P.M. & Safley, Jr. L.M. 1985. Rapid Methods for Determining Nutrients in Livestock Manures. *Trans ASAE* **28**(6),1817–1824.

Defra. 2004. Mapping the Problem. Risks of Diffuse Pollution From Agriculture. London, UK.

ESRI. 2010. ArcGIS 10 Help.

Gerhart, J.M. 1986. Ground-Water Recharge and its Effects on Nitrate Concentration Beneath a Manured Field Site in Pennsylvania. Ground Water July-August 1986, vol. 24, no.4.

Haygarth, P.M., Chapman, P.J., Jarvis, S.C., Smith, R.V. 1998. Phosphorus Budgets for Two Contrasting Grassland Farming Systems in The UK. Soil Use Manage 14:160–7.

Hillel, D. 1980. Application of Soil Physics. Academic Press, New York.

Hodgkin, E.P. & Hamilton, B.H., 1993. Fertilizer and Eutrophication in Southwestern Australia: Setting the Scene. *Fertilizer Research* **36**, 95–103, Kluwer Academic.

KeDong, A., Jing, Z., DangYang, Z. 2013. Estimation of Phosphourus in Livestock Manure And its Pollution Risk Regionally. *Journal of Henan Agricultural Sciences* **42**(8), p.53–56.

Kessel, J.S., Thompson, R.B. & Reeves III., J.B. 1999. Rapid On-Farm Analysis of Manure Nutrients Using Quick Tests. *Journal of Production Agriculture* **12**(2), 215–224.

Kızıl, Ü. & Lindley, J.A. 2001. Comparison of Different Techniques in The Determination of Animal Manure Characteristics. ASAE/CSAE North Central Sections Conference Brookings, South Dakota. p. SD 01–106.

Midwest Plan Service (MWPS). 1993. Livestock Waste Facilities Handbook, 112 pp. ISBN: 0-89373-089-0.

NRCS, 2005. Applying Manure in Sensitive Areas. Minnesota Pollution Control Agency and USDA Natural Resources Conservation Service.

Sharpley, A.N., Chapra, S.C., Wedepohl, R., Sims, J.T., Daniel, T.C. & Reddy, K.R., 1994. Managing Agricultural Phosphorus for Protection of Surface Waters: Issues and Options. *Journal of Environmental Quality* **3**, 437–51.

Sradnick, A., Oltmanns, M., Raupp, J. & Joergensen, R.G., 2014. Microbial Residue Indices Down the Soil Profile After Long-Term Addition of Farmyard Manure and Mineral Fertilizer to a Sandy Soil. Elsevier Ltd, Oxford, UK, *Geoderma* **226–227**, 79–84.

TUİK, 2011. Turkish Statistical Institute, Annual statistics.

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Evaluation of the surface temperature of laying hens in different thermal environments during the initial stage of age based on thermographic images

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Abstract. The initial stage of laying hens requires important care in relation to the thermal environment, in view of the good development of the birds, the obtaining of good quality pullets and, consequently, the adequate laying rate of adult birds.
The aim of the present study was to study, through thermographic images, the variation of the superficial temperature of laying birds of the Lohmann LSL Lite line, from one to forty-two days of age, submitted to different thermal environments. For this experiment, 864 layer chicks were distributed homogeneously in four climatic chambers. The characterization of the different environments was as follows: thermal comfort conditions (32.8 °C–20.2 °C), two cold stress levels (28.0 °C–17.9 °C and 25.5 °C–17.3 °C) and one level of heat stress (37.4 °C–23.3 °C). The black globe temperature and humidity index (BGHI) was also calculated during the trials. The data were evaluated through the Tukey test, adopting the level of 5% of probability. Via infrared thermography the temperatures of head, body and shank of the laying birds were recorded. The results showed effect ($P < 0.05$) of the temperature of each environment on the surface temperature of the birds. Along with the rise of the ambient temperature, an increase in the surface temperature (head and shank) was found.
Under the recommended comfort treatment, the performance of laying birds during the early-stage, related to the superficial temperature of the birds shows the best values with temperature ranges of 32.8 °C–20.2 °C and BGHI values between 82.3 ± 1.3 and 66.4 ± 1.3.

Key words: environmental conditions, surface temperature, poultry, layer chicks, images analysis, infrared thermography.

INTRODUCTION

The thermal environment during the initial stage of laying hens should be well managed since temperature stress can affect the animal's metabolism, being an important factor in the production efficiency. During the initial stage, the greatest weight variations and the development of organs and all tissues occur. The complete and adequate formation of the organs should occur until five or six weeks of age, and during this period the physiological system is still in development both anatomically and functionally (Albino et al., 2014).

In the current intensive breeding system, the environment has a direct influence on the comfort and animal welfare conditions, affecting the maintenance of the thermal balance inside the facilities and the expression of their natural behaviour, influencing the productive performance of the laying birds (Mashaly et al., 2009; Cândido et al., 2015). The best productivity of the animal is achieved when maintained in a thermoneutral environment, i.e. when the feed energy content is not diverted to compensate for thermal deviations (CIGR, 2002).

The body surface of the birds is characterized by the presence of a layer of feathers, which are more important in the regulation of thermal equilibrium especially when the birds are exposed to cold. During periods of thermal stress, the extremities of birds without feathers, such as the comb, the dewlap and the feet, are usually vasodilated (Richards, 1971; Hillman et al., 1982).

Animal well-being is the full state of physical and mental health, in which the animal is in harmony with the environment where it lives, and a change in the animal's comfort state can be detected through its superficial temperature (Camerini et al., 2016). Nascimento et al. (2014), evaluating the thermal comfort of broiler chickens in two aviaries with different HVAC systems, found that, under conditions of thermal comfort, the superficial temperatures of the birds are strongly associated with the superficial temperatures of the installation.

Relating the thermal well-being to the evaluation of the comfort or stress state of the animals, it is essential to develop measurement techniques easily applicable and non-invasive. Highlighting infrared thermography is a safe and non-invasive thermal profile visualization that can indicate if the animal is under thermal stress (Cilulko et al., 2013). The technique allows a real-time evaluation of the thermal requirements of the animals in order to decide possible adjustments for the best productivity. Infrared cameras measure the amount of IR thermal energy emitted by the surfaces and convert it to surface temperature, producing thermal images that generate a detailed analysis of the temperature (Nascimento et al., 2011).

In order to achieve a better productive performance in poultry breeding, the concern between the interaction of the animal with the environment and the relative energy cost of the physiological adjustments becomes relevant. In this sense, this research was conducted with the objective to correlate the superficial temperature variation of light laying hens, from one to forty-two days of age, with different breeding environments, through thermographic images.

MATERIALS AND METHODS

Characterization of the facilities used during the initial phase

The experiment was developed in four climatic chambers with the following dimensions: 3.20 m long x 2.44 m wide x 2.38 m high, located in the experimental area of the Centre for Research in Ambience and Engineering of Agroindustrial Systems (AMBIAGRO), within the Department of Agricultural Engineering of the Federal University of Viçosa, in Viçosa, Minas Gerais, Brazil. Each climate chamber is equipped with a 2,000 W electric resistance air heater, a hot / cold split air conditioner of rating 3,500 W and an air humidifier with a capacity of 4.5 l and a mist rate of 300 mLh^{-1}. The heater and humidifier are operated by means of an MT-531R Plus electronic controller, temperature and humidity, which has the following specifications: control temperature ranging from -10 °C to 70 °C with a resolution of 0.1 °C, control humidity ranging from 20% to 85%.

The installation has also two AMB axial fans (model FD08025 S1M; DC 12 V, 0.15 A), for the renewal of the air inside the climatic chambers during the whole experimental period.

In each of the four climatic chambers used in this work four different thermal environments were established, constituting four treatments: one of the temperature ranges was considered as the comfort range recommended in the literature (TCL = Comfort Temperature by Literature) (Management Guide Lohmann LSL LITE, n.d.), the others represented two levels of cold stress, mild cold (MiC) and moderate cold (MoC) and one level of heat stress, moderate heat (MoH). Considering that the thermal requirement of the birds varies with the age, an attempt was made to represent this requirement in each week of life of the layer chicks during the experimental period. The variation of the weekly temperature occurred until the fifth week, and the sixth week remained with a temperature similar to that of the fifth week.

Table 1 shows the different temperatures applied during the experimental phase.

Table 1. Air temperature in the internal environment of the climatic chambers, in °C, depending on the treatment and age of the layer chicks

Thermal environment	Temperature (°C)				
	1–7days	8–14days	15–21 days	22–28 days	29–42 days
Moderate heat (MoH)	38	31	29	26	22
Literature approach (TCL)	31-35	28	26	23	19
Mild Cold (MiC)	28	25	23	20	17
Moderate Cold (MoC)	25	22	20	17	17

Management Guide Lohmann LSL LITE (n.d.); Albino et al. (2014); Ferreira (2016).

The relative air humidity was monitored and values maintained throughout the experimental period and in all treatments around 60%, in a range between 55 and 65%, since it is considered an adequate value for poultry production, regardless of the age of the birds (Tinôco, 2001; Ferreira, 2016).

Instruments and measurements used in the characterization of environments

From the first day of experiment the values of air temperature, relative humidity (RH) and black globe temperature (BGT) were recorded every 5 minutes, 24 hours per day, throughout the experimental period.

To measure air temperature and RH, HOBO® T / RH dataloggers, Model U14-001 (-20 °C to + 70 °C), with an accuracy of 0.7 °C for temperature and ± 3% over range of 20% to 80% for RH, were used. In order to obtain the BGT, a black globe was installed inside each climatic chamber, within which a Testo temperature sensor, model 174, with a resolution of 0.1 °C, measuring range from -30 to 70 °C and accuracy of ± 0.5 °C was installed. The sensors were placed at the height of the birds, in the centre of each climatic chamber. Based on the records, the Black Globe Humidity and Temperature Index (BGHI) was calculated by means of the Eq. 1 (Buffington et al., 1981). BGHI is used as reference in many experimental trials carried out in similar conditions in poultry sector in Brazil (Cella et al., 2001; Medeiros et al., 2005; Jacome et al., 2007). It is an accurate indicator of animal comfort and production, preferred to THI under heat-stressing environmental conditions with animals exposed to incident solar radiation, in real breeding situations.

$$BGHI = BGT + DPT\ (0.36) + 41.5 \qquad (1)$$

where: BGHI = Black Globe Humidity and Temperature Index; BGT = Black Globe Temperature, in °C; DPT = Dew Point Temperature, in °C.

Management of laying birds during the initial phase

The experiment was carried out with laying birds from one to forty-two days of age, considered the initial stage for laying birds. During the experimental phase, 864 lightweight laying hens of the Lohmann LSL Lite line were housed in cages, distributed homogeneously in four climatic chambers (four treatments), totalling 216 birds per treatment (Fig. 1). The cages were 0.50 m² in surface (0.50 m wide x 1.00 m long) and 0.50 m high, being six units per chamber.

A B


Figure 1. A) Outside view of the four climatic chambers; B) inside view of one climatic chamber.

From the first day to the end of the fourth week, each cage housed 36 chickens in order to guarantee a density of 140 $cm^2\ bird^{-1}$. From the beginning of the fifth week until the end of the sixth week, the density was of 285 $cm^2\ bird^{-1}$, which corresponds to 18 birds in each cage (Management Guide Lohmann LSL Lite, n.d.; Patterson & Siegel, 1998). This procedure was adopted to guarantee the density used by the poultry industry, under field conditions, for each of the different ages.

For the period from one to forty-two days water and feed were distributed ad libitum, and the work of filling up occurred twice a day (7 and 17 h), in order to keep the drinkers and feeders always supplied.

The experiment was conducted in a completely randomized experimental design, with four treatments (moderate heat, recommended comfort, mild cold and moderate cold), and in subplots with six replications. The data were evaluated through analysis of variance and the means compared using the Tukey test, adopting the level of 5% of probability. The results were interpreted statistically using the System Program for Statistical Analysis and Genetics – SAEG (2007).

Collection of data on physiological variables and productive performance of birds

Additionally, as used by Camerini et al. (2016), the superficial temperature of the head, body and shank were recorded using a ThermaCAM® b60 thermographic camera, FLIR Systems, Wilsonville, OR, USA, temperature range of -20 to 120 °C, ± 2%. Thermographic images of five random birds per cage were obtained, totalling 30 birds for each treatment. The images were processed using the software FLIR Quick Report, 1.2 SP2, FLIR Systems, Wilsonville, OR, USA, thus obtaining the average temperature of the selected areas of the head, body and shank of the birds. The coefficient of emissivity (ε) adopted was 0.95, as Nääs et al. (2010). In all the trials, the thermographic camera was positioned at a distance of 1.30 m from the bird on a side, to better focus and to photograph.

The birds were weighed weekly (BW, in grams). To evaluate the performance the following data were calculated: weight gain (WG, in grams); feed intake (FI), calculated as the difference between the feed provided and leftovers, during the experimental period; feed conversion (FC), consisting of the ratio between weight gain and feed intake.

RESULTS AND DISCUSSION

The values of the physiological and productive performance of birds from one to forty-two days of age in the different thermal environments are presented in Table 2. The conditions of comfort temperature (TCL) allow to obtain better productive performance in terms of weight gain and feed conversion, although the values (BW and FC) do not differ statistically in the four situations.

Table 2. Mean values of head, body and shank temperatures of the birds and accumulated values for body weight (BW) and feed conversion (FC) parameters in laying birds of the Lohmann LSL Lite line during the complete initial phase cycle (1 to 42 days of age), according to the different treatments (TR)

TR	Animal response				
	Head temperature (°C)	Body temperature (°C)	Shank temperature (°C)	BW (g.ave)	FC
MoH	43.42 ± 2.8	40.55 ± 4.8	43.48 ± 3.1	410.72 ± 4.8	2.96
TCL	42.03 ± 1.7	38.98 ± 4.2	42.28 ± 3.0	430.42 ± 3.8	2.81
MiC	41.18 ± 0.6	37.44 ± 2.9	40.73 ± 2.4	409.44 ± 5.2	2.98
MoC	38.73 ± 1.3	34.89 ± 3.3	38.22 ± 2.8	411.68 ± 6.4	3.18

Moderate heat (MoH), comfort recommended by the literature (TCL), mild cold (MiC) and moderate cold (MoC).

Fig. 2 shows a thermographic image taken during trials and processed using the software FLIR Quick Report, 1.2 SP2.

Table 3 shows the average temperature values of thermographic images. In this work the average temperature of the body, head and shank of the birds were recorded, which differed ($P < 0.05$) for all treatments in relation to each evaluation day. Based on these results it is possible to highlight the strong effect that different temperatures exert on birds, thus modifying the physiological response to a given situation.

The observed values for the surface temperature were, in general, higher for the treatments moderate heat and recommended comfort, showing that there was increase of the surface temperature as the ambient temperature increased. Results are in line with research carried out by Nascimento et al. (2011). Evaluating the surface temperature of broilers from 7 to 35 days of age housed in climatic chambers and raised under three different temperatures (18 °C, 25 °C and 32 °C), the authors observed that the values of surface temperature increased significantly with air temperature rising.

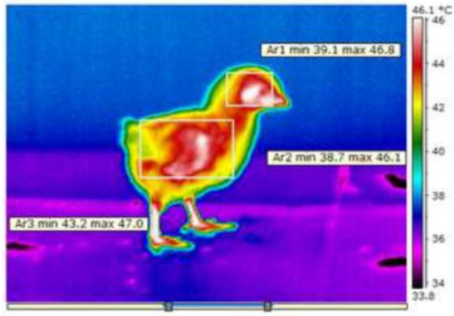

Figure 2. Example of thermographic image taken during trials.

The lower surface temperatures were found in mild and moderate cold stress treatments due to the peripheral vasoconstriction, in which as a way of preventing the loss of heat the bird reduces the blood circulation in order to conserve heat.

It can be observed that the lower values of superficial temperature of the head, body and shank occurred in mild cold treatments and moderate cold treatments. These treatments presented lower body weight and high feed conversion (Table 2), which occurred due to the increase in feed intake used primarily for the addition of calories to maintain homeothermia, not for a weight gain. As a matter of fact, there is a minimum of the metabolic heat production in the 'comfort range', out of which the energy intake increases, even if the temperature rises. At lower temperatures consumption is stimulated, constituting a mechanism of defence of the bird against possible variations of body temperature (Ferreira, 2016).

The temperature values found in the head and shank were higher than the body temperature. This behaviour was also observed by Camerini et al. (2016) which, evaluating the surface temperature of commercial laying birds under different climatic conditions (20 °C, 26 °C and 32 °C), observed that body, head and leg temperatures increased with the rising of air temperature and head temperature values were higher than body and shank temperatures.

This response is due to the fact that in the head region the high surface temperature, favoured by the membranous surface and rich vascular network, makes this area an important site of thermal exchange, where there is a sensitive heat flow from the animal to the environment (Camerini et al., 2016). Hillman et al. (1982) stated that during periods of thermal stress the extremities of birds without feathers, such as comb and dewlap or feet, are usually vasodilated causing greater heat loss. Also for Abreu et al. (2012), the regions without feathers have greater contribution in the exchanges between the corporeal surface and the surrounding environment.

Shinder et al. (2007) observed the effect of exposure of 3 and 4–day–old broilers at low temperatures and found that heat loss from the legs differed from the facial region, suggesting that the legs are a major organ for vasomotor responses, while the face is a more conservative vasoregulatory organ.

The lower temperature found in the body is due to the fact that the feathers contribute to the regulation of the thermal equilibrium. According to Melo et al. (2016), the bird parts covered with feathers favour some thermal insulation and make it difficult to exchange heat with the medium.

Table 3 shows an anomalous trend of temperatures at 36 days of age for all the examined situations. At the beginning of the fifth week the chickens were moved to give a proper surface per head (from 36 to 18 birds per cage). No other specific reasons have been found to explain this behaviour. Further trials could be useful to understand if the values found in the study are reliable and effectively related to managerial conditions or are due to some problems occurred during data collection.

Table 3. Mean values of head temperature, body temperature and shank temperature for laying birds of the Lohmann LSL Lite line, 1 to 42 days of age, for the respective combinations of days and thermal environments

Days of age	Head temperature (ºC)			
	MoH	TCL	MiC	MoC
8	48.65^{a}	43.46^{b}	41.94^{c}	39.61^{d}
15	43.89^{a}	43.71^{a}	41.70^{b}	40.01^{c}
22	43.57^{a}	41.19^{b}	40.44^{b}	37.37^{c}
29	42.25^{a}	41.87^{a}	40.32^{b}	36.70^{c}
36	40.39^{a}	40.03^{a}	41.17^{a}	39.83^{b}
42	41.79^{a}	41.94^{a}	41.54^{a}	38.84^{b}
Days of age	Body temperature (ºC)			
	MoH	TCL	MiC	MoC
8	48.28^{a}	42.72^{b}	41.21^{c}	38.67^{d}
15	43.02^{a}	43.09^{a}	40.69^{b}	38.69^{c}
22	41.81^{a}	39.45^{b}	37.66^{c}	34.16^{d}
29	38.52^{a}	37.80^{a}	34.91^{b}	31.61^{c}
36	35.09^{a}	34.69^{a}	35.22^{a}	35.15^{a}
42	36.60^{a}	36.15^{a}	34.99^{a}	31.06^{b}
Days of age	Shank temperature (ºC)			
	MoH	TCL	MiC	MoC
8	49.00^{a}	42.97^{b}	40.66^{b}	36.82^{c}
15	44.72^{a}	45.48^{a}	43.30^{ab}	40.93^{b}
22	43.55^{a}	41.62^{a}	41.18^{ab}	37.99^{b}
29	40.67^{a}	40.42^{a}	36.03^{b}	33.57^{b}
36	40.57^{a}	40.51^{a}	41.24^{a}	41.23^{a}
42	42.39^{a}	42.73^{a}	41.99^{ab}	38.83^{b}

Moderate heat (MoH), literature approach (TCL), mild cold (MiC) and moderate cold (MoC). The averages followed by at least one letter in the row do not differ, at the 5% probability level by the Tukey test.

The values of temperature and relative humidity of the ambient air, and respective values of BGHI, related to laying birds from one to forty-two days of age, for each treatment are presented in Table 4.

Concerning the BGHI, this index was taken as reference and widely used in studies carried out in Brazil in poultry sector. The main studies refer to broilers (Cella et al., 2001; Medeiros et al., 2005) and some reference values were given only for broilers in different breeding phases. This study applies BGHI to laying hens, trying to give a first contribute to define comfort BGHI values for laying hens during the initial stage of breeding.

Finally, it is observed that the mean values of temperature and relative air humidity remained close to the values proposed for each thermal environment, indicating an adequate control of the environment inside the climatic chambers.

Table 4. Average and standard deviations of the values of air temperature (Tair), relative air humidity (RH) and black globe temperature and humidity index (BGHI) for each climatic condition evaluated in the period from 1 to 42 days

Thermal environment	T_{air} (°C)	UR(%)	BGHI
		(1 – 7 days)	
Moderate heat (MoH)	37.4 ± 0.9	55.5 ± 8.2	87.7 ± 1.5
Literature approach (TCL)	32.8 ± 1.3	56.5 ± 7.6	82.3 ±1.3
Mild Cold (MiC)	28.0 ± 0.3	62.4 ± 3.5	76.3 ± 0.5
Moderate Cold (MoC)	25.5 ± 0.2	57.6 ± 3.5	72.6 ± 0.5
	(8–14 days)		
Moderate heat (MoH)	31.1 ± 1.3	64.1 ± 5.1	80.7 ± 0.6
Literature approach (TCL)	28.2 ± 0.5	62.6 ± 3.4	76.9 ± 0.8
Mild Cold (MiC)	25.3 ± 0.6	55.8 ± 10.1	71.9 ± 1.4
Moderate Cold (MoC)	22.1 ± 0.6	64.9 ± 6.5	69.1 ± 1.2
	(15–21 days)		
Moderate heat (MoH)	29.2 ± 0.7	61.1 ± 6.2	77.5 ± 1.1
Literature approach (TCL)	26.1 ± 0.5	60.4 ± 3.4	72.7 ± 0.9
Mild Cold (MiC)	23.1 ±0.5	61.9 ± 11.2	70.9 ± 1.4
Moderate Cold (MoC)	20.1± 0.8	64.1 ± 4.8	66.3 ± 1.1
	(22–28 days)		
Moderate heat (MoH)	26.0 ± 0.6	65.3 ± 8.1	73.8 ± 1.0
Literature approach (TCL)	23.4± 0.7	62.8 ± 4.7	70.9 ± 1.2
Mild Cold (MiC)	20.3 ± 0.5	60.3 ±7.2	66.8 ± 0.8
Moderate Cold (MoC)	17.9 ± 0.5	64.6 ± 5.9	63.7 ± 0.6
	(29–42 days)		
Moderate heat (MoH)	23.3 ± 1.4	65.6 ± 5.5	70.2 ± 2.4
Literature approach (TCL)	20.2 ± 1.1	65.7 ± 4.7	66.4 ± 1.3
Mild Cold (MiC)	17.9 ± 1.2	65.5 ± 5.9	64.1 ± 0.2
Moderate Cold (MoC)	17.3 ± 0.2	64.2 ± 4.3	62.6 ± 0.2

Moderate heat (MoH), literature approach (TCL), mild cold (MiC) and moderate cold (MoC).

CONCLUSIONS

The research allows to draw some conclusions, which can be useful in further studies on laying hens kept in different thermal conditions.

The use of infrared thermographic imaging has effectively allowed to identify the distribution of the surface temperature of birds occurring at different environmental temperatures. Variations of the surface temperature between the different treatments and higher surface temperatures for the regions without feathers such as the head and shanks of the layer chicks have been detected. Further studies in different breeding conditions should be useful to confirm the values found in these trials.

The performance of layer chicks during the initial phase (from one to forty-two days of age) is better in the comfort treatment as recommended in the literature, with a temperature range of 32.8–20.2 °C and BGHI values between 82.3 ± 1.3 and 66.4 ± 1.3, compared to treatments of moderate heat stress and mild and moderate cold stress. These results confirm that the microclimatic conditions recommended in literature provide acceptable thermal comfort and well-being to birds of this age.

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REFERENCES

Abreu, P.G., Abreu, V.M., Coldebella, A., Hassemer, M.J. & Tomazelli, I.L. 2012. Morphologic measures as a function of the weight and broiler age by means of images. *Rev. Bras. Eng. Agríc. Ambient.* **16**, 795–801 (in Portuguese).

Albino, L.F.T., Carvalho, B.R., Maia, R.C. & Barros, V.R.S.M. 2014. *Laying hens: breeding and feeding*. Viçosa, Aprenda Fácil, 376 pp. (in Portuguese).

Buffington, D. E., Colazo-Arocho, A. & Canton, G. H. 1981. Black globe humidity index (BGHI) as comfort equation for dairy cows. *Trans. ASAE* **24**, 711–714.

Camerini, N.L., Silva, R.C., Nascimento, J.W.B., Oliveira, D.L. & Souza, B.B. 2016. Surface temperature variation of laying hens created in two creation systems using Thermography. *Agropecuária Científica no Semiárido* **12**, 145–152 (in Portuguese).

Cândido, M.G.L., Teles Junior, C.G.S., Tinôco, I.F.F., Arcila, J.C.P., Queiroz, P.P., Oliveira, K.P., França, L.G.F., Coelho, D.J.R. & Barbari, M. 2015. Evaluation of the feeding behavior of broilers in different thermal environments via image analysis. In: *Precision Livestock Farming '15*, 15-18 September, Milan, Italy, pp. 202-207.

Cella, P.S., Donzele, J.L., Oliveira, R. F.M., Albino, L.F.T., Ferreira, A.S., Gomes, P.C., Valerio, S.R. & Apolonio, L.R. 2001. Lysine levels keeping amino acid relationships for 1-21 days broiler chickens, in different thermal environments. *R. Bras. Zootec*. **33**, 433-439 (in Portuguese).

CIGR. 2002. *Climatization of Animal Houses - Heat and moisture production at animal and house levels*. 4th Report of Working Group of International Commission of Agricultural Engineering, Section II. Editors: Pedersen, S. & Sällvik, K., 46 pp.

Cilulko, J., Janiszewski, P., Bogdaszewski, M. & Szczylskagie, E. 2013. Infrared thermal imaging in studies of wild animals. *Eur. J. Wildlife Res.* **59**, 17–23.

Ferreira, R.A. 2016. *Greater production with better environment for poultry, pigs and cattle*. Learn Easy, Viçosa, 296 pp (in Portuguese).

Hillman, P.E., Scott, N.R. & Van Thienhoven, A. 1982. Vasomotion in chicken foot: dual innervation of arteriovenous anastomoses. *Animal Journal Physiology* **242**, 582–590.

Jácome, I.M.T.D., Furtado, D.A., Leal, A.F., Silva, J.H. & Moura, J.F. 2007. Evaluation of thermal comfort indexes for laying-hen houses in the northeast of Brazil. *Rev. Bras. Eng. Agríc. Ambient.* **11**, 527-531 (in Portuguese).

Lohmann LSL-Lite (n.d.). Management guide. www.hylinena.com/UserDocs/ products/Lohmann:LSL-Lite.pdf. Accessed 11.8.2016.

Mashaly, M.M., Hendricks, G.L., Kalama, M.A., Gehad, A.E., Abbas, A.O. & Patterson, P.H. 2004. Effect of heat stress on production parameters and immune responses of commercial laying hens. *Poult. Sci*. **83**, 889–894.

Medeiros, C.M., Baêta, F.C., Oliveira, R., Tinôco, I.F.F., Albino, L.F.T. & Cecon, P.R. 2005. Effects of air temperature, relative humidity and velocity on broilers. *Engenharia na Agricultura* **13**, 277-286 (in Portuguese).

Melo, A.S., Fernandes, R.T.V., Marinho, J.B.M., Arruda, A.M.V., Figueirêdo, L.C. & Fernandes, R.T.V. 2016. Relationship between temperature and nutrition on laying performance. *Pubvet*. **10**, 855–860 (in Portuguese).

Nascimento, G.R., Nääs, I.A., Baracho, M.S., Pereira, D.F. & Neves, D.P. 2014. Infrared thermography in the estimation of thermal comfort of broilers. *Rev. Bras. Eng. Agríc. Ambient.* **18**, 658– 663 (in Portuguese).

Nascimento, G.R., Nääs, I.A., Pereira, D.F., Baracho, M.S. & Garcia, R.2011. Assessment of broiler surface temperature variation when exposed to different air temperatures. *Braz. J. Poultry Sci.* **13** 259–263 (in Portuguese).

Nääs, I.D.A., Romanini, C.E.B., Neves, D.P., Nascimento, G.R.D. & Vercellino, R.D.A. (2010). Broiler surface temperature distribution of 42 day old chickens. *Sci. Agric.* **67** 497–502.

Patterson, P.H. & Siegel, H.S. 1998. Impact of cage density on pullet performance and blood parameters of stress. *Poultry Sci.* **77**, 32–40.

Richards, S.A. 1971. The significance of changes in the temperature of the skin and body core of the chicken in the regulation of heat loss. *J. Physiol.* **216**, 1–10.

Shinder, D., Rusal, M., Tanny, J., Druyan, S. & Yahav, S. 2007. Thermoregulatory responses of chicks (Gallus domesticus) to low ambient temperatures at an early age. *Poultry Sci.* **86**, 2200–2209.

Tinôco, I.F.F. 2001. Industrial aviculture: new concepts of materials, conceptions and constructive techniques available for Brazilian poultry houses. *Braz. J. Poultry Sci.* **3,** 1–26 (in Portuguese).

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Fungicidal activity of ultradisperse humic sapropel suspensions

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Abstract. The study compared the effect of two ultradisperse humic sapropel suspensions (UDHSS), obtained in Seryodka deposit (Pskov region, Russia), on viability of *Aspergillus niger* in four experiments. In Experiment 1, *Aspergillus niger* strain L–4 conidia with titre (3.1–3.7) × 10^3 CFU cm^{-3} were suspended in 0.1 cm^3, 1.0 cm^3, 2.0 cm^3, 3.0 cm^3, or 5.0 cm^3 of either UDHSS, and immediately incubated on wort agar. In Experiments 2 and 3, *Aspergillus niger* L–4 conidia with the same titre were suspended in and remained in contact with 0.1 cm^3, 1.0 cm^3, 2.0 cm^3, 3.0 cm^3, or 5.0 cm^3 of UDHSS for 2 or 24 hours at (20.5 ± 0.5) °C (68.9 ± 0.9°F) and incubated on wort agar. The number of colonies in Petri dishes upon 24 hours and 5 days of cultivation was observed. In Experiment 4, contamination of barley grain and distillers' dry grain (DDG) was simulated. DDG treated with 20 cm^3 kg^{-1} of either suspension was inseminated with *Aspergillus niger* L–4 at (5.1–5.3) × 10^3 CFU cm^{-3}, and put under standard storage conditions, changes of microflora examined at 24 hour intervals during 5 days. As a result of Experiment 1, in consideration to statistical significance, there was little fungicidal action on *Aspergillus* conidia. In Experiments 2 and 3, a prominent fungicidal effect was demonstrated by both sapropel suspensions. In Experiment 4, both types of suspensions exhibited a statistically significant effect on *Aspergillus* conidia only in samples previously remaining in contact with 3.0 or 5.0 cm^3 of suspension. Amplitude of the effect proved to be dependent on both UDHSS dosage and time of contact (2 or 24 hours).

Key words: *Aspergillus niger*, distillers' dry grain, ultradisperse sapropel suspensions, fungicidal activity.

INTRODUCTION

Sapropel is benthos found in bodies of still fresh water, formed under anaerobic conditions from dead organic matter of hydrobiotic microflora and microfauna. The principal components of sapropels are minerals and organic compounds known as humic substances. The ratio between mineral and organic components would change depending on depth of sapropel deposition, size of the body of water, its natural surroundings, and many other factors (Avdeyeva et al., 2009).

Humic substances in sapropels contain three types of compounds: fulvic acids, humic acids and humin (Shtin, 2005; Kosov, 2007; Buzlama et al., 2010).

Fulvic acids are components of humus comprising a pronounced peripheral area and a less prominent aromatic core. Fulvic acids are the first products of humification (Shtin, 2005).

Humic acids are components of humus comprising a non-pronounced peripheral area and a prominent heterocyclic core. Hydrogen atoms in prosthetic groups are easily substituted by metal ions, forming salts (humates) (Kireycheva, 2006).

Humin is a non-dissolvable component of humus containing both fulvic acid and humic acid residues strongly bonded with mineral soil components. Such complexes are also known as ulmins (Shtin, 2005; Lishtvan et al., 2012).

The minerals contained in sapropels are non-metallic ions of carbon, phosphorus, silicon, and sulphur, and multiple trace elements: beryllium, boron, brome, chrome, among others.

Previously, several studies have suggested that some of said components may cause antimicrobial activity of sapropels (Kireycheva & Khokhlova, 2000; Gorbunovskaya & Kurzo, 2001; Dolgopolov, 2006; Kulikova et al., 2013; Platonov et al., 2014).

Substandard procedures in storage of food industry produce and raw materials may cause contamination by a microflora of bacteria and fungi. Contamination not only compromises food safety, but may also cause loss of valuable nutrients, since very active hydrolytic enzymes can be synthesized by some of the microorganisms causing spoilage, including *Aspergillus niger* fungus.

Due to high activity of its hydrolases (mainly amylases), *Aspergillus niger* is used for obtaining commercial enzymes. High output citric and gluconic acid production from molasses or a starchy material, e.g. grain, can also be achieved with specialized strains of the fungus (Vybornova & Sharova, 2015).

To prevent contamination and deterioration of stored food and raw materials, many physical and chemical means can be applied (Abraskova et al., 2013). In biotechnological practices, where sterility is vital, various antiseptics (Sharova et al., 2012) and other means of antimicrobial action (Sharova & Kamen’kova, 2012) are also used.

The studies mentioned above (Gorbunovskaya & Kurzo, 2001; Dolgopolov, 2006; Kulikova et al., 2013; Platonov et al., 2014) provide proof that humic substances and particularly humates contain microbial growth, the amplitude of the effect being on par with synthetic antibiotics such as hydrocortisone. Inhibitory effect towards *Staphylococcus aureus*, *Escherichia coli* and other bacteria, as well as *Candida* yeast, was demonstrated. To make use of biologic activity of humic salts, sapropels should be subjected to extraction. It is believed that variations in extraction techniques affect properties exhibited by the recovered material, as more bioactive substances may be made available with more rigorous treatment (Gostischeva et al., 2004).

The containing effect may prove useful in pharmacology and food industry, including food production facilities that recycle other manufacturers’ by-products. One such by-product is distillers’ dry grain (DDG), which can be used as feed at livestock plants. Adding antibiotics to DDG has been an accepted practice for years, but is ceding (Jacques, 2003) due to growing awareness of antibiotic misuse danger for both humans and animals (World Health Organization, 2015). Sapropel treatment of animal feed reportedly improves livestock productivity (Kireycheva & Khokhlova, 2000; Dolgopolov, 2006), which provides an alternative to antibiotics in feed preservation.

The present study aimed to demonstrate potential of sapropels as anti-spoilage agents for grain and DDG storage stability assurance.

MATERIALS AND METHODS

The objects of the study were ultradisperse humic sapropel suspensions (referred to from here on as 'UDHSS–1' and 'UDHSS–2') obtained in RAS Lake Ecology Institute with alkaline extraction and ultrasound treatment of air-dry sapropels from Seryodka deposit (Pskov region, Russia). Both samples were subjected to ultrasound at 35 kHz frequency and pressure of 2 W cm^{-2}. The principal difference between the two suspensions was more intense thermal treatment during UDHSS–2 extraction: 40 °C (104 °F) as compared to 20 °C (68°F) for UDHSS–1.

The materials of the study were barley of 2015 autumn harvest, as well as distillers' dry grain (DDG). DDG was recovered from whole stillage as 'wet cake' at 30% moisture and dehydrated to 10% moisture to imitate standard storage humidity.

Automatic titrator 848 Titrino Plus (Metrohm) was used for determination of UDHSS pH. The device operates in two modes: titration with automatic endpoint determination and pH measurement, the latter used in the experiments (other preferences by default). Time of assay was no less than 3 minutes.

Refractometer PTR 46 (Index Instruments) was used for assessment of UDHSS extract, under the manufacturers protocol 'Brix measurement with temperature correction'.

Moisture analyzer MOC120H (Shimadzu) was used for assessment of all materials moisture content, under the manufacturer's protocol 'Slow drying method' with automatic endpoint determination. The endpoint was determined as the point at which mass drift fell below the preset value of 0.001 g.

Polarimeter PolAA FF55 (Optical Activity) was used for measuring apparent starch in barley and DDG according to Ewers method (ISO/TC 93, 1997).

Protein content in DDG was measured according to ASBC method Brewers' Grains–7 (ASBC, 1992).

Humic acid content was measured with ISO method 19822:89 (EC Joint Research Centre, 1989).

Chromium, copper, iron, manganese, and zinc content was measured according to ISO method 17321:2008 (EC Joint Research Centre, 2008).

Cadmium and lead content was measured with ISO method 17318:2015 (EC Joint Research Centre, 2015).

Lipid content in DDG was measured with ISO method 3596:2000 (ISO/TC 34, 2000).

The effect of UDHSS on vitality of *Aspergillus niger*, a common contaminant of stored grain, as well as stored DDG, was studied in four experiments. Strain L–4 of *Aspergillus niger*, chosen for its high enzymatic activity, was cultivated in 750 cm^3 shaker flasks on the following medium: 150.00 g dm^{-3} carbon source; 2.50 g dm^{-3} ammonium nitrate (NH_4NO_3); 0.25 g dm^{-3} heptahydrous magnesium sulphate ($MgSO_4$

7H_2O); 0.16 g dm^{-3} potassium phosphate (KH_2PO_4); water enough to get 750 cm^3; pH 6.5 (Mushnikova et al., 2001; Vybornova & Sharova, 2015).

In order to assess antifungal activity of UDHSS, their respective minimum inhibitory concentrations were determined with the common dilution method (EUCAST, 2017). Broth microdilution is usually advised, but for single-strain cultures, 1 cm^3 dilution (macrodilution) may be used, as fidelity loss is negligible due to strain uniformity of the culture. Additionally, wort agar was used instead of broth so that all samples could be kept together in the same incubators. Total number of colony-forming units (CFU) in 1 cm^3 suspensions after incubation on wort agar at 32 or 37 °C (90 or 100°F) was calculated. 1 cm^3 of each suspension was mixed with 8–12 cm^3 wort agar at 45 °C (113°F), before cooling of the agar, in a sterile Petri dish, two samples per each suspension, and incubated one at 32 °C (90°F) and the other at 37 °C (100°F) for (24 ± 2) hours stacked upside down.

In Experiment 1, *Aspergillus niger* strain L–4 conidia with titre (3.1–3.7) × 10^3 CFU cm^{-3} were suspended in either UDHSS, the volume of the suspensions varying between 0.1 cm^3, 1.0 cm^3, 2.0 cm^3, and 5.0 cm^3. Immediately after, the conidia were incubated on wort agar.

In Experiments 2 and 3, *Aspergillus niger* L–4 conidia with the same titre were suspended and remained in contact with in 0.1 cm^3, 1.0 cm^3, 2.0 cm^3, or 5.0 cm^3 of one of UDHSS for 2 or 24 hours at (20.5 ± 0.5) °C (68.9 ± 0.9°F) and incubated on wort agar. The number of colonies in Petri dishes upon 24 hours of cultivation was observed for all suspended *Aspergillus* samples.

In Experiment 4, contamination of barley grain and distillers' dry grain (DDG) was simulated. Grains of barley used in the study were sampled at a warehouse and proved to be previously contaminated with spoilage microorganisms (but not *Aspergillus niger*) which made the experiment resemble actual storage conditions. Barley and DDG were treated with 20 cm^3 of either sapropel suspension per 1 kg. The materials were then inseminated with *Aspergillus niger* L–4 at (5.1–5.3) × 10^3 CFU cm^{-3}, put under standard storage conditions, and examined at for changes of microflora 24 hour intervals during 5 days.

RESULTS AND DISCUSSION

Physical and chemical composition of UDHSS, barley, and DDG

According to UDHSS assay carried out, the suspensions were equally strong alkali but were quite different in almost every other aspect. UDHSS–2 had extract, sugars, lipids, and many metals content, especially iron, higher compared to UDHSS–1 (Table 1).

Basic physical and chemical properties of barley grain were assayed (Table 2) and found to comply with food grade standards for moisture content, Ewers apparent starch, and foreign particles content (Skurikhin & Tutel'ian, 2002).

Table 1. Physical and chemical properties of UDHSS samples

Parameter	Measurement unit	Value	
		UDHSS-1	UDHSS-2
pH		13.10	13.20
Extract	°Plato	4.61	14.95
Sugars	mg cm^{-3}	3.20	5.50
Lipids	mg cm^{-3}	275.00	1,070.00
Humic acids	% (dry matter)	20.70	38.72
Trace metals	mg kg^{-1}		
Cd		1.35	1.34
Co		7.49	7.09
Cr		1.23	4.00
Cu		0.96	9.15
Fe		8.28	456.3
Mn		4.46	4.34
Ni		6.92	6.78
Pb		8.11	9.62
Zn		2.38	1.94

Table 2. Physical, chemical and nutritive properties of barley grain

Parameter	Measurement unit	Value
Moisture	%	8.51 ± 0.10
Apparent starch	% (dry matter)	56.70 ± 1.10
Foreign particles		0.69 ± 0.10

Physical, chemical and nutritive properties of DDG were also assayed (Table 3).

Table 3. Physical, chemical and nutritive properties of distillers' dry grain

Parameter	Measurement unit	Value
pH	–	4.67
Extract	°Plato	90.60
Sugars	% (dry matter)	12.70
Crude protein	% (dry matter)	27.10 ± 1.90
Digestible protein	% dry (matter)	21.10 ± 1.10
Hydrolysable carbohydrates	% (dry matter)	2.25 ± 0.11
Total lipid	% (dry matter)	5.40 ± 0.30
Total ash	% (dry matter)	4.49 ± 0.22
Total fibre	% (dry matter)	7.00 ± 0.40

Experiments 1–3. Fungicidal effect of UDHSS on *Aspergillus niger* conidia

In the first three experiments, fungicidal effect of UDHSS on *Aspergillus* conidia was assayed after 24 hours of incubation on wort agar (Table 4).

Table 4. Fungicidal effect of UDHSS after 24 hours of incubation

Sample name	Time at (20.5 ± 0.5) °*C* (69 °*F*), hours	Volume of UDHSS, cm^3				
		0.1	1.0	2.0	3.0	5.0
Fungal growth in Experiment 1, *CFU* cm^{-3} ($P < 0.05$)						
UDHSS–1	–	$3–4 \times 10^3$	$3–4 \times 10^3$	$3–4 \times 10^3$	50–200	50–200
UDHSS–2	–	$3–4 \times 10^3$	$3–4 \times 10^3$	$3–4 \times 10^3$	–	5–10
Fungal growth in Experiments 2 and 3, *CFU* cm^{-3} ($P < 0.01$)						
UDHSS–1	2	5–10	5–10	–	–	–
UDHSS–2	2	5–10	5–10	–	–	–
UDHSS–1	24	–	–	–	–	–
UDHSS–2	24	–	–	–	–	–

In Experiment 1, fungicidal effect of UDHSS on *Aspergillus* conidia was observed in samples with 3.0 or 5.0 cm^3 of a suspension only. UDHSS–2 has exhibited a stronger fungicidal effect than UDHSS–1.

In Experiments 2 and 3, both types of suspensions had a significant fungicidal effect on *Aspergillus* conidia only in samples previously remaining in contact with 3.0 or 5.0 cm^3 of UDHSS, more notably UDHSS–2.

Additionally, fungicidal effect on *Aspergillus* conidia upon 5 days of incubation was assayed (Table 5).

Table 5. Fungicidal effect of UDHSS after 5 days of incubation

Sample name	Time at (20.5±0.5) °C (68.9 °F), hours	Volume of UDHSS, cm^3				
		0.1	1.0	2.0	3.0	5.0
Fungal growth in Experiment 1, CFU cm^{-3} (P < 0.05)						
UDHSS–1	–	$3–4 \times 10^3$	$3–4 \times 10^3$	$3–4 \times 10^3$	$3–4 \times 10^3$	$3–4 \times 10^3$
UDHSS–2	–	$3–4 \times 10^3$	$3–4 \times 10^3$	$3–4 \times 10^3$	$3–4 \times 10^3$	$3–4 \times 10^3$
Fungal growth in Experiments 2 and 3, CFU cm^{-3} (P < 0.01)						
UDHSS–1	2	$3–4 \times 10^2$	$3–4 \times 10^2$	5–10	–	–
UDHSS–2	2	$3–4 \times 10^2$	$3–4 \times 10^2$	5–10	–	–
UDHSS–1	24	50–200	50–200	5–10	–	–
UDHSS–2	24	50–200	50–200	5–10	–	–

During 5 days of incubation, again both types of suspensions had a notable effect on *Aspergillus* conidia only if contact with 3.0 or 5.0 cm^3 of a suspension was maintained.

Experiment 4. Effect of sapropel extracts on barley grain and DDG spoilage microflora

Grains of barley used in the study proved to be previously contaminated with spoilage microorganisms, but not *Aspergillus niger* (Table 6).

UDHSS had an effect on spoilage microflora, including *Aspergillus niger*, in all samples, but it was only in samples with 0.5 cm^3 or more UDHSS that a lasting antimicrobial effect was observed.

Table 6. The effect of UDHSS on barley grain spoilage microflora

Sample name	Volume of UDHSS, cm^3	Time of storage, hours				
		24	48	72	96	120
Control (no *Aspergillus*)	–	‡	‡	‡‡	‡‡	‡‡‡
Control (with *Aspergillus*)	–	‡ 50–200	‡ 50–200	‡‡ 50–200	‡‡ 50–200	‡‡ $3–4 \times 10^2$
UDHSS–1	0.1	–	+	+	‡ 5–10	‡ 5–10
UDHSS–2	0.1	–	–	–	‡ 5–10	‡ 5–10
UDHSS–1	0.5	–	–	–	5–10	‡ 5–10
UDHSS–2	0.5	–	–	–	–	5–10
UDHSS–1	1.0	–	–	–	–	–
UDHSS–2	1.0	–	–	–	–	–

Legend. «‡»: growth density of other microorganisms than Aspergillus niger. «–»: no growth; «‡»: moderate growth; «‡‡»: significant growth; «‡‡‡»: dense growth.

DDG used in the study proved to be previously contaminated with spoilage microorganisms., but not *Aspergillus niger* (Table 7).

Table 7. The effect of UDHSS on DDG spoilage microflora

Sample name	Volume of UDHSS, cm^3	Time of storage, hours				
		24	48	72	96	120
Control (no *Aspergillus*)	–	–	–	‡‡	‡‡	‡‡‡
Control (with *Aspergillus*)	–	–	‡ 50–200	‡ 50–200	‡ 50–200	‡‡ $3–4 \times 10^2$
UDHSS–1	0.1	–	–	–	–	+
UDHSS–2	0.1	–	–	–	–	–
UDHSS–1	0.5	–	–	–	–	–
UDHSS–2	0.5	–	–	–	–	–
UDHSS–1	1.0	–	–	–	–	–
UDHSS–2	1.0	–	–	–	–	–

Legend. «‡»: growth of other microorganisms than Aspergillus niger. «–»: no growth; «‡»: moderate growth; «‡‡»: significant growth; «‡‡‡»: dense growth.

After 5 days of incubation, both types of suspensions have shown a significant fungicidal effect on *Aspergillus* conidia, more notably UDHSS–2. While amplitude of the effect again proved to be proportional to suspension volume, the dosage necessary for an antimicrobial effect to show was 6 times less, 0.5 cm^3, compared to the effective minimum in the previous experiments, 3.0 cm^3 UDHSS. This can be attributed to some constituents of barley kernels and DDG that may exhibit a synergic antimicrobial effect if the stored material is treated with UDHSS.

CONCLUSIONS

In the current study, ultradisperse humic sapropel suspensions have proven to have significant fungicidal properties, consistently dependent on volume applied, even in small doses. UDHSS–2 sample was found to exhibit higher antifungal potency, probably due to more fungicidal components extracted with more intense thermal treatment.

The pronounced containing effect of sapropel suspensions on *Aspergillus niger* conidia may be attributed to inhibition of *Aspergillus* cell growth and enzyme synthesis by copper, iron and zinc atoms. Since UDHSS–2 contained ten times more copper and 55 times more iron compared to UDHSS–1, a conclusion can be drawn that these metals are at least partly responsible for loss of fungal viability.

Additionally, lipids contained in both suspensions may affect spore surface permeability, preventing nutrient uptake and spore germination.

As an adverse effect, some amounts of nutrients and vitamins contained in the suspensions may cause development of microbial colonies other than *Aspergillus niger*. Careful dosage of UDHSS for antimicrobial use is therefore advised.

Fungicidal properties of UDHSS may find application in industrial grain, and by-products such as distillers' grain, storage procedures. Sapropel can be found in lakes of various regions, so its use for economical hygienic procedures in food and microbial biotechnology is open to consideration. However, properties of sapropels may vary significantly, which requires study of its chemical composition for extraction techniques, suspension dosage and exposure time adjustment.

REFERENCES

Abraskova, S.V., Shashko, Y.K. & Shashko, M.N. 2013. Biological Safety of Feedstuffs. Minsk, 256 p. (in Russian).

ASBC (American Society of Brewer Chemists). 1992. Brewers' Grains–7. Protein (N × .25) by Combustion. Available: http://methods.asbcnet.org/methods/BrewersGrains–7.pdf. Addressed 03.31.2017.

Avdeyeva, L.N., Kovalyenko, T.A. Krivonos, O.I., Plaksin, G.V. & Strunina, N.N. 2009. Determination of sapropel chemical composition // *Chemistry and Chem. Eng.* **52**(3), 121–123 (in Russian).

Buzlama, A.V. & Chernov, Y.N. 2010. Pharmacological properties, action pathways and prospectives of humic substances in medicine: an analysis. *Exper. Clin. Pharm.* **73**(9), 43–48 (in Russian).

Dolgopolov, V.N. 2006. Trials of Gumival™ yield better bovine, swine and fowl stock productivity. In: *Proceedings of conference on summaries and perspectives of humin preparations in livestock industry*. Moscow, p. 40–43 (in Russian).

Dyomin, V.V., Tyeryent'yev, V.A. & Zavgorodnaya, Y.A. 2003. Action pathway of humic substances on living cells. In: *Proceedings of International conference on humus components in the biosphere*. Moscow–Saint Petersburg, pp. 34–35 (in Russian).

EC Joint Research Centre, 1989. ISO/CD 19822 Fertilizers and soil conditioners – Determination of humic and fulvic acids in commercial solid and liquid humic products using alkaline extraction, hydrophobic adsorbent resin and gravimetric determination. *http://www.iso.org/iso/home/store/catalogue_ics/catalogue_detail_ics.htm?ics1=65&ics2=080&csnumber=66271*. Accessed 02.01.2017.

EC Joint Research Centre, 2008. ISO 17321:2008 Fertilizers and soil conditioners – Determination of calcium, sodium, phosphorus, magnesium, potassium, sulphur, iron, zinc, copper, manganese, cobalt and molybdenum by ICP-AES. *http://www.iso.org/iso/home/store/catalogue_ics/catalogue_detail_ics.htm?ics1=65&ics2=080&csnumber=59568*. Accessed 02.01.2017.

EC Joint Research Centre, 2015. ISO 17318:2015 Fertilizers and soil conditioners – Determination of arsenic, cadmium, chromium, lead and mercury contents by AAS. *http://www.iso.org/iso/home/store/catalogue_ics/catalogue_detail_ics.htm?ics1=65&ics2=080&csnumber=59575*. Accessed 02.01.2015.

EUCAST (European Committee on Antimicrobial Susceptibility Testing), 2017. Method for the determination of broth dilution minimum inhibitory concentrations of antifungal agents for conidia forming moulds. *http://www.eucast.org/fileadmin/src/media/PDFs/EUCAST_files/AFST/Files/EUCAST_E_Def_9_3_1_Mould_testing_definitive.pdf*. Accessed 02.01.2017.

Gorbunovskaya, O.M. & Kurzo, V.B. 2001. New methods of sapropel composition analysis. *Chemistry and Chem. Eng.* **2**, 73–81 (in Russian).

Gostischeva, M.V., Fyed’ko, I.V. & Posnichenko, Y.S. 2004. A comparative survey of humic acid extraction from peat in humin preparation // *TUSHS Newsletter*: *Autom. Systems in Data Proc. and Design*, p. 66–69 (in Russian).

ISO/TC 93 (International Organization for Standardization Technical Committee 93), 1997. ISO 10520:1997 Native starch – Determination of starch content – Ewers polarimetric method. *https://www.iso.org/obp/ui/#iso:std:iso:10520:ed-1:v1:en.* Accessed: 03.31.2017.

ISO/TC 93 (International Organization for Standardization Technical Committee 34), 2000. ISO 3596:2000 Animal and vegetable fats and oils – Determination of unsaponifiable matter – Method using diethyl ether extraction. *https://www.iso.org/obp/ui/ #iso:std:iso:3596:ed-1:v1:en.* Accessed: 03.31.2017.

Jacques, K.A. 2003. Ethanol production and the modern livestock feed industry: a relationship continuing to grow. *The Alcohol Textbook*, *4th ed*. 377–385

Kireycheva, I.D. 2006. Chemical nature and biological activity of humic acids. *Study and utilization of peat and sapropel resources*, 315–321 (in Russian).

Kireycheva, L.V. & Khokhlova, O.B. 2000. Elemental composition of humic substances in sapropel deposits. *RAAS Newsletter* **4**, 59–62 (in Russian).

Kosov, V.I. 2007. Sapropel. Resources, Engineering, Geoecology. Saint Petersburg, Nauka, 244 pp. (in Russian).

Kulikova, N.A., Filippova, O.I. Abros’kin, D.P. & Klyain, O.I. 2013. Modern approach to humic substance biological activity assessment. In: *Proceedings of International conference on biodiagnostics in soil ecology analysis*. Moscow, BINOM, pp. 116–119 (in Russian).

Lishtvan, I.I., Kaputskiy, F.N. & Yanuta, Y.G. 2012. Humic acid reactions with metal ions and metal–humic complex structure. *BSU Newsletter* **2**(2), 12–16 (in Russian).

Mushnikova, L.N., Nikiforova, T.A., Sharova, N.Y. & Pozdnyakova, T.A. 2001. Physical, chemical and microbiological composition of carbon mediums for citric acid biosynthesis. *Agricultural Materials Storage and Utilization* **7**, 7–9 (in Russian).

Platonov, V.V., Khadartsev, A.A. Fridzon, K.Y. & Chunosov, S.N. 2014. Chemical composition and biological activity of Glubokoye lake sapropel (Tatarstan). *New Med. Eng. Newsletter* **3**, 112–118 (in Russian). ISSN 1609–2163.23.

Sharova, N.Y. & Kamen’kova, N.V. 2012. Application of ultrasound and infrared radiation to microbial contamination control in citric acid production // *Agricultural Materials Storage and Utilization*, 4, p. 16–17 (in Russian).

Sharova, N.Y., Kamen'kova, N.V. & Volkova, A.A., 2012. Application of ultrasound and infrared radiation to microbial contamination control in citric acid production. *Agricultural Materials Storage and Utilization* **9**, 31–33 (in Russian).

Shtin, S.M. 2005. Lake Sapropels Complex Utilization. Moscow, MSU, 213 p. (in Russian).

Vybornova, T.V. & Sharova, N.Y. 2015. A citric acid producing strain of Aspergillus niger. Patent RU2558228, C12P 7⁄48, C12N 1⁄14, C12R 1⁄685. (in Russian).

Skurikhin, I.M., prof., MAI member, V.A. Tutel'ian, prof., RAMS member (eds.), 2002. Chemical Composition of Foodstuffs in Russian Market: a Factbook. Moscow, DeLiprint, 236 p. (in Russian).

Vyershinin, V.I. & Pyertsev, N.V. 2005. Planning and Statistical Evaluation of Chemical Experiments: A Reference. Omsk, OmSU, 216 pp. (in Russian).

World Health Organization, 2015. Global Action Plan on Antimicrobial Resistance. *http://www.who.int/iris/bitstream/10665/193736/1/9789241509763_eng.pdf*. Available: 03.31.2017.

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Impact of differences in combustion conditions of rape straw on the amount of flue gases and fly ash properties

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Abstract. The rising trend of biomass energy usage as a renewable energy source raises issues with combustion waste products, mostly bottom ash and its potential for further use. Rape straw was selected as a fuel sample for experiments because of the fact, that this crop figures among the 10 most important crops in the world and its straw is frequently used as a source of renewable energy. The rape straw was processed in pelletizing line LSP 1800 of the company ATEA PRAHA Ltd. into pellets with diameter of 8 mm and length 15 to 30 mm. Composition of bottom ash arising during the energy utilization of biomass is primarily dependent on the composition of input raw material and next on the combustion technology. Therefore, the aim of this article is to clarify the influence of excess air amount on the composition of end products in combustion of rape straw pellets in three combustion modes (low, optimal and high excess air).
The last part of study were combustion tests and measurements on a laboratory hot-air stove – KNP from the company KOVO NOVAK. Excess air coefficient values ranged between 3.31 and 6.77. The average net calorific value of the original rape straw sample was about 15.95 MJ kg^{-1}. Input raw material may not have always been completely combusted in the device, and therefore the ash could contain elevated amounts of hazardous elements. These substances are a limiting factor for application of the ash into soil. Overall, ash from biomass not only offers a wide range of potential applications thanks to its physical and chemical properties, but also returns some of the nutrients back to the soil closing the nutrient cycle and reducing the landfill of such material. And last but not least it enables cost reduction in agricultural production spent on mineral fertilizers.

Key words: rape straw, combustion conditions, ash properties, emission concentrations, flue gas temperature.

INTRODUCTION

During energy utilization of biomass the issue of ash handling arises. Composition of these end products of combustion is largely dependent on the fuel composition and used combustion technology and its configuration (Bradna et al., 2016). Plants growing on forest or agricultural land not only create organic matter but also take nutrients required for growth, which after burning usually accumulate in the solid non-combustible residue – ashes. One option of using these residues is the application on agricultural land, to which nutrients are returned (Zemanová et al., 2014).

Combustion of solid fuels, biomass included, produces undesirable gaseous and particulate emissions in flue gases. These substances have to be subsequently removed from the flue gas to comply with emission limits for gases emitted into the atmosphere (Fournel et al., 2015). The process of solid fuels combustion should always be run at the optimal conditions and efficiency for a particular combustion plant. From available literature (Malaťák et al., 2016), (Khodaei et al., 2017) it is known that operation of combustion devices is better when the fuel is drier, because it carries more net calorific value per unit of weight and less inner space of a combustion device is needed to firstly dry the fuel. As a consequence, overall higher surface area of fuel and more material is burning simultaneously in a given combustion device and the performance is accordingly higher as well. Net calorific value of biofuels from plant biomass is primarily dependent on the water and ash content in the fuel (Bradna & Malaťák, 2016). The construction of various furnace types as well as input material preparation for combustion depends on basic properties of used biofuels.

This paper focuses on the aforementioned topic. In the first part selected rape straw pellet samples are evaluated using elemental analysis. Following is an operational measurement of emission concentrations during combustion of samples on an automatic hot-air stove KNP from the company KOVO NOVAK. In these tests effects of operational temperature and amount of combustion air are identified and analyzed for individual samples.

Different types of solid biofuels vary in their characteristics such as the net calorific value, moisture or chemical composition (Vassilev et al., 2010). Contents of hazardous elements present in the biofuel influences the final amount of these elements left in ash. The content of hazardous elements is also significantly influenced by their behavior during combustion and accordingly by separation of individual fractions of ash (Niu et al., 2010).

MATERIALS AND METHODS

Rape straw has been chosen as the most suitable biofuel for the experimental measurement. This material was transformed into the form of pellets by pelletizing line LSP 1800 (company ATEA PRAHA Ltd.). Pellets had diameter of 8 mm and length of 15–30 mm. This work firstly focus on the determination of the elemental composition of samples. Before each combustion test samples for determination of elemental analyses were taken. Pellet samples were taken at 3 points: immediately after pelletizing, after thirty days of storage and just prior to the combustion tests. During these experiments, basic parameters of fuel were examined, specifically the contents of water, ash, volatile and non-volatile combustible matter, and contents of carbon, nitrogen, oxygen, hydrogen, sulphur and chlorine.

The CHN analyzer Perkin-Elmer 2400 was used for determination of the elements carbon, hydrogen and nitrogen. Chlorine and sulphur were determined by burning of samples in oxygen-hydrogen flame in Wickbold apparatus. The amount of ash and total water content (non-combustible substances) were determined by burning, respectively drying of the sample. Gross calorific value was determined by calorimetric method in the calorimeter IKA 2000.

The net calorific value of fuel as well as the amount of oxygen required for complete combustion of fuel, quantity and composition of flue gas and flue gas density were calculated by stoichiometric calculations. These calculations were converted to normal conditions, i.e. temperature0 °C and pressure = 101.325 kPa. After the theoretical analysis, practical measurements of combustion process were carried out focusing on emission concentrations. These tests were carried out on an automatic hot-air stove KNP made by company KOVO NOVAK. This stove has a burner with automatic ignition and is equipped with automatic fuel supply by a screw conveyor. The transport of pellets was performed from the pellet hopper with a capacity of 50 litres.

During combustion experiments combustion process could be influenced by adjusting the combustion air intake and by the rate of fuel supply. During experimental tests varying excess air coefficients were used in order to determine combustion characteristics.

Three combustion modes were selected:

1) Combustion under low excess of air - the device was set to maximum fuel supply and the quantity of combustion air was regulated to the lowest possible amount.

2) Combustion under optimum excess air coefficient – fuel and combustion air supply rate were set to a level, when the emission concentrations of carbon dioxide reached maximum value and the concentrations of carbon monoxide reached minimum.

3) Combustion under high excess air coefficient – the combustion device was fed with low fuel supply rate and high supply of combustion air simultaneously.

A multifunction analyzer of flue gas Madur GA-60, based on the principle of electrochemical converters, was used to monitor emission concentrations. Concentrations of carbon monoxide and dioxide, oxygen, nitrogen monoxide and dioxide, sulfur dioxide, hydrogen chloride were measured as well as excess air coefficient. Madur GA-60 also enables the measurement of ambient and flue gas temperature. Based on these temperatures and chemical parameters this device performs calculation of combustion characteristics. The emission concentration values are converted for normal conditions of dry flue gas and reference oxygen content in flue gas. The results of measurements were processed by statistical regression analysis for expressing the mathematical relationship of carbon monoxide and dioxide, flue gas temperature and total nitrogen oxides depending on excess air coefficient.

The elemental analysis of solid combustion end products with different excess air coefficients were carried out at the end of laboratory tests. The concentration of individual elements in the samples were determined by flame atomic absorption spectrophotometry on the device Varian-400 SpectrAA. The mineral compositions, with regard to samples utilization as soil amendment, were determined according to Száková et al. (2013) and available metal fractions were determined by extraction (Trakal et al., 2013).

RESULTS AND DISCUSSION

The results of elemental analyses are shown in Table 1 and 2. The results are divided into 3 analyses of samples from rape straw after pelletizing and one sample of uncompressed rape straw for comparison. The average values of pellets used for stoichiometric calculations are at the bottom of tables. The results show that the dependence of net calorific value on the ash and water content in the fuel in its original state is not clearly confirmed, which confirm also Müller et al. (2015) and Niu et al. (2010).

Table 1. Elemental analysis of the rape straw samples (in original state)

Sample	Water Content (% wt.)	Ashes (% wt.)	Volatile Combustible (% wt.)	Non-volatile Combustible (% wt.)	Gross Calorific Value (MJ kg^{-1})	Net Calorific Value (MJ kg^{-1})
	W	A	V	NV	Q_s	Q_i
Rape straw before processing	9.37	4.98	68.85	16.80	16.71	15.34
Rape straw pellets 1 (diameter 8 mm)	7.85	5.64	71.11	16.40	16.75	15.23
Rape straw pellets 2 (diameter 8 mm)	8.80	4.13	71.19	15.88	17.98	16.47
Rape straw pellets 3 (diameter 8 mm)	7.45	4.83	72.28	17.44	17.36	16.15
Average values of pellet samples	8.03	4.87	71.53	16.57	17.36	15.95
Statistical dispersion	0.57	0.62	0.53	0.65	0.50	0.53

Table 1 shows that the total water content in all samples was quite low. After pelletizing it ranged from 7.45 to 8.80 (% wt.). This had a positive effect on the net calorific value of samples. When considering the ash content, the samples from rape straw had higher content than e.g. pure wood samples. This fact confirm also Shen & Xue (2015) who carried out elemental analyses on samples of pure wood and the amount of ash in pure wood stayed under 1% wt. Combustion of rape straw in small combustion devices produces relatively higher amount of solid residue after combustion and increases the amount of solid particles in the flue gas. On the other hand, it produces a substantial amount of ash usable as a soil amendment (Mollon et al., 2016).

The average net calorific value of the rape straw samples in the original state was around 15.95 MJ kg^{-1}. These values are comparable to wheat straw with its value around 15.55 MJ kg^{-1} (Bradna & Malaťák, 2016).

For all samples analysis of nitrogen, sulphur and chlorine contents were carried out (see. Table 2). Average concentrations of chlorine were found in examined samples of rape straw in its original state, where the average value was around 0.18% wt. Chlorine passes during the combustion process for the most part into the gaseous phase. If the chlorine concentration in the fuel is high there can arise problems. On the one hand, significance of problems with chlorine is based on the emissions of HCl and their possible influence on the formation of polychlorinated dibenzo/dioxins and furans (PCDD/F). Another issue are the corrosive effects of these elements or their derived compounds on parts of combustion devices (Niu et al., 2010).

Sulphur also leaves for the most part during combustion in the gas phase as SO_2 or SO_3. Emissions of sulphur in combustion devices for solid fuels from renewable resources generally do not present a problem regarding maximum limiting values. This fact is confirmed also in the evaluated samples (see. Table 2). A high concentration of oxygen was found in the samples – over 37% wt. in average. Oxygen is a problematic component of fuel because it binds hydrogen and partly also carbon to hydroxides, water and oxides (particularly nitrogen and chlorine). The adverse effect is based on their interaction with the combustion device, especially the heat transfer surfaces.

Table 2. Elemental analysis of the rape straw samples (in original state)

Sample	Carbon C (% wt.)	Hydrogen H (% wt.)	Nitrogen N (% wt.)	Sulphur S (% wt.)	Oxygen O (% wt.)	Chlorine (% wt.)
	C	H	N	S	O	Cl
Rape straw before processing	41.38	5.20	0.57	0.11	38.24	0.15
Rape straw pellets 1 liameter 8 mm)	42.64	6.11	0.84	0.14	36.64	0.14
Rape straw pellets 2 (diameter 8 mm)	42.83	5.95	0.47	0.12	37.54	0.16
Rape straw pellets 3 (diameter 8 mm)	43.70	4.90	0.72	0.23	37.94	0.23
Average values	43.06	5.65	0.68	0.16	37.37	0.18
Statistical dispersion	0.46	0.54	0.15	0.05	0.54	0.04

For samples of rape straw high emissions of nitrogen (see Table 3) were evident, because this type of energy plant has quite high content of nitrogen in the combustible (see Table 2) compared to fossil or wood fuels (Vassilev et al., 2010). Dependence of emission concentrations on contents of individual elements in the samples is evident from their elemental composition given in Table 2. The values shown in Table 3 confirm that maintaining the optimum excess air coefficient is essential during combustion, because this state guarantees such combustion conditions which do not generate high emission concentrations of unburned components and do not increase the heat losses (Bradna & Malaťák, 2016).

Table 3. Average values of thermal properties and emission concentration of the rape straw pellets (diameter 8 mm)

	Average	s^2	s	V	Max.	Min.
$T_{ambient}$ (°C)	33.40	9.09	3.02	0.09	37.00	26.00
$T_{flue\text{-}gas}$ (°C)	240.36	0.35	0.59	0.00	241.30	238.34
O_2 (%)	16.72	0.38	0.62	0.04	17.90	14.66
n (-)	4.99	0.45	0.67	0.13	6.77	3.31
CO_2 (%)	3.10	0.22	0.47	0.15	4.62	1.65
CO (mg m^{-3})	1,071.48	44,810.63	211.68	0.20	1,938.00	810.00
SO_2 (mg m^{-3})	262.09	9,454.44	30.47	0.01	349.11	134.06
NO_x (mg m^{-3})	1,848.85	12,595.59	112.23	0.06	1,992.55	1,487.00

For the evaluation of combustion process quality graphs of dependencies of carbon monoxide and carbon dioxide on the excess air coefficient are shown in Fig. 1. Excess air coefficient influences behaviour of the combustion device and the combustion process itself.

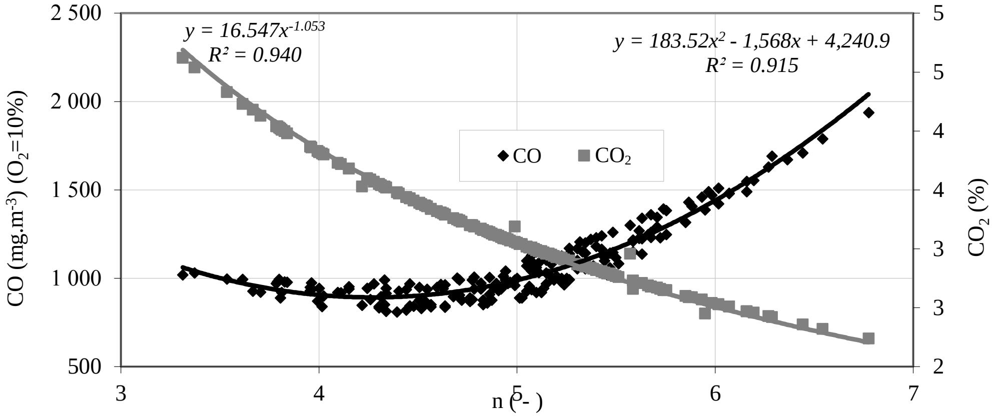

Figure 1. Dependence of carbon monoxide and carbon dioxide on the excess air coefficient – combustion of the rape straw pellets in diameter 8 mm.

When burning pellets from rape straw (see Fig. 1), increasing excess air coefficient *n* increased the emission concentrations of carbon monoxide according to the equation:

$$CO = 183.52n^2 - 1{,}568n + 4{,}240.90 \text{ (mg m}^{-3}\text{)} \quad (1)$$

With confidence level of $R^2 = 0.9159$, when increasing n in the range from 3.31 to 6.77, this also leads to reduction in the carbon dioxide concentration according to the equation:

$$CO_2 = 16.547n^{-1.053} \text{ (\%)} \quad (2)$$

When increasing excess air coefficient $n > 5$ (see Fig. 2) dampening of combustion process starts and flue gas temperature goes below 240 °C. This flue gas cooling can be defined by the equation:

$$T_{flue\text{-}gas} = -0.2545n^2 + 1.6943n + 238.36 \text{ (°C)} \quad (3)$$

With confidence level of $R^2 = 0.9571$.

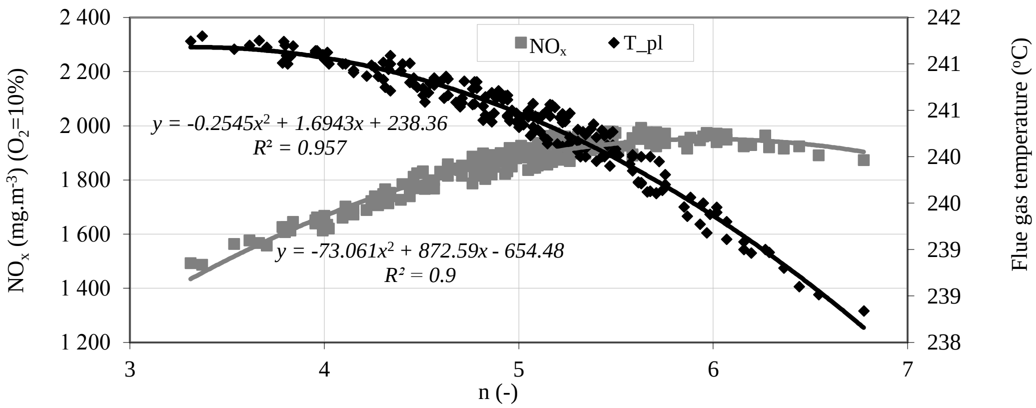

Figure 2. Dependence of nitrogen oxides and flue gas temperature on the excess air coefficient - combustion of the rape straw pellets in diameter 8 mm.

Increase in NO_x emissions while increasing the amount of supplied combustion air was likely mainly caused by nitrogen reacting with oxygen and produced nitrogen oxides (see Fig. 2). Dependence of concentration of nitrogen oxides on the excess air coefficient is described by the equation:

$$NO_x = -73.061n^2 + 872.59n - 654.48 \text{ (mg m}^{-3}\text{)} \tag{4}$$

With confidence level of $R^2 = 0.9368$.

In the range of optimum excess air coefficient, the concentrations of nitrogen oxides are very low. According to the measurements of rape straw combustion the optimal setting of the combustion device is in the range of excess air coefficient from 4 to 5. This level of excess air coefficient was also studied by Shen & Xue, (2015); Bradna & Malaťák, (2016). Concentration of carbon monoxide in this range of excess air coefficient is about 1,000 mg m^{-3}. This range of the excess air coefficient prevents significant cooling of the flue gases. Combustion with low excess air is considered when of the excess air coefficient is less than 4. Combustion with high excess air coefficient is standardized at values greater than 5.

The sampling of fly ash was performed each time during measuring interval in each particular combustion mode. The sampling point for collection of fly ash was the flue duct. Analyses of the mineral composition of fly ash produced in the three different combustion modes are shown in Table 4.

Table 4. The average values of mineral composition of fly ash from rape straw pellets

	low excess air	high excess air	optimal excess air
Al (mg kg^{-1})	1,293.00	1,346.45	900.41
As (mg kg^{-1})	0.80	3.31	0.16
B (mg kg^{-1})	321.93	192.11	83.44
Cd (mg kg^{-1})	0.25	0.34	0.01
Cr (mg kg^{-1})	5.37	8.50	3.22
Cu (mg kg^{-1})	21.32	25.64	22.77
Fe (mg kg^{-1})	2,803.15	4,039.38	1,245.43
Mn (mg kg^{-1})	654.38	959.17	805.60
Mo (mg kg^{-1})	1.89	2.47	2.02
Ni (mg kg^{-1})	3.10	4.73	3.30
Pb (mg kg^{-1})	2.93	4.41	1.41
S (mg kg^{-1})	1,119.35	956.85	417.08
Zn (mg kg^{-1})	97.95	103.83	15.12
P (mg kg^{-1})	4,351.02	5,049.24	5,823.80
K (mg kg^{-1})	15,894.91	22,011.82	32,572.04
Ca (mg kg^{-1})	14,962.56	19,944.90	26,380.83
Mg (mg kg^{-1})	4,910.13	5,182.26	6,875.37

From the Table 4 it is evident that the values of cadmium in fly ash are on average significantly below 1 mg kg^{-1}. Comparing results of analyses to the limits given by valid legislation applicable for soil amendments in the Czech Republic, we find that the values of cadmium in fly ash should pose no threat when applied to soil. On the other hand, ash from wood chips generally exceeds the legal limits for cadmium set at the value of 5 mg kg^{-1}, which confirms also Berra et al. (2011).

Measured values of lead in the fly ash from rape straw was on average significantly below the limit of 10 mg kg^{-1}. Higher potassium content in ash ~~is~~ results due to higher levels of this element in the raw material itself. Higher calcium content in ash leads to increased pH values and such materials could be used for treatment of soil reaction in particular in strongly acidic or heavy soils (Obernberger & Supancic, 2009).

In the mode of optimum excess air during the combustion of rape straw pellets higher concentrations of P, K, Ca and Mg in the ash were reached. In the overall assessment, it can be said that for the use on agricultural land ashes from the combustion of rape straw are completely satisfactory in regard to the current legislation for soil amendments. The average content of hazardous elements in each sample of fly ash are fully compliant with the limits.

CONCLUSIONS

The right choice of the combustion device is very dependent on the type and form of biomass. Selection of the combustion device type is primarily influenced by the characteristics of biofuels, among which are included, in particular, moisture, ash content, net calorific value, the proportion of volatile matter, combustible carbon content and also the alkali metals content. For rape straw with an average proportion of 0.68% of the nitrogen in the fuel was measured large concentration of nitrogen oxides in the flue gas (approximately 1,848.85 mg m^{-3}), which is dependent on increasing excess air coefficient. The excess air coefficient also affect the combustion process and the overall amount of flue gas, wherein the optimal limit for rape straw combustion in the selected combustion device is in the range 3.5 to 4.5. Assessment of the suitability and optimization of solid biofuel utilization in combustion devices with regard to the quality of the solid by-products is also an integral part of other works (Niu et al., 2010; Mollon et al., 2013).

Input material may not always be completely incinerated in a combustion device, and thus the ash can contain elevated amounts of hazardous elements. These substances can be a limiting factor for application of ash on soil or any other use. Solid biofuels can be considered a renewable energy source only in the case when the energy contribution is much greater than the costs of growing, harvesting and further processing (drying, pressing etc.). Therefore, assessing the utilization options of biomass ash in the life cycle of a renewable energy source plays an important role both for the environment and the economy in the production of solid biofuels.

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REFERENCES

Berra, M., De Casa, G., Dell´Orso, M., Galeotti, L., Mangialardi, T., Paolini, A.E. & Piga, L. 2011. *Recycling of biomass ashes, Chapter* **10**: Reuse of woody biomass fly ash in cement – based materials: leasing tests. Springer-Verlag, Berlin Heidelberg.

Bradna, J. & Malaťák, J. 2016. Flue gases thermal emission concentration during waste biomass combustion in small combustion device with manual fuel supply. *Research in Agricultural Engineering* **62**(1), 1–7.

Bradna, J., Malaťák, J. & Hájek, D. 2016. The properties of wheat straw combustion and use of fly ash as a soil amendment. *Agronomy Research* **14**(4), 1257–1265.

Fournel, S., Palacios, J.H., Morissette, R., Villeneuve, J., Godbout, S., Heitz, M. & Savoie, P. 2015. Influence of biomass properties on technical and environmental performance of a multi-fuel boiler during on-farm combustion of energy crops. *Applied Energy* **141**, 247–259.

Khodaei, H., Guzzomi, F., Patiño, D., Rashidian, B. & Yeoh, G.H. 2017. Air staging strategies in biomass combustion-gaseous and particulate emission reduction potentials. *Fuel Processing Technology* **157**, 29–41.

Malat'ák, J., Bradna, J. & Velebil, J. 2016. Combustion of briquettes from oversize fraction of compost from wood waste and other biomass residues. *Agronomy Research* **14**(2), 525–532.

Mollon, L.C., Norton, G.J., Trakal, L., Moreno-Jimenez, E., Elouali, F.Z., Hough, R.L. & Beesley, L. 2016. Mobility and toxicity of heavy metal(loid)s arising from contaminated wood ash application to a pasture grassland soil. *Environmental Pollution* **218**, 419–427.

Müller, M., Horníčková, Š., Hrabě, P. & Mařík, J. 2015. Analysis of physical, mechanical and chemical properties of seeds and kernels of Jatropha curcas. *Research in Agricultural Engineering* **61**(3), 99–105.

Niu, Y., Tan, H., Wang, X., Liu, Z., Liu, H., Liu, Y. & Xu, T. 2010. Study on fusion characteristics of biomass ash. *Bioresource Technology* **101**(23), 9373–9381.

Obernberger, I. & Supancic, K. 2009. Possibilities of ash utilisation from biomass combustion plants. In: Proceedings of the **17**th European Biomass Conference and Exhibition, Hamburg, ETA-Renewable Energies (Ed.), Italy.

Shen, G. & Xue, M. 2015. Comparison of carbon monoxide and particulate matter emissions from residential burnings of pelletized biofuels and traditional solid fuels. *Energy and Fuels* **28**(6), 3933–3939.

Száková, J., Ochecová, P., Hanzlíček, T., Perná, I. & Tlustoš, P. 2013. Variability of total and mobile element contents in ash derived from biomass combustion. *Chemical Papers* **67**(11), 1376–1385.

Trakal, L., Neuberg, M., Száková, J., Vohník, M., Tejnecký, V., Drábek, O. & Tlustoš, P. 2013. Phytoextraction and Assisted Phytoextraction of Metals from Agriculture Used Soil. *Communications in Soil Science and Plant Analysis* **44**(12), 1862–1872.

Vassilev, S.V., Baxter, D., Andersen, L.K. & Vassileva, C.G. 2010. An overview of the chemical composition of biomass. *Fuel* **89**(5), 913–933.

Zemanová, V., Trakal, L., Ochecová, P., Száková, J. & Pavlíková, D. 2014. A model experiment: competitive sorption of Cd, Cu, Pb and Zn by three different soils. *Soil and Water Research* **9**(3), 97–103.

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Method of designing of manure utilization technology

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Abstract. Specific feature of modern livestock farms is concentration of a large number of animals and subsequent significant environmental load. The biggest negative impacts are on the atmosphere through ammonia emissions and on water bodies through nitrogen and phosphorus compounds leakage, with manure being the major source of these pollutants. The proper choice of an effective low-cost manure handling technology with high nutrients retention ensures the environmentally sound operation of these farms. With this aim in view a designing method of manure utilization technologies is proposed. Relevant available technologies were reviewed, a mathematical model was created and technology assessment criterion was defined. Manure utilization technology is understood as a set of activities, including manure processing, manure storage (if necessary) and soil application of organic fertilizers. To create a mathematical model 12 manure utilization technologies were examined. These technologies are based on various methods of manure processing, such as long-term maturing, composting, biofermentation, separation into fractions, drying and biogas production. The created mathematical model takes into account the economic and environmental performance of each technology. The proposed approach makes it possible to calculate and compare the level of nitrogen preservation in manure and required inputs for different technologies depending on the farm animal stock. To assess and select the most suited technology the eco-efficiency criterion is suggested, which takes into account the yield increase, the cost of generated energy (for biogas production), and reduced negative impact on the environment. The paper presents example of using the method to make a choice of technologies for a dairy farm. Experience in the use of the method shows that the average values of nitrogen preservation in the manure, which may be achieved without involving excessive costs, are 72% for cattle manure, 70% for pig manure and 78% for poultry manure.

Key words: environmental safety, technology assessment, utilization of manure technology, technology designing, best available technique.

INTRODUCTION

Specific feature of modern livestock farms is concentration of a large number of animals and subsequent significant environmental load. The biggest negative impacts are on the atmosphere through ammonia emissions and on water bodies through nitrogen and phosphorus compounds leakage, with manure being the major source of these pollutants (Integrated Pollution Prevention and Control, 2003). So it is very important to introduce the assessment of environmental safety of a technology already on the designing stage. This makes assessment of environmental safety at technology designing stage much more important. Currently, there are several methods of manure processing (Best Available Techniques, 2015) and the proposed method solves the problem of choosing recycling technologies for conditions of specific farm. The method was developed taking into account the modern technology assessment approach 'best available techniques' with the aim to reduce the negative impact of the technology without undue cost (Subbotin & Vasilev, 2016).

MATERIALS AND METHODS

Manure utilization technology is understood as a set of activities, including manure processing, manure storage (if necessary) and soil application of organic fertilizers. The proposed method consists of three stages:

1. Analysis of farm conditions. Choice of technologies appropriate to farm conditions and calculation of indicative values of the parameters for the available technology.
2. Choice of the most efficient (with minimal negative impact without undue cost) technology and forming technological solutions, which are understood as a set of machines, equipment and constructions (based on selected technology).
3. Calculation of indicators for the formed technology solutions and optimization of technological solution choice by Pareto optimization method.

At the first stage animal species, number of animals, water content in manure, size of field area and distance to this were considered. Depending on farm conditions suitable technologies were selected from the following 12 manure utilization practices:

1. Long-term storage and application of solid or liquid organic fertilizer.
2. Passive composting in clamps and application of solid organic fertilizers.
3. Active composting in clamps and application of solid organic fertilizers.
4. Biofermentation in chamber-type installation constructions and application of solid organic fertilizers.
5. Biofermentation in drum installation s and application of solid organic fertilizers.
6. Biological treatment of liquid pig manure in aeration tanks and application of liquid organic fertilizer.
7. Manure separation into fractions with further processing of the solid fraction by composting methods or biofermentation and long-term maturing of the liquid fraction and application of solid and liquid organic fertilizers.
8. Manure separation into fractions with further processing of the solid fraction by composting methods or biofermentation, advanced treatment of liquid fraction by biological methods and application of solid and liquid organic fertilizers.
9. Manure separation into fractions by using flocculants, further processing of the solid fraction by composting methods or biofermentation and advanced treatment of liquid fraction by biological methods and application of solid and liquid organic fertilizers.
10. Drying of manure, granulation and application of solid organic fertilizers.
11. Anaerobic treatment with generation of electricity and heat (biogas production) and application of solid and liquid organic fertilizer.
12. Vacuum drying of manure, granulation and application of solid organic fertilizers.

For selected technologies approximate values of economic and environmental indicators (E_{BAT}, C_C, and E_E) are calculated and used to determine the most efficient technology. E_{BAT} is an indicator of economic efficiency of introducing the best available technology (BAT):

$$E_{BAT} = \frac{Cop}{Lb - L} \tag{1}$$

where *Cop* – annual operating costs for the considered technology; Lb – nitrogen loss for reference technology; L – nitrogen loss for considered technology;
C_C is comprehensive cost indicator:

$$C_C = \frac{UC_c + UC_{op}}{NUE} \tag{2}$$

where UC_C – unit operating costs (per ton); UC_{OP} – unit capital costs (per ton); NUE (nitrogen use efficiency) index is environmental safety indicator, which shows the preservation of nitrogen and is calculated as the ratio of the amount of nitrogen in raw materials or products at the beginning of the production process to the amount of nitrogen at the time the process is completed (Maximov et al., 2014).

To estimate NUE index for technologies Spesivtsev-Drozdov calculation method was applied (Briukhanov et al., 2016).

E_E is ecological and economic impact of technology introduction:

$$E_E = P_h + P_{en} + Env_P \tag{3}$$

where P_h – profit from sale of additional crops or organic fertilizer; P_{en} – profit or benefit from generated energy (for biogas technology); Env_p – economic effect of reducing negative impacts on the environment.

Various technological solutions were suggested for the most efficient technology and indicators E_{BAT}, C_C, and E_E were calculated for each technological solution.

The third stage is to optimize the technological solution choice by Pareto optimization method by three indicators: E_{BAT}, C_C, and E_E. If optimization result is several variants (not one), then the final decision is taken by an expert.

RESULTS AND DISCUSSION

Experience of using the proposed method for assessing the potential of modernization of existing farms showed good results – provided specific farms solutions allow to reduce operating costs and/or reduce nitrogen loss.

Consider the application of the method to select manure utilization technology for cattle farm with loose tied housing system. Total animal stock is 2,600 head, manure water content is 92%, average transportation distance of organic fertilizers is 10 km. In first stage 4 technologies were selected for such farms:

1. Long-term maturing and application of liquid organic fertilizer.
2. Manure separation into fractions with further processing of the solid fraction by composting methods and long-term maturing of the liquid fraction and application of solid and liquid organic fertilizers.
3. Manure separation into fractions with further processing of the solid fraction by biofermentation and long-term maturing of the liquid fraction and application of solid and liquid organic fertilizers.

4. Anaerobic treatment with generation of electricity and heat (biogas production) and application of solid and liquid organic fertilizer.

Comparison of indicative values of technologies indicators is shown in Figs 1 & 2.

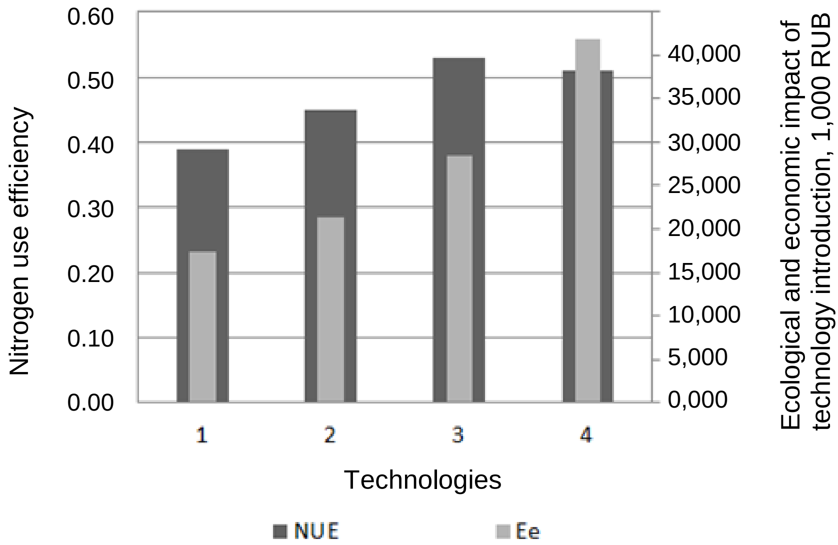

Figure 1. Comparison of NUE and E_E indicators for selected technologies.

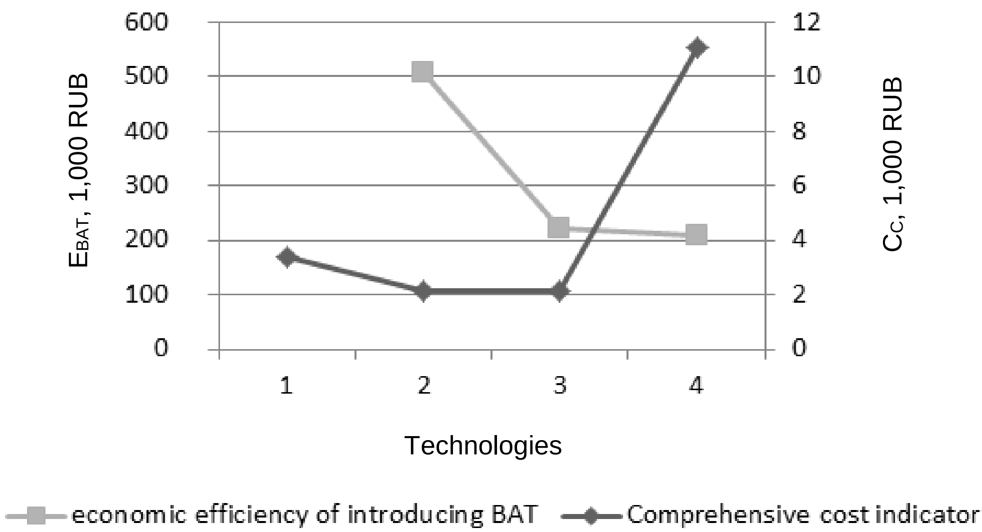

Figure 2. Comparison of E_{BAT} and C_C indicators for selected technologies.

The most rational in this case is Technology 3. For this technology, 12 technological solutions were formed taking into account the farm size with various equipments used in different combinations. The calculated data for the technological solutions are shown in Table 1.

Table 1. Calculated data for the technological solutions based on Technology 3

Indicator		C_C	E_E	E_{BAT}
Unit		1,000 RUB	1,000 RUB	1,000 RUB per ton
Optimization direction		min	max	min
Technological solutions (based onTechnology 3)	1	41,306	28,428.8	-*
	2	42,401	29,925.0	883.24
	3	43,071	34,912.5	275.20
	4	23,408	31,421.3	603.18
	5	23,774	33,416.3	409.21
	6	22,678	38,403.8	208.33
	7	42,888	27,431.3	-**
	8	42,888	28,927.5	1,666.08
	9	42,768	33,915.0	308.81
	10	19,756	29,925.0	854.45
	11	20,121	31,920.0	497.36
	12	19,025	37,406.3	221.70

* First technological solution is reference solution (for calculating E_{BAT} indicator); ** The seventh technological solution is less effective than the reference solution (in terms of nitrogen loss).

In this case, the Pareto optimal technological solutions are 6 and 12. They include the use of covered lagoons for storage and machines for spreading liquid fertilizer with hose or injection systems.

Application experience of the method for over 50 farms located in the North-West Russia shows that the average values of nitrogen preservation in the manure, which may be achieved without involving excessive costs, are 72% for cattle manure, 70% for pig manure and 78% for poultry manure.

CONCLUSIONS

1. Experience of using of the proposed method for existing farms showed good results – in most cases it is possible to reduce operating costs and / or nitrogen loss.

2. The method can be used for modernization of existing farms and selection the most rational manure utilization technology when establishing a new farm.

3. Application of the method has revealed that average values of nitrogen preservation in the manure, which may be achieved without involving excessive costs, are 72% for cattle manure, 70% for pig manure and 78% for poultry manure.

REFERENCES

Best Available Techniques (BAT) Reference Document for the Intensive Rearing of Poultry or Pigs FINAL Draft – 2015. [online] [11.04.2017]. Available at: http://eippcb.jrc.ec.europa.eu/reference/BREF/IRPP_Final_Draft_082015_bw.pdf

BriukhanovA, Y., Trifanov, A. V., Spesivtsev, A. V. & Subbotin, I. A. 2016, Logical-linguistic modeling in addressing agro-environmental challenges. In: *XIX IEEE International Conference on Soft Computing and Measurements (SCM)*, St. Petersburg, pp. 164–166. doi: 10.1109/SCM.2016.7519716

Integrated Pollution Prevention and Control (IPPC) Reference Document on Best Available Techniques for Intensive Rearing of Poultry and Pigs 2003. [online] [11.04.2017]. Available at: http://eippcb.jrc.ec.europa.eu/reference/BREF/irpp_bref_0703.pdf

Subbotin, I. & Vasilev, E. 2016, Formalization of criteria for determining best available technologies: the case of Russia / ENGINEERING FOR RURAL DEVELOPMENT Proceedings. P. 845–850.

Maximov, D.A., Bryukhanov, A.Y., Subbotin, I.A. & Vasilyev, E.V. 2014, Selecting manure management technologies to reduce ammonia emissions from big livestock farms in the Northwestern Federal District of Russia. *Ammonia workshop 2012 Saint Petersburg. Abating ammonia emissions in the UNECE and EECCA region.* RIVM, Bilthoven, The Netherlands, pp. 163–168.

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The influence of agricultural traffic on soil infiltration rates

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Abstract. The objective of the study was to investigate the effect of agricultural machinery passes on soil infiltration rate. The experiment was conducted in a large covered area (Soil Hall) with the sandy loam soil type. Four compactions levels were applied: control, one, two and three tractor passes.
The infiltration measurements were conducted using two methods: Simplified Falling–Head (SFH) and Mini Disk (MD). The other supporting measurements were disturbed soil samples and cone index measurements.
Based on the SFH method it was observed that as the number of passes increased from 0 to 3 the infiltration rate decreased. The MD results also decreased with the increase in the number of passes. The bulk densities (at 0–0.07 m depth) increased with the number of tractor passes, under the conditions of soil gravimetric moisture content ranging between 14 and 18% vol. The cone index values at the depth of 0–0.05 m increased with the number of passes.
When comparing the results obtained using the MD and SFH, a strong relationship was not found. It could be concluded that the SFH method might be more robust and appropriate for determining the effect of the number of tractor passes on the soil water infiltration in these conditions.

Key words: cone index, infiltration rate, soil compaction.

INTRODUCTION

Infiltration rate is an important parameter of soil which is influenced by agricultural traffic and its intensity. Therefore, the infiltration characteristic of the soil is a good guide how to find out the soil compaction. Traffic intensity results in an increase in soil bulk density values which negatively affect the soil infiltration parameters in comparison to the non–trafficked soil (Liebig et al., 1993; Yuxia et al., 2001; Hamza & Anderson, 2005; Raper & Kirby, 2006). For example Chamen (2011) stated that the non–compacted soil has 4 or 5 times higher infiltration rate than once run over soil. During Yuxia's et al. (2001) controlled traffic farming (CTF) experiment, wheeled and non–wheeled areas were compared (compacted and non–compacted) in a field–scale experiment. This experiment was established on a field which was not trafficked for 5 years and a single wheeling compaction was created by a John Deere 4040 tractor (4,000 kg of rear axle weight). The infiltration was simulated by a portable rainfall simulator with a constant rainfall rate of 122 mm h^{-1} (the experiment included 10 and 20 minutes of simulated rainfall). The results of this experiment showed that the non–compacted soil had infiltration rate between 50 and 100 mm h^{-1} (with 80% cover and without any surface residue cover, respectively) while the compacted areas had infiltration rate between 10 and 25 mm h^{-1}. Therefore, the decrease in infiltration rate on the compacted soil ranged from 50 to 90% in comparison to the non–compacted soil. Zhang et al. (2006) used three levels of soil compaction by increasing bulk density by 0, 10 and 20% in laboratory conditions. The soil samples were taken from the depths of 0–0.5 cm and 0.10–0.15 cm on two plots (*Chromic Cambisols* and *Calcic Cambisols*). Two methods of infiltration rate measurements were used, which were: constant head method (saturated hydraulic conductivity) and the hot–air method (unsaturated hydraulic conductivity). The saturated hydraulic conductivity showed differences between each type of soil compaction in *Calcic Cambisols* at both depths, while in *Chromic Cambisols* the difference was observed just for the highest level of soil compaction (20%). For the unsaturated hydraulic conductivity there were no major differences among the compaction levels and depths.

Agricultural machinery is not the only factor which can influence soil physical and infiltration properties, the other factor is livestock traffic. The study of evaluating influence of grazing on soil physical and infiltration parameters was conducted in the USA (Castellano & Valone, 2007). This study focused on three grazing areas in Arizona, USA, with different grassland establishment (1954, 1977 and 1993) all with similar gravelly sandy loam soils. For the water infiltration rate measurements, a double ring infiltrometer was used and the measurements were done in and outside of the grazing site. The results showed a decrease in infiltration rate on the non–grazed areas by up to 30–50% for the 1954 and 1977 sites while for the 1993 site was no difference in water infiltration rate. The measurements of cone index during this experiment showed higher values for the non–grazed sites then the grazed sites, while again for 1993 site was no difference found. One of the causes of changes in soil physical properties can be the cycles of soil moisture content and also changes in temperature during the whole season. The other possibility is the long–time gap of livestock removal and vegetation change. Another research compared the effect of traffic intensity resulting from a tractor with a trailer and grazing livestock with the same target ground pressure of 200–250 kPa (Chyba et al., 2014). The study showed a decrease in cone index values at depths ranging from 0.10 to 0.25 m for livestock compared to the tractor with the trailer. However, there was no statistically significant difference in surface infiltration rate using the simplified falling–head (SFH) method.

The infiltration properties of the soil are very influenced by soil bulk density. Soil bulk density is described as the mass of soil particles over the overall soil volume which is occupied by the particles. The soil bulk density is also one of the key indicators of the soil compaction (Johnson & Bailey, 2002). The soil bulk density and its relation to the soil compaction were studied in many research studies. One research monitored soil bulk densities of wheeled and non–wheeled soil up to the depth of 0.6 m (Defossez & Richard, 2002). The research showed that the bulk density of the wheeled area near to the soil surface were up to 200 kg m^{-3} higher than the non–wheeled area to the depth of 0.25 m. These differences in soil bulk density decreased with depth down to 0.45 m where the differences were not observed. Similar results were obtained by

Dickson & Ritchie (1996), Gómez et al. (1999) and Ekwue & Harrilal (2010) who monitored three different compaction levels and their effects on soil bulk density.

Soil compaction can also be measured using a penetrometer/penetrologger where soil cone indexes are evaluated. Cone index is a value of soil resistance against a cone of known dimensions, its angle and area (ASAE, 2004). The cone index measurement has advantages over soil sampling (bulk density samples) as data from a whole soil profile (limited by penetrometer reach) can be simply obtained with a possibility of automation (Raper, 2005). A correlation between an increasing soil compaction and an increasing cone index values was observed in many studies (Alakukku, 1996; Arvidsson & Håkansson, 1996; Radford et al., 2007). On the other hand, the cone index measurement has also some disadvantages, the main one is its soil moisture dependence (Ayers & Perumpral, 1982; Varga et al., 2014; Chyba et al., 2016).

MATERIALS AND METHODS

This experiment was conducted in a large covered area measuring 60 x 30 m (Soil Hall) which is located at Harper Adams University, UK (latitude 52.781908, longitude –2.427952) and the measurements were conducted on 22nd to 27th of June 2012. The Soil Hall provides good facilities for conducting practical studies without the influence of the weather. The soil type used in the experiment was sandy loam with the following soil fractions: 65% sand, 19% clay and 16% silt particles (Krištof et al., 2010). The soil used in the experiment was prepared by deep loosening (0.5 m), ploughing (0.2 m) and power harrowing (0.075 m). Three days after that four compaction levels were applied: 0 pass (control), one pass, two passes and three passes using a Massey Ferguson 8480 tractor (total weight 13,159 kg, 140 kPa and 7,655 kg tyre inflation pressure an weight for front axle, 120 kPa and 5,504 kg for the rear axle respectively). The traffic intensity treatments were selected based on Kroulik et al. (2010), who evaluated traffic parameters of agricultural vehicles. Once the area was prepared and trafficked the measurements of both types of soil infiltration rate, soil sampling and cone index were performed on all types of compaction. A randomised block design with five replications was used.

To estimate infiltration rate by the SFH method it is necessary to push or hammer a cylinder of known diameter A (m) into the soil so that water could flow down only vertically way into the soil. Then the known volume of water is poured into the cylinder onto the soil surface. While the water is poured the time measurement began. When all the water is drained into the soil, the time t_a (s) measurement ends. For the estimation of infiltration rate K_{fs} (mm h^{-1}), it is necessary to measure the soil moisture content inside of the cylinder (field saturated water content θfs) and outside of the cylinder (soil water content θi) and its difference $\Delta\theta$ (L^3 L^{-3}). The measurement of soil moisture content was conducted outside of the cylinder so the soil in the measuring area did not get disturbed. The measured values were than calculated using the following equation:

$$K_{fs} = \frac{\Delta\theta}{(1-\Delta\theta)t_a}\left[\frac{D}{\Delta\theta} - \frac{\left(D+\frac{1}{\alpha^*}\right)}{1-\Delta\theta} ln\left(1+\frac{(1-\Delta\theta)D}{\Delta\theta\left(D+\frac{1}{\alpha^*}\right)}\right)\right] \tag{1}$$

where: D – is the proportion of V (volume of water) and A (diameter of cylinder) and represents the water level equal to the water volume (Bagarello et al., 2004 & 2006);

α^* (m^{-1}) – represents the proportion of saturated hydraulic conductivity and soil potential of saturation flow and was estimated by Elrick et al. (1989) (Table 1).

Table 1. Elrick´s estimation of α^* (Elrick et al., 1989)

$\alpha^* = 1\ m^{-1}$	Compacted clays (e.g., landfill caps and liners, lacustrine or marine sediments, etc.).
$\alpha^* = 4\ m^{-1}$	Unstructured fine textured soils primarily
$\alpha^* = 12\ m^{-1}$	Most structured soils from clays through clay loams; also includes unstructured medium and fine sands and sandy loams. The first choice for most soils.
$\alpha^* = 36\ m^{-1}$	Coarse and gravelly sands; may also include some highly structured soils with large cracks and macropores.

During the measurements based on the SFH method, cylinders with a diameter of 152 mm, height 150 mm and thickness of 2 mm were used (Fig. 1). The moisture content was measured using a Theta Probe (HH2 moisture meter, Delta T Devices) and the volume of water applied was 0.3 cm^3. Parameter α^* of 30 m^{-1} was used because of the poor structure of the soil.

Figure 1. SFH measurements where 5 cylinders were used.

The measurements using a Mini Disk (tension infiltrometer) were conducted according to the instructions of DECAGON Devices manual. The calculation and results were obtained from a spreadsheet macro (MS EXCEL) from the manufacturer website (DECAGON Devices, 2016). Each measurement took 900 s and the readings were performed every 30 s. The suction effect was set to 20 mm for 0 passes, 10 mm for 1 and 2 passes and 5 mm for 3 passes.

Soil samples were taken using stainless steel cylinders with a volume (V_s) of 285 cm^3 and height of 0.07 m. The sampling depth was up to 0.28 m. For the estimation of the soil moisture content the disturbed soil samples were dried to the constant weight at 105°C (Valla et al., 2011). The initial moisture content θ_{mom} (% vol.) was calculated from the equation:

$$\theta_{mom} = G_A - G_F \quad (2)$$

where: G_A – sample with natural moisture content (g); G_F – sample dried to the constant weight (g).

For the soil bulk density ρ_d (g cm^{-3}) the following equation was used:

$$\rho_d = \frac{G_F}{V_S} \quad (3)$$

If the sampling cylinder has a different volume than 100 cm^3, it is necessary to make a conversion for further calculations so that the resulting values are divided by the volume of the cylinder used (V_S) and multiplied by one hundred.

The measurements of the cone index values were taken using Eijkelkamp penetrologger ART.NR.06.15.01 with a cone angle of 30° and an area of 100 mm^2 up to the depth of 0.3 m (ASAE, 2004).

MS Office Excel and Statistica 12 software (*Tukey test*, *ANOVA*) were used for data evaluation.

RESULTS AND DISCUSSION

The soil volumetric moisture content ranged from 12 to18% vol. up to the depth of 0.28 m with mean value of 16% vol.

The results of the SFH and MD infiltration rates are shown in Fig. 2. The SFH values are highly dependent on number of passes. The soil infiltration rate was high for the untrafficked soil 22.43 mm h^{-1}, then the values after the first pass decreased by 82% (5.5 times lower) and after the second pass it decreased further by 16%, which was found to be in agreement with Yuxia et al. (2001) and Chamen (2011). After the second and third pass infiltration rate was found to be at lowest levels (in a region of 0.4 mm h^{-1}) and there was no significant difference between these two values. It is expected that there would be no changes in soil infiltration rate with additional passes of the tractor. The untrafficked soil showed very high variability (confidence intervals) which decreased with the number of passes.

The results of MD (tension infiltrometer) in contrast with head (SFH) method showed no statistically significant difference (Fig. 2). It is due to the large confidence interval spread. However, it can be seen that the mean values decreased with the increasing number of passes which was, in a small range of soil bulk density values, also monitored by Zhao et al. (2014). It is expected that the SFH method can monitor the first serious compaction while MD method could show the statistical difference after multiple passes of a tractor where the SFH is probably less sensitive.

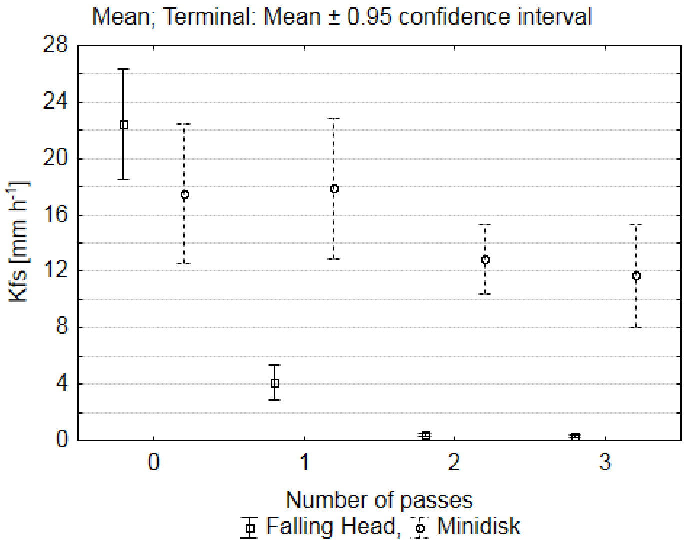

Figure 2. SFH and MD results.

The values of dry bulk density (Table 2) showed that the compaction level is uniform throughout the measured depth for each variant. It is also clear that as the number of passes increased in the most cases, the soil bulk density also increased as previously discussed (Defossez & Richard, 2002; Johnson & Bailey, 2002).

Table 2. The mean values of dry bulk density

Depth [m]	Bulk density [g cm^{-3}]							
	0 passes		1 pass		2 passes		3 passes	
0–0.07	1.42	a 1	1.60	a,b 1	1.71	b,c 1	1.68	b,c 1
0.07–0.14	1.41	a 1	1.58	a 1	1.61	a 1	1.60	a 1
0.14–0.21	1.44	a 1	1.58	a 1	1.59	a 1	1.57	a 1
0.21–0.28	1.43	a 1	1.56	a,b 1	1.63	b 1	1.59	a,b 1

Homogenous groups in: columns – 1, 2 …; rows – a,b ….

Also the values of cone indexes showed a significant effect of tractor passes on soil (Fig. 3). As the number of passes increased, the cone index values increased thought the soil profile. Concluding SFH, bulk densities and cone index values describe well the influence of soil compaction on the soil physical and infiltration properties.

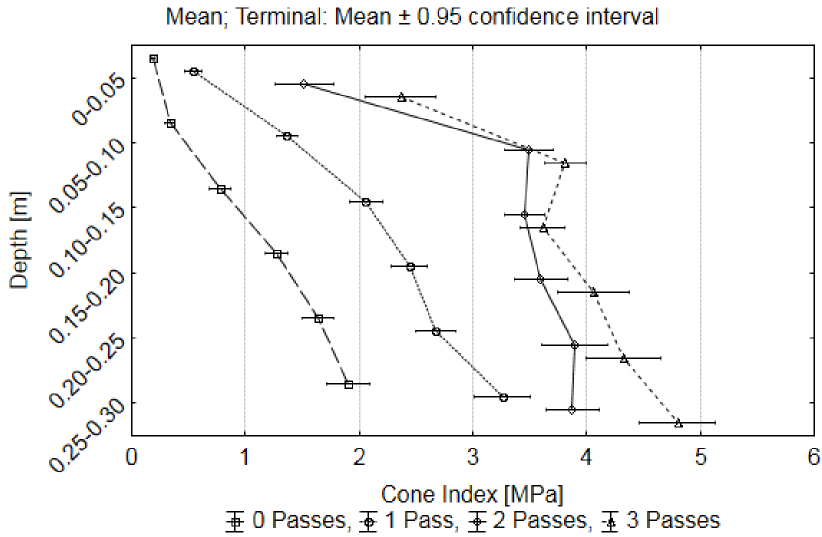

Figure 3. Cone index results at FC.

The comparison and identification of dependencies of the SFH and the MD infiltration methods (Fig. 4) showed a logarithmic trend with mid dependency ($R^2 = 0.2355$) according to Chráska (2000). As both methods measure the same parameter an increasing correlation was expected.

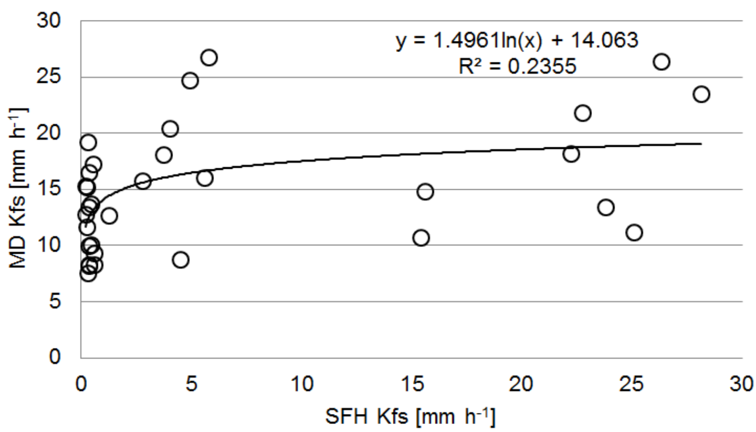

Figure 4. Correlation between MD and SFH method.

The correlation of both infiltration methods and soil bulk density (sampling depth of 0.07–0.14 m) showed linear trends with high dependency for the SFH method ($R^2 = 0.5944$) while for the MD method poor correlation ($R^2 = 0.0883$) was found (Fig. 5). According to the literature, a decreasing trend of correlation between soil water infiltration and bulk density was expected and also confirmed in both measured cases (Liebig et al., 1993; Yuxia et al., 2001).

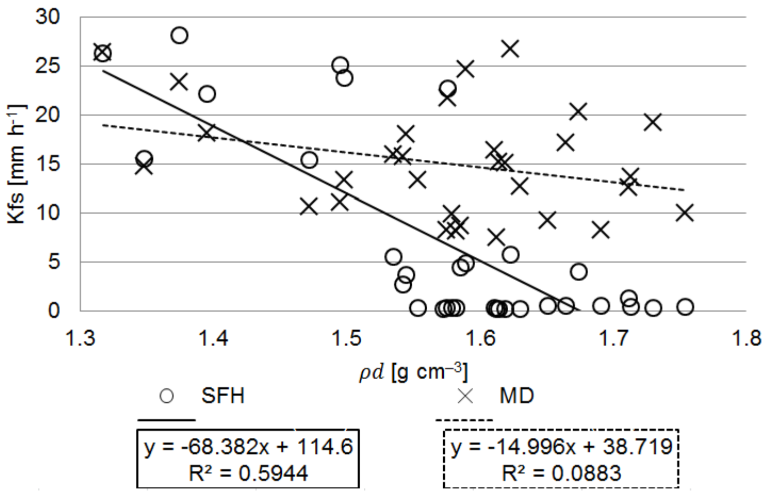

Figure 5. Correlation between infiltration methods (SFH and MD) and soil dry bulk density.

The expected trends of correlation of infiltration methods and cone index values should be similar to the trends showed in Fig. 5. As expected the linear decreasing correlation between the MD and cone index was confirmed with mid dependency (R^2 = 0.1887). In the case of SFH and cone index a decreasing power trend was found (Fig. 6) with a very high correlation (R^2 = 0.865).

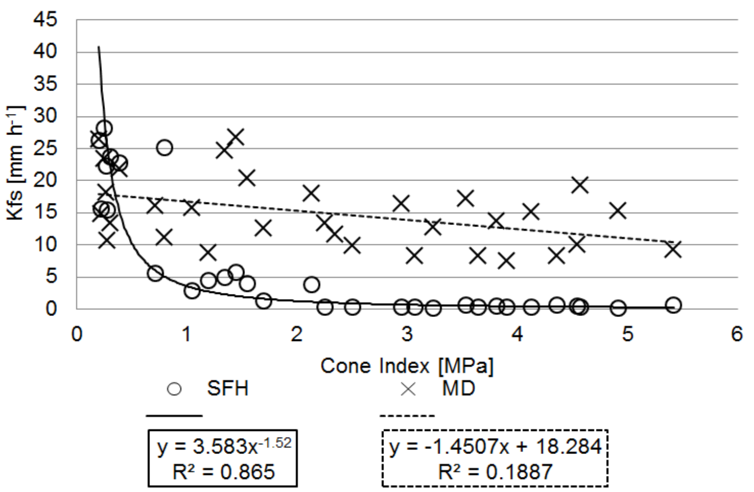

Figure 6. Correlation between infiltration methods (SFH and MD) and cone index.

The resulting measurements performed with MD and SFH method allowed a comparison of these methods to be made. However, the coefficients of correlation were at mid dependency (Fig. 5). The possible reason for this could be a different principle of the measurement methods. The minidisc method is based on the suction ability of the soil and is not affected by the ambient air pressure, while the SFH method is based on the Earth´s gravity and the ability of water to penetrate into the soil (Elrick et al., 1989).

CONCLUSIONS

1. The effect of vehicle traffic on soil infiltration has been significant:
   a) The non-compacted soil had its water infiltration rate up to 6 times higher than the trafficked;
   b) The results showed statistical differences between each compaction levels; moreover it was found that after two passes there were no changes in soil water infiltration rate measured by SFH method under these conditions;
   c) In case of the MD measurements, that the changes in soil water infiltration rate are expected to occur even after multiple passages.

2. A comparison of the infiltration methods used showed that both methods are applicable in practice, but not mutually interchangeable, as proven by a calculation of a coefficient of determination. The advantage of MD method is possibility to undertake many replications on a small area with almost no disturbance to the soil surface and small amount of water applied while the SFH method is more practical for field application. However, on severely compacted soils the MD method is less time consuming.

3. The effect of soil compaction on water infiltration highlights the importance of the techniques resulting in minimising soil compaction such as controlled traffic farming (CTF), linked operations, conservation tillage etc. These reduce trafficked areas which leads to a reduction of soil compaction and an increase in the water infiltration rate of a field.

REFERENCES

Alakukku, L. 1996. Persistence of soil compaction due to high axle load traffic. II. Long–term effects on the properties of fine–textured and organic soils. *Soil and Tillage Research* **37**, 223–238.

Arvidsson, J. & Håkansson, I. 1996. Do effects of soil compaction persist after ploughing? Results from 21 long–term field experiments in Sweden. *Soil and Tillage Research* 30, 75–197.

ASAE, S. 2004. *Soil cone penetrometer.* 49th Ed. editor St. Joseph: St. Joseph, Mich.: ASAE.

Ayers, P. & Perumpral, J. 1982. Moisture and density effect on cone index. *Transactions of the ASAE* **25**, 1169–1172.

Bagarello, V., Elrick, D.E., Iovino, M. & Sgroi, A. 2006. A laboratory analysis of falling head infiltration procedures for estimating the hydraulic conductivity of soils. *Geoderma* **135**, 322–334.

Bagarello, V., Iovino, M. & Elrick, D. 2004. A simplified falling–head technique for rapid determination of field–saturated hydraulic conductivity. *Soil Science Society of America Journal* **68**, 66–73.

Castellano, M.J. & Valone, T.J. 2007. Livestock, soil compaction and water infiltration rate: Evaluating a potential desertification recovery mechanism. *Journal of Arid Environments,* **71**, 97–108.

DECAGON Devices 2016. *https://www.decagon.com/en/hydrology/hydraulic-conductivity/mini-disk-portable-tension-infiltrometer/.* Accessed 20.11.2016.

Defossez, P. & Richard, G. 2002. Models of soil compaction due to traffic and their evaluation. *Soil and Tillage Research* **67**, 41–64.

Dickson, J.W. & Ritchie, R.M. 1996. Zero and reduced ground pressure traffic systems in an arable rotation 2. Soil and crop responses. *Soil and Tillage Research* **38**, 89–113.

Ekwue, E.I. & Harrilal, A. 2010. Effect of soiltype, peat, slope, compactioneffort and their interactions on infiltration, runoff and raindrop erosion of some Trinidadian soils. *Biosystems Engineering* **105**, 112–118.

Elrick, D.E., Reynolds, W.D. & Tan, K.A. 1989. Hydraulic conductivity measurement in the unsaturated zone using improved well analyses. *Ground Water Monitoring & Remedition* **3**, 184–193.

Gómez, J.A., Giráldez, J.V., Pastor, M. & Fereres, E. 1999. Effects of tillagemethod on soilphysicalproperties, infiltration and yield in an olive orchard. *Soil and Tillage Research* **52**, 167–175.

Hamza, M.A. & Anderson, W. 2005. Soilcompaction in croppingsystems: A review of the nature, causes and possible solutions. *Soil and Tillage Research* **82**, 121–145.

Chamen, W. 2011. The effect of low and controlled traffic systems on soil physical properties, yields and the profitability of cereal crops on a range of soil types, *thesis submitted in fulfilment of the requirements for the PhD. Cranfield: Cranfield University.*

Chráska, M. 1998. *Basics of research in pedagogy.* Palacký University Olomouc, Olomouc, 257 pp. (in Czech)

Chyba, J., Kroulík, M., Krištof, K., Misiewicz, P.A. & Chaney, K. 2014. Influence of soil compaction by farm machinery and livestock on water infiltration rate on grassland. *Agronomy Research* **12**, 59–64.

Chyba, J., Kumhála, F. & Novák, P. 2016. Mapping and differences of soil physical properties. In: *6th International Conference on Trends in Agricultural Engineering 2016-Part I.* Czech Republic, Prague, pp. 224–229.

Johnson, C.E. & Bailey, A.C. 2002. Soil Compaction. *Advances in Soil Dynamics* **2**, 155–183.

Krištof, K., Boďo, T. & Misiewicz, P.A. 2010. Influence of work implements on selected soil properties. In: *Technika v technológiách agrosektora 2010.* Slovak Republic, Nitra, pp. 86–92. (in Slovak)

Kroulík, M., Kvíz, Z., Kumhála, F., Hůla & J., Loch, T. 2010. Procedures of soil farming allowing reduction of compaction. *Precision Agriculture* **12**, 317–333.

Liebig, M. A., Jones, A.J., Mielke, L.N. & Doran, J.W. 1993. Controlled wheel traffic effects on soil properties in ridge tillage. *Soil Science Society of America Journal* **57**, 1061–1066.

Radford, B.J., Yule, D.F., McGarry, D. & Playford, C. 2007. Amelioration of soil compaction can take 5 years on a vertisol under no till in the semi–arid subtropics. *Soil and Tillage Research* **97**, 249–255.

Raper, R.L. 2005. Agricultural traffic impacts on soil. *Journal of Terramechanics* **42**, 259–280.

Raper, R.L. & Kirby, J.M. 2006. Soil compaction: How to do it, undo it, or avoid it. In: *Agricultural Equipment Techonology Conference*. USA, Louisville, Kentucky, pp. 1–14.

Valla, M., Kozák, J., Němeček, J., Matula, S., Borůvka, L. & Drábek, O. 2011. *Pedologic practice.* Czech University of Life Sciences Prague, Prague, 155 pp. (in Czech)

Varga, F., Tkáč, Z., Šima, T., Hujo, Ľ., Kosiba, J. & Uhrinová, D. 2014. Measurement of soil resistance by using a horizontal penetrometer working with the two–argument comparative method. *Agronomy Research* **12**, 187–196.

Yuxia, L., Tullberg, J.N. & Freebairn, D.M. 2001. Traffic and residue cover effects on infiltration. *Australian Journal of Soil Research* **39**, 239–247.

Zhang, S., Grip, H. & Lövdahl, L. 2006. Effect of soil compaction on hydraulic properties of two loess soils in China. *Soil and Tillage Research* **90**, 117–125.

Zhao, X., Wu, P., Gao, X., Tian, L. & Li, H. 2014. Changes of soil hydraulic properties under early-stage natural vegetation recovering on the Loess Plateau of China. *CATENA* **113**, 386–391.

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Suitability of oat bran for methane production

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Abstract. There is need to investigate the suitability of various cheaper biomasses for energy production. It is necessary to explore ways to improve the anaerobic fermentation process with the help of various catalysts. Biocatalyst Metaferm produced in Latvia previous studies with other biomass gave an increase in production. The purpose of study is evaluation of suitability of granular and crushed oat bran waste biomass for the production of methane and influence of catalyst Metaferm on anaerobic digestion (AD) process. The biomass anaerobic digestion process was investigated in 0.75 L digesters, operated in batch mode at temperature 38 ± 1.0 °C. The average biogas yield per unit of dry organic matter added (DOM) from digestion of granular oat bran was 0.400 L g^{-1}_{DOM} and methane yield was 0.193 L g^{-1}_{DOM}. Average biogas yield from digestion of crushed oat bran was 0.439 L L g^{-1}_{DOM} and specific methane yield was 0.193 L L g^{-1}_{DOM}. Adding of 1 mL Metaferm in substrates with not crushed or crushed oat bran increases specific methane yield by 0.227 L g^{-1}_{DOM} or 0.236 L g^{-1}_{DOM} respectively. Investigated oat bran can be used for methane production, but methane production was less than from traditional biomass, e.g. maize silage.

Key words: anaerobic digestion, oat bran, biogas, methane, additive Metaferm.

INTRODUCTION

59 biogas plants are working today in Latvia. Recent government decisions decreased the support for producers of biogas, due to new tax imposed. There is need to investigate the suitability of various cheaper biomasses for energy production (Rivza et al., 2012).

The aim of the study is to find out the potential of biogas production from oat brans as raw material and to investigate the effect of catalyst Metaferm for improving of anaerobic digestion process.

The process of anaerobic digestion of waste resulting in production of biogas and organic fertilizer is one of the most perspective and environmentally friendly way for the waste utilization. Over the last decade considerable efforts have been made in development of biogas production technologies in many countries in the EU (Kaparaju et al., 2002; Gomez, 2007). The most important purpose of biogas plant is utilisation of organic wastes, e.g. manure, household organic waste, wastewater sludge, and the second purpose is to meet the growing energy demands in the situation, when prices on fuel and energy are increasing. In recent years the biogas production is expanding significantly also in Latvia.

Oat bran is produced by rolling and/or milling of oats and its separating by sieving or other suitable means to obtain the oat flour. By-product oat bran fraction is not more than 50% of the original biomaterial. Oat bran fraction has the total betaglucan content in dry matter (DM) at least 5.5% and the total dietary fiber content of at least 16.0%. At least one-third of the total dietary fiber is soluble fiber. Biogas production from oat bran has potential for energy generation, however, each substrate characteristic should be carefully evaluated to enable the optimization of the anaerobic digestion (AD) process. Biochemical methane potential assays were performed to evaluate the energy potential of the substrates (Misi et al., 2001). Oat husk is lignocellulosic biomass and it is a by-product of mills. Research results on usage of oat husk for biogas and methane production is reported (Kusch et al., 2011). Oat husk was used in innovative continuous two phase, two stage prototype biogas plant at Yettereneby Farm in Jarna, Sweden (2003) for production of biogas in solid phase slow process. The biogas production by this method is slow but it is a steady process (Kaparju et al., 2002).

Our few studies showed that the damaged oat products can be successfully utilised in the production of biogas. The average methane yield from crushed oats was 303 L kg_{DOM}^{-1} and the average methane content was 63.1% (Dubrovskis et al., 2012). The raw materials can be also food production by-products, residues and damaged products that are not more usable for food consumption.

MATERIALS AND METHODS

The biogas production potential was measured using laboratory equipment consisting of 16 bioreactors. Fermentation temperature was maintained 38 ± 1 °C inside containers during batch mode process. Mixture consists of 500 g inoculum (fermented cow manure) and added biomass sample (10 g non-crushed oat bran or 10 g crushed oat bran, into 0.75 L bioreactors for anaerobic fermentation. Dry matter, ashes and organic dry matter content was determined for every sample before filling into bioreactor for anaerobic treatment. Measuring accuracies were following: ± 0.2 g for inoculums and substrate weight (scales model Kern FKB 16KO2), ± 0.001 g for biomass samples for dry matter, organic matter and ashes weight analyses, ± 0.02 pH (accessory PP-50), ± 0.05 L for gases volume, and ± 0.1 °C for temperature inside the bioreactors. Biogas composition, e.g. methane, carbon dioxide, oxygen and hydrogen sulphide was investigated with the gas analyser GA 2000. Gases volume measurements were provided 3–7 times, depending on gases volume, during AD process. Dry matter was determined by specialized unit Shimazy at temperature 105 °C, and ashing was performed in oven Nabertherm at temperature 550 °C using the standard heating cycle lasting approx. 0.70 hours in total. Standard error was calculated by standardized data processing tools for each group of digesters. For calculations of results were used widely approved methods (Angelidaki et al., 2009; Kaltschmitt 2010).

RESULTS AND DISCUSSION

Anaerobic fermentation of out bran for biogas and methane production was provided using 14 bioreactors for inoculum (IN) and out bran mixture and 2 bioreactors for control with inoculum only. Biogas and methane data from all bioreactors were used to calculate the average biogas and methane volume for each group of similar bioreactors filled in with the same sample replications.

The results of substrate components and raw substrates analyses for every group with similar samples replications before anaerobic fermentation are summarized below in Table 1.

Table 1. The results of the analyses of raw materials

Reactor	Raw material	pH	TS, %	TS, g	Ash, %	DOM, %	DOM, g	Weight, g
R1, R16	IN 500	7.4	2.88	14.40	23.45	76.55	11.023	500
R2-R4	IN500+ON10	7.2	4.58	22.34	13.58	86.42	20.170	510
R2-R8	ON10	4.2	89.4	8.94	7.34	92.66	8.284	10
R5-R8	IN500+ON10+1MF		4.57	22.34	13.58	86.42	20.170	511
R9-15	OC10		90.17	9.017	5.84	94.16	8.490	10
R9-11	IN500+OC10		4.59	23.417	16.67	83.33	19.513	510
R12-15	IN500+OC10+1MF		4.58	23.417	16.67	83.33	19.513	511

Abbreviations: R1–R16 – bioreactors numbers;TS – total solids; Ash – ashes; DOM – dry organic matter; IN – inoculum; AN – not crushed oat bran; AS – crushed oat bran; 1MF – 1 mL additive Metaferm.

Biogas and methane yield and average methane concentration in biogas from not crushed and crushed oat bran and for substrates with additive Metaferm is shown in Table 2.

Table 2. Biogas and methane released from oat bran in anaerobic fermentation process

Reactor	Raw material	Biogas, L	Biogas, L g^{-1}_{DOM}	Methane aver. %	Methane, L	Methane, L g^{-1}_{DOM}
R1	IN500	0.4		1.25	0.005	
R16	IN500	0.4		0.75	0.003	
Average, R1, R16		0.4			0.004	
R2	IN500+ON10	3.5	0.423	38.11	1.334	0.161
R3	IN500+ON10	3.5	0.423	48.10	1.684	0.203
R4	IN500+ON10	3.9	0.471	45.92	1.791	0.216
Average, R2-R4		3.633	0.439 ± 0.024	44.12	1.603	0.193 ± 0.027
R5	IN500+ON10+1MF	3.9	0.471	50.46	1.968	0.238
R6	IN500+ON10+1MF	3.9	0.471	46.95	1.831	0.221
R7	IN500+ON10+1MF	3.4	0.410	51.53	1.752	0.211
R8	IN500+ON10+1MF	3.7	0.447	53.16	1.967	0.237
Average, R5-R8		3.725	0.449 ± 0.031	50.47	1.880	0.227 ± 0.014
R9	IN500+OC10	3.5	0.412	47.37	1.658	0.195
R10	IN500+OC10	3.2	0.377	49.00	1.568	0.185
R11	IN500+OC10	3.5	0.412	48.00	1.680	0.198
Average, R9-R11		3.4	0.400 ± 0.018	48.08	1.635	0.193 ± 0.007
R12	IN500+OC10+1MF	5.0	0.588	53.20	2.660	0.313
R13	IN500+OC10+1MF	3.8	0.448	49.71	1.889	0.222
R14	IN500+OC10+1MF	3.9	0.459	53.54	2.088	0.246
R15	IN500+OC10+1MF	3.2	0.377	43.34	1.387	0.163
Average, R12-R15		3.975	0.468 ± 0.105	50.47	2.006	0.236 ± 0.075

Abbreviations: L g^{-1}_{DOM} – litres per 1 gram dry organic matter of the original raw material.

Average volume of biogas (0.4 L) or methane (0.04 L) released in control bioreactors R1, R16 is already subtracted from biogas volume from every bioreactor filled with inoculum and out bran biomass (Table 2).

The obtained methane yield is very similar for not crushed or crushed oat bran. Typically, grinding of the raw material prior to AD process greatly increases the methane yield due to the greater surface area available for microorganisms. Lower results in this case may be explained by evidence of thicker surface layer created by smaller particles not submerged in substrate thus having less mixing possibilities.

Compared with other biomass methane yield it is not high, due to emerging thick surface layer, slowing down digestion process.

Specific biogas and methane production from oat bran with and without additive Metaferm is shown in Fig. 1.

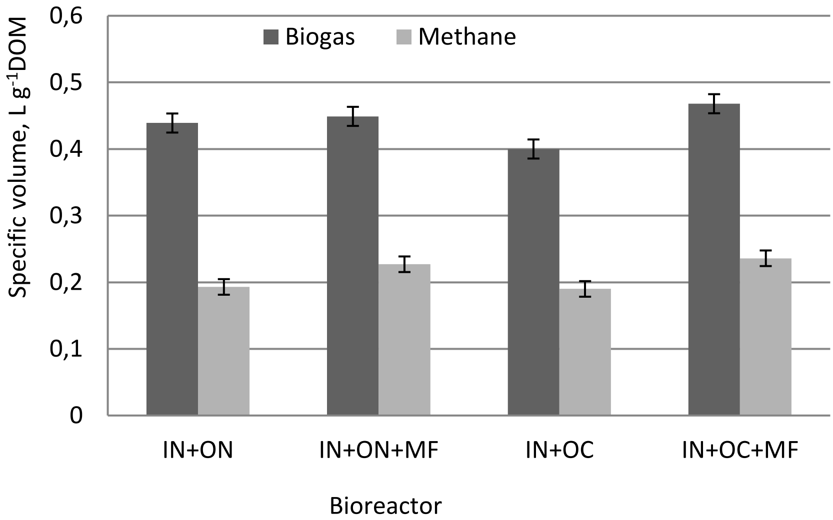

Figure 1. Specific biogas and methane production from oat bran.

Investigated specific methane yield from not crushed and crushed oat bran was approximately equal. Addition of 1 mL Metaferm into not crushed or crushed oat bran mixtures increase specific methane yield significantly by 22.28% or 17.62% respectively. This can be explained by the fact that Metaferm promotes methane formation and have positive effect on bacteria activity.

The relatively low average methane content of gas is explained by the fact that the raw material contains a lot of lignin, cellulose and hemicellulose, which is difficulty to be degraded by bacteria. The relatively low methane yield from added dry organic matter could also be explained by the relatively high initial air volume in bioreactors above the substrate at a start of investigations.

The average methane content (Fig. 2) increases if the oat bran was crushed or additive Metaferm was added in substrates, therefore, chopping of oat bran is recommended before usage for biogas production.

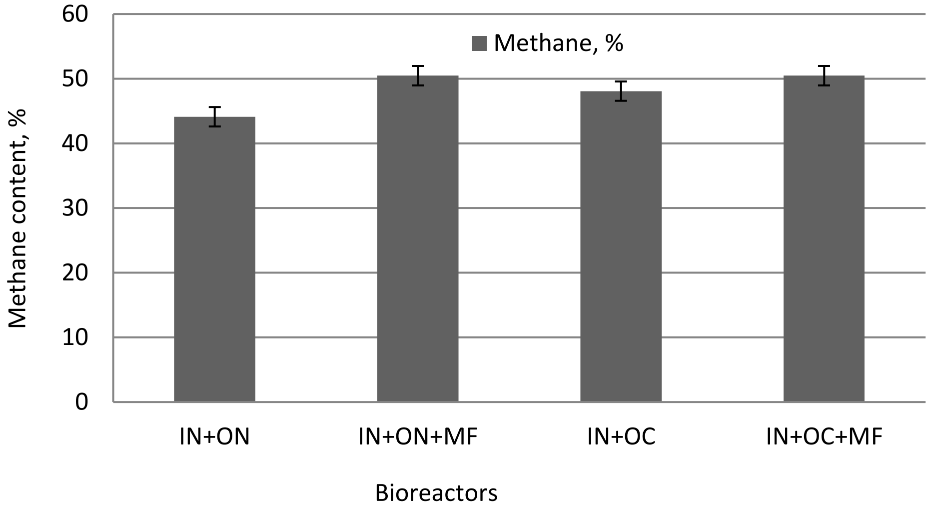

Figure 2. Methane content in biogas from oat bran without and with additive Metaferm.

Usage of additive Metaferm increases both methane production and methane content in biogas, thus it can be recommended for improvement of methane yield and quality of biogas obtainable from the oat bran biomass.

CONCLUSIONS

The average methane production from not crushed and crushed oat bran was the same (0.193 L g^{-1}_{DOM}), however the average methane content in biogas from crushed oat bran was 48% that was by 4% higher compared to methane in biogas from not crushed oat bran.

The average methane yield from not crushed oat bran with added 1 mL Metaferm was 0.238 L g^{-1}_{DOM}, or by 22.28% higher compared to oat bran without additive Metaferm.

The average methane yield from crushed oat bran with additive 1 mL Metaferm was 0.236 L g^{-1}_{DOM}, or by 17.62% higher compared to oat bran without additive Metaferm. It is proposed that additive MF3 may contain the some components facilitating the activity of bacteria.

The average methane content in biogas from not crushed oat bran or from crushed oat bran with added Metaferm is by 6.4% or by 2.4 higher compared to methane content from same substrates without additive Metaferm respectively.

The research results shows that both not crushed or crushed oat bran are acceptable as the raw material for the production of methane.

It is recommended, that oat bran is wetted and stirred before its usage in a biogas plant to reduce the upper biomass layer. Also regular stirring and mixing of upper layer is recommended during anaerobic fermentation process.

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REFERENCES

Angelidaki, I., Alves, M., Bolzonella, D., Borzacconi, L., Campos, J., Guwy, A., Kalyuzhnyi, S. & Jenicek, P. 2009. Defining the biomethane potential: proposed protocol for batch assays, *Water Sci. Technol.* **59**(5), 927–934.

Gomez, C.2007. Biogas in change. *16th annual meeting of the German Biogas Association.* 31.01–2.02.2007.

Dubrovskis, V., Plume, I., Kotelenecs, V., Zabarovskis, E. 2011. Biogas production and biogas potential from agricultural biomass and organic residues in Latvia. *Proceedings of International Congress Biogas in Progress 2*. Hohenheim. Stuttgart **2**, 80–83.

Dubrovskis, V., Adamovics, A. 2012. Horizons of Bioenergy (*Bioenerģētikas horizonti*), p. 352. (in Latvian).

Dubrovskis, V., Kotelenecs, V., Zabarovskis, E., Celms, A. & Plume, I. 2012. Biogas production potential from agricultural biomass and organic residues in Latvia. Renewable Energy and Energy Efficiency, 115–120.

Kaltschmitt, M. 2010. Handbook of methods (*Methodenhandbuch*), Leipzig, p. 93 (In German).

Kaparaju, P., Luostarinen, S., Kalmari, J., Rintala, J. 2002. Co-digestion of energy crops and industrial con-fectionery by-products with cow manure: batch-scale and farm-scale evaluation. *Water Sci. Technology* **45**(10), 275–80.

Kusch, S, Schumacher, B., Oechsner, H., Schafer, W. 2011. Methane yield of oat husks. *Biomass Bioenergy* **35**, 2627–2633.

Misi, S., Forster, C.F. 2001. Batch co-digestion of multi-component agro-wastes. *Bioresource technology* **80**, 19–28.

Rivza, P. (ed.). 2012. *Renewable energy and its effective use in Latvia*, Jelgava, p. 392.

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The search for practical and reliable observational or technical risk assessment methods to be used in prevention of musculoskeletal disorders

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Abstract. Work-related musculoskeletal disorders (WRMSDs) are still frequent, inducing very large costs for companies and societies all over the world. Ergonomists work to prevent these disorders and to make organisations sustainable. In their work it is important to identify risks in a reliable way, to prioritise risks, and then to perform interventions (participatory interventions have shown to more often be successful), so that the risks and the disorders may be reduced. Risks are most often assessed by observation. Two projects are described. In the first project the inter-observer reliability of six observational methods was found to be low in risk assessments concerning repetition, movements and postures. Also the inter-method reliability was often low, i.e. when the same work is assessed with different methods different risk estimates are often obtained. In the second described project, easy-to-use methods for measurements of postures and movements were developed and validated. Hence, there are now validated technical methods that are easy to use. But, today's inexpensive electronic devices should be utilized to a higher degree, in developing tools, together with practitioners, that are attractive, easy and time efficient to use, and which should increase the reliability in risk assessments of work tasks and jobs.

Key words: Biomechanical exposure, Observation, Direct measurements, Validity, Reliability, Usability.

INTRODUCTION

Work-related musculoskeletal disorders (WMSDs) are still frequent, inducing very large costs for organisations and societies all over the world. Factors in the physical workload, such as excessive and/or prolonged muscular load, repetitive work and work in awkward and constrained postures, are known risk factors for developing WMSDs in the neck/shoulder region and in arms and hands (European Agency for Safety and Health at Work, 2010).

In order to identify risk occupations, jobs and tasks, for interventions, as well as while planning new jobs and work stations, and to facilitate evaluations of interventions in terms of decreased exposure to risk factors, there is a need for valid, reliable and useful methods for risk assessment of biomechanical exposure.

After assessing and prioritise risks, by the level of acuteness and their seriousness versus the cost of the solutions, interventions should be performed (participatory interventions have shown to more often be successful; Westgaard & Winkel, 1997), so that the risks and the disorders may be reduced.

Many researchers and company ergonomists have worked with risk assessments and many methods, especially observational methods, have been proposed in the literature and are used by practitioners and researchers (Takala et al., 2010; Eliasson & Nyman, 2013; Kalkis et al., 2014; Kong et al., 2017). It is still a popular and interesting field which is indicated by the fact that the observational methods review article (Takala et al., 2010), that was the result of an Nordic collaboration led by Dr. Esa-Pekka Takala at the Finnish Institute of Occupational Health, have been cited about 100 times in other scientific publications. In that review, the authors identified 30 eligible observational methods. Of these, 19 had been compared to one or more methods. Intra- and inter-observer repeatability was reported for 7 and 17 methods, respectively. The methods are generally constructed based on epidemiologic findings, but their ability to predict future MSD (predictive validity) is rarely studied.

In a study comparing observations and inclinometer measurements, Trask et al. (2014) concluded: 'Since observations were biased, inclinometers consistently outperformed observation when both bias and precision were included in statistical performance'. Moreover, dynamic work is best quantified with technical measurements. The general opinion about technical measurements have been, at least until now, that they are time consuming, require expensive equipment, demand technical knowledge to perform, and are therefore not suitable for actors in the work environment field, such as the occupational health services. However, there are now, because of the development of electronics components, a number of low-cost (about \$100–\$200) technical devices available, i.e. accelerometers, that may be used to monitoring human motions (Korshøj et al., 2014; Skotte et al., 2014; Dahlqvist et al., 2016). These devices are accelerometers with integrated data loggers. There are also inertial measurement units (IMUs) that in addition to a three-axial accelerometer include a gyroscope and a magnetometer.

The overall aim of this research effort is to test existing methods, and to design and validate new methods for risk assessment of biomechanical exposure. In this article two just carried out research projects are described, and the future is discussed, in the field of ergonomics risk assessment.

MATERIALS AND METHODS

Observational methods – reliability, validity, and usability

Although there are many methods available, often ergonomists in the field, for different reasons, e.g. lack of time and/or lack of knowledge of adequate methods, use their own knowledge and experience, when performing risk assessments. In the first of the two described projects, six selected risk assessment methods were evaluated concerning their reliability, validity, and usability (Forsman et al., 2015). The reliability of assessments that ergonomists performed based on their own experience and knowledge, without any specific method, was also investigated.

The six selected methods were:

1. Occupational Repetitive Actions checklist (OCRA; Takala et al., 2010),
2. Quick Exposure Checklist (QEC; Takala et al., 2010),
3. Strain Index (SI; Takala et al., 2010),
4. Assessment of Repetitive Tasks (ART; www.hse.gov.uk/msd/uld/art/index.htm),
5. Hand Arm Risk-assessment Method (HARM; Douwes & de Kraker, 2009),

6. Repetitive work model by the Swedish Work Environment Authority (SWEA, 2012).

Ten video-recorded (3-6 minutes) work tasks were included: 2 supermarket work tasks, meat cutting and packing, engine assembly, hairdressing, 2 cleaning tasks and 2 post sorting tasks. For each work task, data of the work task length (between 2–7 hours per workday), pause schedules, handled weights and physical factors, as well as the employees' ratings of force exertion, work demands and control were given.

Twelve experienced ergonomists made assessments of the ten work tasks in their own pace. The ergonomists were all educated physiotherapists, who were recruited from occupational health services (OHS) and through social media posts to members of the Swedish Ergonomist and Human Factors Society. To be included in the study they should be employed by OHS (or equivalent) and have at least one year of work experience with risk assessments. Firstly they did assessments without using any specific method, as over-all risk, and specified for eight body regions into: high risk (red), moderate risk (yellow) and or low risk (green) (Eliasson et al., 2017). Then, they used the six methods twice, with at least four weeks between the occasions. Before the first assessment, the ergonomists were trained in each method. The videos could be paused or repeated as needed. The assessment times were registered, and the ergonomists were given an evaluation questionnaire on completion of each of the methods.

As an alternative for predictive validity, consensus assessments were carried out by three experts (Kjellberg et al., 2015). They first did own assessments, carefully, in accordance with the manual of each method, and then agreed in the group. Three months later, they again, together, repeated the assessments, in the reversed method order. The experts' assessments were used as a gold standard for concurrent validity of the ergonomists' ratings, and for inter-method comparisons.

To take the agreement due to chance into account, the linearly weighted Kappa coefficient, K_w was the parameter primarily chosen for inter- and intra-observer reliability and validity. The K_w was firstly computed pairwise for all pairs, and then averaged in the way recommended by Davies & Fleiss (1982), Hallgren (2012).

New easy-to-use technical measurements of postures and movements

The second project of the two projects described here was set up to (1) together with actors at the OHS develop easy-to-use methods of technical measurements of postures and movements during work, and which automatically provides informative charts and graphs; (2) validate the new methods against previously validated methods, which today are used by researchers, and (3) test the new methods concerning the time required and their usability for actors within the OHS (Dahlqvist et al., 2016; Yang et al., 2017).

The project included one method for full-day measurements, with a quality equal to similar research methods. The high data quality makes these simplified measurements fully comparable with those reported in the literature. It consists of small accelerometer-devices with integrated USB-memories. They measure postures and movements of head, back and both upper arms. The method includes a simple protocol where you note the start- and end times for work and breaks. After the measurement, the devices are connected to a computer and the noted times are used in a program that computes and presents the workload in figures and tables. An 'even easier' method for shorter measurements was developed as an application for iPhone/iPod. It is called

ErgoArmMeter and measures the arm elevations. Directly after a measurement it shows statistical parameters of angles and angular velocities (Yang et al., 2017).

The new methods were validated, i.e. they were compared with previously validated methods, in static postures, during standardised movements (moving the arm back and forth in different paces), and during simulated work tasks.

RESULTS AND DISCUSSION

Observational methods – reliability, validity, and usability

For sole observation without any specific method, the average inter-observer, weighted Kappa, K_w, for the over-all risk was 0.32, i.e. the agreement above what could be expected by random was 32%. The intra-observer ditto was 0.41. The corresponding K_w for 8 body-part-ratings were in average 0.21, and 0.35.

The K_w of the inter-observer reliability for over-all risk in three levels were in OCRA 0.37, QEC 0.54, HARM 0.65, and SWEA 0.28. The K_w for specific body parts were, in QEC, 0.44 (shoulder), 0.49 (back), 0.67 (shoulder), 0.86 (neck), SI 0.47 (hand), ART 0.58 (left side) and 0.65 (right side). In the SWEA model, the K_w was below 0.4 for all five questions.

The relatively high reliability found for HARM (K_w = 0.65) was at first thought to depend on the clear pictures (photographs) in the scoring sheets showing neutral and awkward postures for wrists, shoulders and neck. But when observing the computed separate K_w for each rated HARM item, all K_w for items concerning repetition, movements and postures were below 0.3, i.e. at the same level as those without any specific method. Hence, the clear pictures did not seem to make it easier to rate postures and movements. The relatively high reliability of HARM instead seems to depend on the data of the work task that were given to the ergonomists (see methods above), for example the task length which in HARM has a high impact on the resulting estimated risk level. Throughout the methods, the K_w was generally the lowest for ratings of body postures.

As expected, the intra-rater K_w was somewhat higher than the corresponding inter-rater K_w in all methods, and the validity K_w. correlated with the inter-rater K_w. The obtained risk levels varied considerably between the methods, the pairwise K_w ranged from 0.10 (HARM-QEC) to 0.74 (ART-OCRA) (Kjellberg et al., 2015).

The mean score of 8 usability ratings was the highest for ART and the lowest for OCRA. OCRA also had the longest average assessment time.

As shown above, and which is in agreement with previous findings, there is a considerable variation not only between ergonomists' assessments of risks levels for MSDs in the observation methods, but also between methods. However, since observation without the use of any specific method have a low, non-acceptable reliability, it is recommended to use one or more systematic methods, and to a larger degree combine observations with validated methods of direct measurements.

New easy-to-use technical measurements of postures and movements

The three different types of methods all showed similar results to the previously validated methods (i.e. they are comparable with the previously used technical research methods). One example of a comparison is shown in Fig. 1, where a high correlation between the optical system and the iPhone system for arm flexion postures is shown.

Each one of the here described three methods for measurements of postures and movements have been presented at conferences and in education of ergonomists. The methods, especially the iPhone application, have been used by physiotherapists/ergonomists for workplace improvements, and in master thesis projects. The new methods are easier to use. They are also easier to wear (less obstructive) for the workers than the cabled sensors of the previous research methods. Because the validity of the new methods, they are now also used in research projects. During the development process, we received feedback from the OHS, and we counteracted the weaknesses that we and the OHS discovered.

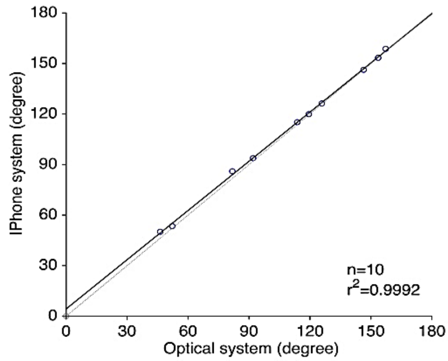

Figure 1. Upper arm inclination results from arm flexion validation experiment (Yang & Forsman, 2015).

The future of ergonomics risk assessments

A vision, which researchers in this field share, is that there should be practical tools available and that the ergonomists and other practitioners use them. Now, more and more methods are being developed, but there is a delay in the ergonomists' use of these methods. In Sweden the use of the QEC method (Takala et al., 2010) is increasing, also the use of HARM (Douwes & de Kraker, 2009) is becoming more frequently used. The methods are often presented as good if they cover many aspects, very little information is usually given about reliability issues. Also ergonomists, as well as other professionals, have their basic education and their usual way to work; it is hard to change the way you usually do things. A recommendation out of this research effort is to use systematic tools for risk assessments, at least the scientifically documented observational methods. When the results are presented from the part where no specific method was used, and a very low reliability in the assessments is revealed, ergonomists agree that systematic methods should be used. Systematic and direct measurement risk assessment methods should be included in the education programs for ergonomists.

Direct measurements are more reliable. But observational methods may cover more dimensions. A possible future is to use a combination, i.e. combined methods, where the dimensions of the lowest reliability in observational methods are replaced by technical, practical methods.

The new iPhone application (ErgoArmMeter; free to download from App Store) for upper arm posture and movement measurements is very easy to use, and may be a start for of ergonomists to a new way to work. The application only include upper arm, but other measurements, as e.g. wrist postures and movements should be possible to include, by utilizing gyroscopes, accelerometers, and magnetometers on external inertial measurement units (IMUs). These applications would then include measurements of repetitively, estimated by measured angular velocity. They could also include checklists for input of e.g. forces (measured or observed), additional factors such as auto-control (job-control), temperature, rest-schedules and vibrations.

A development of an easy-to-use method including postures, movements, and handled tum-grip forces, have been started by a consortium with Swedish universities and companies (e.g. KTH Royal Institute of Technology, Karolinska Institutet, Chalmers, Universities of Borås and Gävle; Scania, Volvo and Hultafors workwear). The project is called 'Smart textiles', and the plan is to integrate sensors in textiles. Measurements will be made easy, since analyses and interpretation will be carried out automatically.

More reference data from different occupational groups and guidelines with risk action limits are needed for those interpretations. However, a first version of such guidelines are already published as a report in Swedish from Lund University (Hansson et al., 2016), and there are ongoing studies on large material of technical measurements of Danish blue collar workers (Jørgensen et al., 2013).

CONCLUSIONS

The first of the two described projects where observational methods were evaluated showed that those methods, especially in ratings of postures, repetitions and forces, have low reliability. Also the inter-method reliability is often low. Therefore the risk assessment is heavily dependent on the observer and on the method chosen. The new technical measurements have high validity and reliability. They may be used by practitioners to investigate the postures and movements exposure in a work group in an efficient way. And the new Iphone application may be use to quickly and quantitatively compare work techniques (in training) and work stations (in production system development). In the search for practical and reliable risk assessment methods to be used in prevention of musculoskeletal disorders, today's low-cost electronic devices should be utilized to a higher degree. As the technical methods are much more reliable, they should replace observations, when it is possible in practice, and in designing of new risk assessment tools (which should be developed in collaboration with practitioners. Such new tools may combine measurements and checklists in smartphone applications).

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REFERENCES

Dahlqvist, C., Hansson, G.-Å. & Forsman, M. 2016. Validity of a small low-cost triaxial accelerometer with integrated logger for uncomplicated measurements of postures and movements of head, upper back and upper arms. *Applied Ergonomics* **55**, 108–116.

Davies, M.& Fleiss, J.L. 1982. Measuring agreement for multinomial data. *Biometrics* **38**, 1047–1051.

Douwes, M. & de Kraker, H. 2009. Hand arm risk assessment method (HARM), a new practical tool.In: *Proceedings of IEA 2009*. Beijing.

Eliasson, K. & Nyman, T. 2013. Practitioners knowledge, usage and need concerning risk management. In: *Proceedings of the Nordic Ergonomic Society annual conference*. Reykjavik, Iceland.

Eliasson, K., Palm, P., Nyman, T. & Forsman, M. 2017. Inter- and intra-observer reliability of risk assessment of repetitive work without any specific method. *Applied Ergonomics* **62**, 1–8.

European agency for safety and health at work 2010. *OSH in Figures: Work-related Musculoskeletal Disorders in the EU - Facts and Figures*. Luxembourg, pp. 103–150.

Forsman, M., Eliasson, K., Rhén, I.M., Nyman, T. & Kjellberg, K. 2015. Symposium – Observational Risk Assessment Methods. In: *Proceedings of IEA 2015*, Melbourne.

Hallgren, K.A. 2012. Computing inter-rater reliability for observational data: An overview and tutorial. *Tutorials in Quantitative Methods for Psychology* **8**, 23–34.

Hansson, G.-Å., Arvidsson, I. & Nordander, C. 2016. Riktvärden för att bedöma risken för belastningsskador, baserade på tekniska mätningar av exponeringen (In Swedish; English title: 'Recommended action limit values for musculoskeletal risk assessments, based on technical exposure measurements'). *Rapport nr 4/2016.* Arbets- och miljömedicin – Lund. Sweden.

Jørgensen, M.B., Korshøj, M., Lagersted-Olsen, J., Villumsen, M., Mortensen, O.S., Skotte, J., Søgaard, K., Madeleine, P., Thomsen, B.L. & Holtermann, A. 2013. Physical activities at work and risk of musculoskeletal pain and its consequences: protocol for a study with objective field measures among blue-collar workers. *BMC Musculoskelet Disord*. doi: 10.1186/1471-2474-14-213.

Kalkis, H., Roja, Z. & Kalkis, V. 2014. Physical load analysis in hotel cleaning work. *Agronomy Research* **12**(3), 843–850.

Kjellberg, K., Lindberg, P., Nyman, T., Palm, P., Rhen, I.-M., Eliasson, K., Carlsson, R., Balliu, N. & Forsman, M. 2015. Comparisons of six observational methods for risk assessment of repetitive work - results from a consensus assessment. In: *Proceedings, 19th Triennial Congress of the International Ergonomics Association*, Melbourne.

Kong, Y.K., Lee, S.Y., Lee, K.S. & Kim, D.M. 2017. Comparisons of ergonomic evaluation tools (ALLA, RULA, REBA and OWAS) for farm work. *Int J Occup Saf Ergon*. **17**, 1–19.

Korshøj, M., Skotte, J.H., Christiansen, C.S., Mortensen, P., Kristiansen, J., Hanisch, C., Ingebrigtsen, J. & Holtermann, A. 2014. Validity of the Acti4 software using ActiGraph GT3X accelerometer for recording of arm and upper body inclination in simulated work tasks. *Ergonomics* **57**(2), 247–53.

Skotte, J., Korshøj, M., Kristiansen, J., Hanisch, C. & Holtermann, A. 2014. Detection of physical activity types using triaxial accelerometers. *J. Phys. Activity Health* **11**(1) 76–84.

SWEA - Swedish Work Environment Authority. AFS 2012:2 Ergonomics. *www.av.se.*

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.

Trask, C., Mathiassen, S.E., Wahlström, J. & Forsman, M. 2014. Cost-efficient assessment of biomechanical exposure in occupational groups, exemplified by posture observation and inclinometry. *Scand. J. Work Environ. Health* **40**, 252–265.

Yang, L. & Forsman, M. 2015. Development and validation of a novel iOS application for measuring arm inclination. In: *Proceedings of the Nordic Ergonomic Society annual conference*. Lillehammer, Norway.

Yang, L., Grooten, W.J.A. & Forsman, M. 2017. An iPhone application for upper arm posture and movement measurements. *Applied Ergonomics*. In press.

Westgaard, R.H. & Winkel, J. 1997. Ergonomic intervention research for improved musculoskeletal health: A critical review. *International Journal of Industrial Ergonomics* **20**, 463–500.

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Correlation between egg quality parameters, housing thermal conditions and age of laying hens

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Abstract. High environmental temperatures cause a decrease in feed consumption by laying hens and, as a consequence, a reduction of productive performance and egg weight. The hens age is a factor influencing the albumen quality that tends to be more liquefied in older hens. Such variable is analysed by the determination of the Haugh Unit.
The correlations between the egg quality variables (egg weight and Haugh Unit), the thermo-hygrometric conditions in the facility and the age of laying hens were determined in the study and evaluated based on the Pearson correlation coefficient (r) and their significance at the 5% level. The microclimatic data and the eggs were collected in 20 points of poultry facility with birds of 43, 56, 69, 79 and 86 weeks of age, totalling 100 samples.
The results show significant correlations between egg weight and temperature (r = -0.238), egg weight and hens age (r = 0.310), Haugh Unit index and hens age (r = -0.256); a non-significant correlation between the quality parameters with the relative humidity of the air inside the barn.
The egg weight had a weak negative correlation with the ambient temperature and a weak positive correlation with the hens age. Concerning the Haugh Unit, a weak negative correlation with the age of the animals was found. The weak or non-existent correlation of temperature with egg quality parameters can be due to the environmental conditions that remained in the range of thermal comfort for the animals during the trials.

Key words: environmental conditions, thermal comfort, poultry, laying hens, egg quality.

INTRODUCTION

Poultry facilities should be designed to guarantee suitable thermal conditions and satisfactory light intensity to the laying hens for quality egg production. In the design of facilities a particular attention has to be paid to reduce the risks of exposition of the birds to temperature and humidity peaks (Albino et al., 2014). Air temperature is the main factor that could cause losses in animal production on an industrial scale (Vitorasso & Pereira, 2009; Vilela et al., 2015).

The internal quality of the eggs is indirectly influenced by the microclimatic conditions, since, during heat stress, the birds tend to reduce the consumption of food and consequently the weight of the egg is negatively affected. The decrease of the egg weight is an effect of the reduction of the components, or at least some of the components: egg yolk, albumen, shell (Alves, 2007).

According to Ferreira (2010), the temperature inside the poultry house for adult birds may fluctuate between 15 °C and 28 °C, with air relative humidity varying between 40% and 80%. The ideal ambient temperature for egg production would be 21 °C to 26 °C. In the range of 26 °C to 29 °C a slight reduction in egg size can occur and between 29 °C and 32 °C a significant loss in egg size, affecting production, is remarked. Between 35 °C and 38 °C, bird prostration can occur and production can be severely affected (Alves, 2007).

Egg quality is determined in order to verify the differences in fresh egg production due to genetic characteristics, diets and age of laying hens, as well as the influence of the environmental factors to which laying hens are subjected (Alleoni & Antunes, 2001).

The age of the birds is a factor influencing the quality of the albumen and the weight of the eggs. In older birds the albumen tends to be more liquefied and the weight of the egg bigger. These two quality parameters are correlated by means of a mathematical expression called Haugh Unit, proposed by Haugh (1937). In general, higher the value of the Haugh Unit, better the quality of the egg is.

Many factors can affect the value of Haugh Unit, such as storage time, temperature, age of the bird, stress, nutrition (dietary protein and amino acid index, e.g. lysine, methionine, feed enzymes, grain type-protein source), health state, supplements (ascorbic acid, vitamin E), exposure to ammonia, moult induction, use of medications, etc. These factors impair albumen quality through distinct mechanisms, and consequently affect albumen height and thus the value of the Haugh Unit (Roberts, 2004).

Tůmová & Gous (2012) found that eggs of laying hens subjected to an environment with a temperature of 20 °C have greater weight and Haugh Unit value respect to eggs of hens subjected to an environment with a temperature of 28 °C.

In a poultry facility with pad cooling, Abbas et al. (2011) found differences in the air temperature and relative humidity at the extremities and at the centre of the building as well as differences in the egg weight. In the middle of the poultry shed, where the temperatures had smaller values respect to the sides, the eggs presented bigger weights.

The objective of the present work was to determine the correlation between the microclimatic conditions (air temperature and relative humidity) of poultry facilities and the age of the birds, with egg quality parameters (egg weight and Haugh Unit).

MATERIALS AND METHODS

The experiment was carried out in one of the largest commercial egg companies in Brazil, located in the municipality of Itanhandu - MG, south of Minas Gerais, 892 m above sea level, 22°17'45"S latitude and 44°56'5"W longitude. The region has a tropical climate with an average annual temperature of 19 °C, characterized as Cwb (wet temperate climate with dry winter and temperate summer) by Köppen climate classification.

The poultry facilities have similar structures, designed in a vertical system of cages, orientated in the East-West direction and distanced 15 m each other. The dimensions of the buildings are 134 m long, 12.5 m wide, 5 m high. The facilities are made of metal structure, galvanized steel roofing with lantern 1.2 m wide. Inside the facility four batteries of cages, each with 6 floors, are placed. The cages have the dimensions of 0.6 m x 0.5 m x 0.4 m, with 10 birds per cage and a surface per head of 300 cm² head^{-1}. Each facility has the capacity to accommodate up to 100,000 hens of the Hy-Line W-36 line age.

The feed is supplied by means of automatic feeders and water given by means of nipple drinkers. The collection and transport of eggs and the collection and removal of manure are mechanized through mats.

The experimental trials were carried out in one of the poultry facility of the farm. Within the facility, microclimatic data were collected for five days by temperature and relative humidity sensors, DHT-11 (Humidity & Temperature Sensor-DRobotics UK) for five days. The distribution of the sensors was performed in 45 points of the building in vertical and longitudinal directions. In the vertical direction the temperature and relative humidity sensors were installed in three levels of cages (Fig. 1) and, horizontally, in a fourth of the building (Fig. 2).

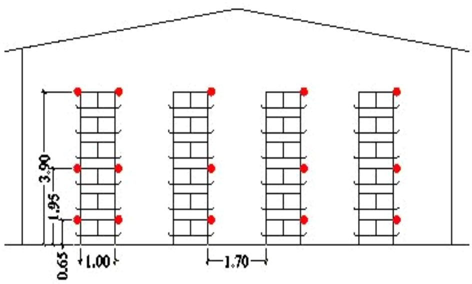

Figure 1. Vertical location of temperature and relative humidity sensors in the facility.

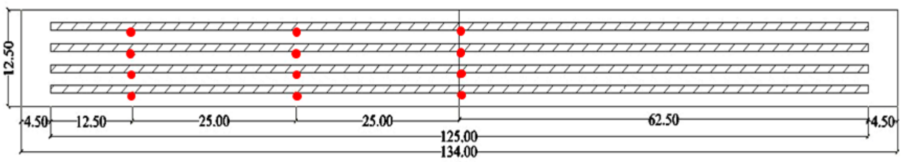

Figure 2. Longitudinal location of temperature and relative humidity sensors in the facility.

Each three sensors were coupled to a microcontroller, Arduino Mega 2560, for processing and storing the data of air temperature and relative humidity, captured by the sensors. In total 45 data collection points/sensors and 9 Arduino Mega 2560 microcontrollers were placed.

The eggs were collected at the collection points of temperature and relative humidity, in cages with laying hens at the ages of 43, 56, 69, 79 and 86 weeks. Egg weight (g), albumen height (mm) and Haugh Unit (UH) were the parameters evaluated to qualify the eggs.

The egg weight was obtained by weighing on a digital scale with an accuracy of 0.01 g. After weighing, the eggs were broken on a flat glass surface and with a tripod micrometre the height of the dense albumen was measured. The Haugh Unit was calculated by the mathematical expression that correlates the height of the dense albumen with the weight of the egg (Eq. 1).

$$HU = 100 \log(H + 7.57 - 1.7W^{0.37}) \quad (1)$$

where: H – height of dense albumen (mm); W – egg weight (g).

The correlations between the egg quality variables (i.e., egg weight and HU), the thermal conditions and the age of the birds were evaluated based on the Pearson correlation coefficient (r) and their significance at the 5% level.

RESULTS AND DISCUSSION

The results show a significant correlation between: egg weight and temperature; egg weight and age; Haugh Unit and age; and non-significant correlation of quality parameters with the relative humidity of the air inside the facility (Table 1).

Table 1. Pearson correlation coefficients between the variables of egg quality, thermal environment of breeding and age of the birds (significance level 5%).

	Age	Temperature	Relative Humidity
Egg weight	0.310 (P < 0.01)	-0.238 (P < 0.01)	0.057 (P > 0.05)
Haugh Unit	-0.256 (P < 0.01)	0.009 (P > 0.05)	-0.067 (P > 0.05)

The egg weight had a weak negative correlation with the ambient temperature and a weak positive correlation with the age of the birds (Figs 3, 4), meaning that the egg weight variable tends to decrease with rising of temperature and to increase with the age of birds. In relation to the Haugh Unit a weak negative correlation with the age of the animals was found (Fig. 5).

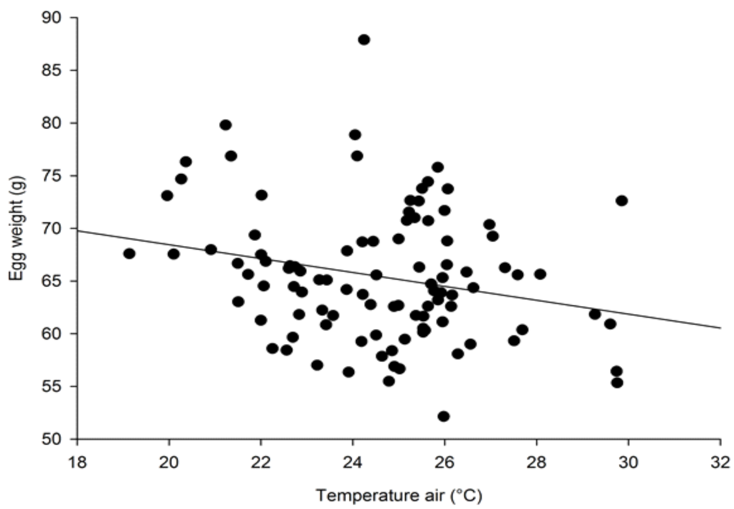

Figure 3. Correlation between air temperature and egg weight.

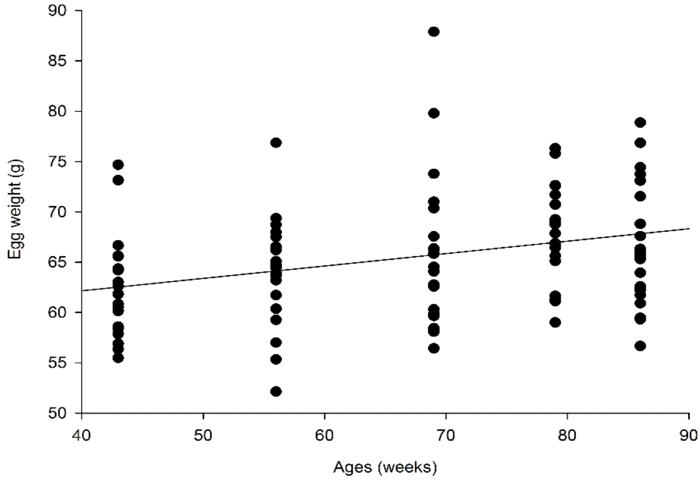

Figure 4. Correlation between age of laying hens and egg weight.

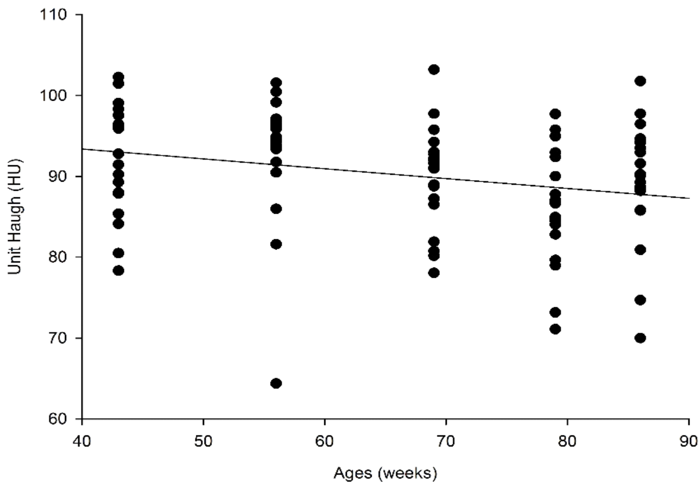

Figure 5. Correlation between Haugh Unit and age of laying hens.

Oliveira et al. (2011) found that laying hens between 23 and 42 weeks of age, kept on floor in a facility with artificial ventilation system and air temperature close to the comfort condition (27 °C), gave higher feed intake (110 $g^{-1}ave^{-1}day^{-1}$) and higher egg weight (58.1 g), compared to laying hens kept in conventional facilities without artificial ventilation (108 $g^{-1}ave^{-1}day^{-1}$ and 58.1 g, respectively).

Faria et al. (2001), analysing the egg quality of laying hens 21 weeks old in different thermal conditions during a period of nine weeks, concluded that the temperature affected the feed intake. The condition of constant heat stress presented lower feed consumption by hens and lower egg weight. Also Zavarize et al. (2011) remarked the influence of thermal conditions on feed intake and egg weight in laying hens.

Torki et al. (2014) found that thermal stress influenced the feed consumption and egg weight of laying hens in an open facility, while protein composition of the feed provided with an average temperature of 30 °C did not interfere on these parameters.

Carvalho et al. (2007) observed an increase in weight and a decrease in Haugh Unit value of eggs for hens with ages of 29, 60 and 69 weeks. The same result on egg quality was obtained by Alves et al. (2007). Menezes et al. (2012) also found a decrease of the Haugh Unit in laying hens eggs of 35, 40, 45 and 50 weeks of age.

CONCLUSIONS

The environmental conditions of poultry facility indirectly affect egg weight. The weak or non-existent correlation of the temperature with the parameters of quality of the egg found in this study can be attributed to favourable thermal conditions during the trials. The temperature of the environment in the period under study remained within the considered range of comfort for the laying hens during production (21 to 26 °C).

As further conclusion, it is possible to state that the age of the hens is a factor contributing directly to the increase in egg weight and to the decrease of the Haugh Unit.

ACKNOWLEDGEMENTS. To CAPES, CNPq and FAPEMIG.

REFERENCE

Abbas, T.E.E., Yousuf, M. M., Ahmed, M.E. & Hassabo, A. A. 2011. Effect of fluctuating ambient temperature on the performance of laying hens in the closed poultry house. *Res. Opin. Anim. Vet. Sci.* **1**, 254–257.

Albino, L.F.T., Carvalho, B.R., Maia, R.C. & Barros, V.R.S.M. 2014. *Laying hens: breeding and feeding*. Viçosa, Aprenda Fácil, 376 pp. (in Portuguese).

Alleoni, A.C.C. & Antunes, A.J. 2001. Haugh unit as a measure of the quality of hen eggs stored under refrigeration. *Sci. Agric.* **58**, 681–685 (in Portuguese).

Alves, S.P., Silva, I.J.O. & Piedade, S.M.S. 2007. Laying hens welfare evaluation: effects of rearing system and bioclimatic environment on performance and egg quality. *Rev. Bras. Zootecn.* **36**, 1388–1394 (in Portuguese).

Carvalho, F.B., Stringhini, J.H., Filho, R.M.J., Leandro, N.S.M., Café, M.B. & Deus, H.A.S.B. 2007. Internal and egg shell quality for eggs collected from laying hens of different genetic lines and ages. *Ciência Animal Brasileira* **8**, n. 1, p. 25–29 (in Portuguese).

Faria, D.E., Junqueira, O.M., Souza, P.A. & Titto, E.A.L. 2001. Performance, Body Temperature and Egg Quality of Laying Hens Fed Vitamins D and C Under Three Environmental Temperatures. *Braz. J. Poultry Sci.* **03**, 49–56 (in Portuguese).

Ferreira, R.A. 2010. *Greater production with better environment for poultry, pigs and cattle*. Viçosa, Aprenda Fácil, 2005, 317 pp. (in Portuguese).

Haugh, R.R. 1937. The Haugh unit for measuring egg quality. *U.S. Egg Poul. magazine* **43**, 552–555.

Menezes, P.C., Lima, E.R., Medeiros, J.P., Oliveira, W.N.K. & Neto, J.E. 2012. Egg quality of laying hens in different conditions of storage, ages and housing densities. *R. Bras. Zootec*. **41**, 2064–2069 (in Portuguese).

Oliveira, E.L., Gomes, F.A., Silva, C.C., Delgado, R.C. & Ferreira, J.B. 2011. Performance, physiological characteristic and quality of eggs of Isa Brown raised in different production systems in the Vale Juruá-Acre. *Enciclopédia Biosfera* **30**, 339–347 (in Portuguese).

Pereira, D.F., Vitorasso, G., Oliveira, S.C., Kakimoto, S.K., Togashi, C.K. & Soares, N.M. 2008. Correlations between thermal environment and egg quality of two layer commercial strains. *Braz. J. Poultry Sci.* **10**, 81–88 (in Portuguese).

Roberts, J.R. 2004. Factor affecting egg internal quality and egg shell quality in laying hens. *J. Poult. Sci.* **41**, 161–177.

Torki, M., Mohebbifar, A., Ghasemi, H.A. & Zardast, A. 2015. Response of laying hens to feeding low-protein amino acid-supplemented diets under high ambient temperature: performance, egg quality, leukocyte profile, blood lipids, and excreta pH. *Int. J. Biometeorol.* **59**, 575–584.

Tůmová, E. & Gous, R.M. 2012. Interaction between oviposition time, age, and environmental temperature and egg quality traits in laying hens and broiler breeders. *Czech J. Anim. Sci*. **57**, 541–549.

Vilela, M.O., Oliveira, J.L., Teles Junior, C.G.S., Tinôco, I.F.F., Baptista, F., Barbari, M., Santos, T.C. & Souza, C.F. 2015. Spatial variation of enthalpy in a commercial broilers housing in a hot climate region. In *Precision Livestock Farming 2015*, Milan, 15–18 September, pp. 531–537.

Vitorasso, G. & Pereira, D.F. 2009. Análise comparativa do ambiente de aviários de postura com diferentes sistemas de acondicionamento. *Rev. Bras. Eng. Agríc. Ambie.* **13**, 788–794 (in Portuguese).

Zavarize, K.C., Sartori, J.R., Pezzato, A.C., Garcia, E.A. & Cruz, V.C. 2011. Glutamine in diet of laying hens submitted to heat stress and thermoneutrality. *Ci. Anim. Bras., Goiânia* **12**(3), 400–406 (in Portuguese).

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Usage of multi-sensory MESH networks in monitoring the welfare of livestock

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Abstract. The trend of monitoring the welfare of livestock is continually developing at the moment. This monitoring leads to the optimization of the needs of livestock, which improves their final outputs. In terms of dairy cows, improvements in their living conditions may have a considerable impact on their productivity and the quality of their milk. Countless indicators such as temperature, humidity, how often they drink or eat, and many other parameters can be monitored. Specific measurements always depend on an initial hypothesis that is determined on the basis of specific problems. The main question still remains regarding how to measure selected variables, particularly how to transfer these outputs so that they can be easily processed. It is this issue that leads to the use of MASH multi-sensory networks.

Key words: MESH netwok, welfare, livestock, sensor networks, transmitter, IQRF, nod.

INTRODUCTION

One of the main goals of the research on livestock welfare is the area of simple data transfer. This always requires investigation supported by measurements which consists of the process of evaluation and gaining of the needed data. These measurements are used to evaluate external conditions which affect the welfare of livestock both directly and indirectly. Currently the most widespread are portable measuring instruments that are used for discontinuous measurement, or long-term measuring instruments located at points of interest for the long term, such as feeding points. This mainly involves wired sensor networks, though simple wireless transmissions are also used at times, the latter speeding up data collection and as for continual measuring they eliminate the risk of interruption of sensor network wired connection. It is mostly due to damage in the wired network that all communication through the used communication line fails, which may cause disconnection of the whole sensor network branch that normally contains many measuring elements. This triggers a critical failure of the whole measured sector leaving the overall measurement results incomplete and inaccurate. Of course there are also many risks and imperfections related to wireless networks that need to be considered. One of the most frequent risks of wireless transmission is natural interference or a limited range of wireless transmitters. Though being serious, these problems have their realistic solutions provided by an IQRF MESH network which can at least partially eliminate them. (Morisse et al., 1997; Milhaud, 2003; Mietzner et al., 2012; Behkami et al., 2017)

MATERIALS AND METHODS

To thoroughly understand the problems, it is needed to define the type of data paths to be subsequently compared. Because of monitoring the development of the situation in the field only continuous forms of monitoring will be evaluated, and in turn the data paths which can be used for this monitoring. Basic types of data transmission include simple direct line and bus connection. For wireless transmission it is a classic wireless transmission with repeaters and MESH type wireless transmission (Tahir & Shah, 2008; Mietzner et al., 2012).

Given the fact that contact monitoring of individual animals is not possible through a direct line and bus connection, these options do not fit the plan to create a system of livestock welfare monitoring with a focus on individual animals and their current state of welfare (Morisse et al., 1997; Milhaud, 2003; Behkami et al., 2017).

A classic wireless transmission using repeaters (see Fig. 1) will operate without wired connection with individual sensors, which in part reduces the problems relating to cable laying as well as final removing of the sensor network. Although it is used quite frequently, it includes a risk of loss of critical points (repeaters) and possibly even loss of data due to natural interference which may impact data paths. In this case it involves the communication between specific network nodes (detector – main unit). (Milhaud, 2003; Bradna & Malaťák, 2016; Behkami et al., 2017)

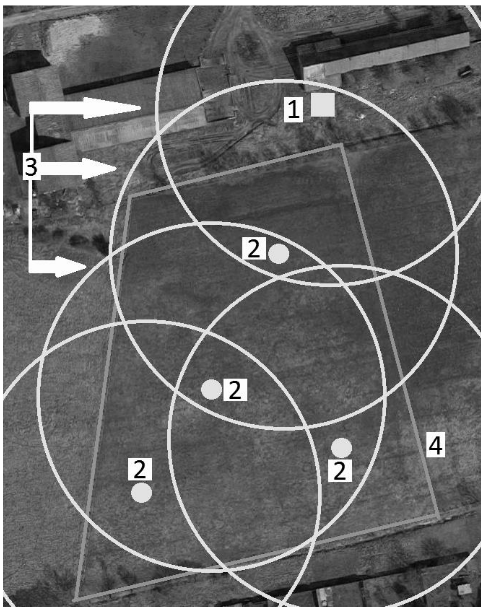

Figure 1. Design for wireless network distribution through stationary repeaters (1 – gateway; 2 – stationary repeater; 3 – wireless range, 4 – fence).

Regarding the classic wireless network we must not forget that each monitored entity has a transmitter on it, which transfers information through repeaters to the gateway – see Fig. 2. It is essential in this connection that repeaters must cover the whole monitored area. (Tahir & Shah, 2008; Dong et al., 2013).

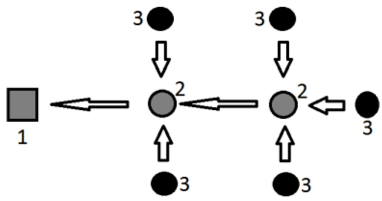

Figure 2. The transfer principle for a classic wireless network (1 – gateway; 2 – stationary repeater; 3 – transmitter).

MESH type wireless transmission (see Fig. 3) is a relatively new method which could find an extensive use right in the measurement of farm animal welfare. In this kind of transmission each transmitter also works as a repeater. This significantly reduces the loss of the needed information as the network points are mutually interchangeable. Therefore the failure of one network element does not create a situation where all communication would be disrupted, but only the one affected specific element of the sensor network will drop out. (Tahir & Shah, 2008; Yang et al., 2013)

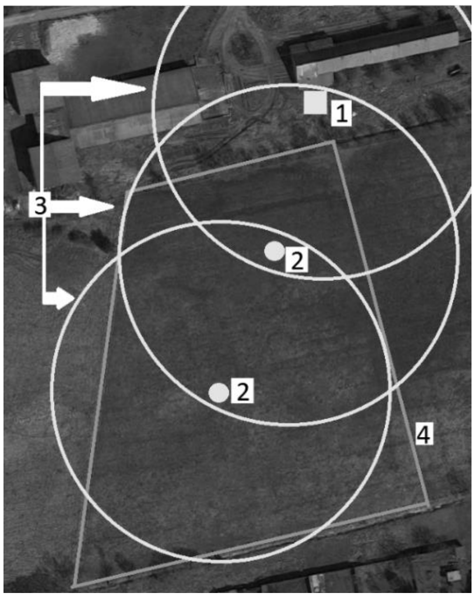

Figure 3. Design for a MESH wireless network distribution (1 – gateway; 2 – stationary repeater; 3 – wireless range, 4 – fence).

At first sight the classic wireless transmission through a MESH network is almost interchangeable. Both the options require stationary repeaters that send the information from transmitters to the gateway. However taking a closer look reveals that individual transmitters send their transferred data to all the other transmitters within their reach and these repeat their message – see Fig. 4. This enhances the network security and reduces the number of needed repeaters as compared to the classic wireless network. In this type of transmission repeaters do not need to cover the whole monitored space (Tahir & Shah, 2008; Dong et al., 2013).

An irregularly shaped pasture of 0.42 km^2 area was chosen to analyse the problems in question. It is a medium size pasture normally used for animal husbandry, where 19 measured points were set up. In order to compare the different types of connection a multi criteria scoring analysis of the options was chosen, considering important parameters that are essential to a sensor network installation and data transmission – see Table I (Mpitziopoulos et al., 2007; Tahir & Shah, 2008; Dong et al., 2013).

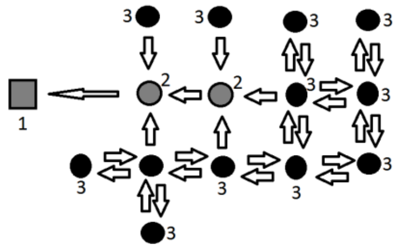

Figure 4. The transfer principle for a MESH wireless network (1 – gateway; 2 – stationary repeater; 3 – transmitter).

Table 1. Important parameters of multi criteria analyses of the options

Basic parameters	Detailed parameters
Safety	– Failure of one member
	– Interruption of routes
Instalation	– Sophistication of instalation
	– The difficulty of removal
Material	– The average price of material

Figure 5. IQRF elements.

The IQRF system was chosen (see Fig. 5) for implementation of MESH wireless transmissions, which enables transfer on ISM868 bands (industrial, scientific and medical). (Mietzner et al., 2012; Mpitziopoulos et al., 2007)

RESULTS AND DISCUSSION

Weight values for the multi criteria scoring analysis of the options were chosen based on price as the crucial criterion, followed by security and level of installation complexity. This is directly proportional to the current demands and pressure created by the private sector in the industry. This method was modified for the individual types of connection in the way that they were assigned a score for each item on a 100-point scale based on the set parameters. The resulting scores for both methods were then converted to percents and shown in Fig. 6.

It clearly follows from the multi criteria scoring analysis of the options that the optimal one for live operation is the wireless sensor network on the MESH basis. Out of a hundred percent that the individual types of data transfer could reach, the MESH type wireless transmissions were awarded 68.5% as opposed to classic wireless transmissions only awarded 31.5%.

MESH type sensor networks operate on different frequencies and based on different technologies. There exist different MESH type technologies (WLAN, Bluetooth, ZigBee, WiMAX and many more), however, given financial considerations, a low frequency IQRF technology is best-suited for the selected use.

As for the final MESH network application, a simple method of its nodes connection and basic configuration of transmission can be used. E.g. to monitor the temperature of an animal, specifically through the sensors attached to it, just a simple hardware connection will do – see Fig. 7.

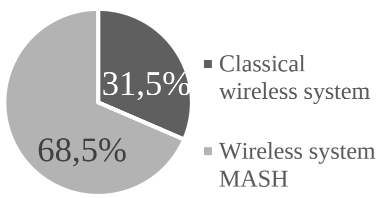

Figure 6. Results of multi criteria analysis of the options.

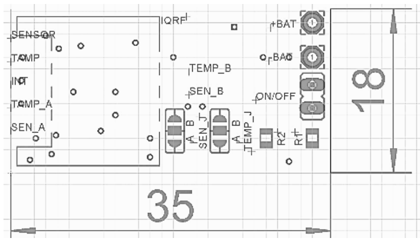

Figure 7. A printed circuit design for IQRF node connection for transmission of temperature.

As follows from the studies on ‘Mitigating jamming attacks in wireless broadcast systems’ and ‘Coping with a Smart Jammer in Wireless Networks: A Stackelberg Game Approach’, it is important for a wireless system to have alternative paths available, be variable and have replaceable key elements of the network. Also it is very important for the system to be able to assess the risks affecting it and adequately respond to them. A similar view was also taken by the authors of the articles ‘Defending wireless sensor networks from jamming attacks’ and ‘Wireless Sensor Networks – A Security Perspective’. Therefore MESH networks are better suited for communication, where nodes function as repeaters as well (Mpitziopoulos et al., 2007; Tahir & Shah, 2008; Dong et al., 2013; Yang et al., 2013; Hart & Hartová, 2016).

CONCLUSIONS

It follows from the multi criteria scoring analysis of the options that wireless transmission through MESH networks is more advantageous than the classic wireless transmission through stationary repeaters. A MESH network comes out as more suitable as compared to classic wireless systems, specifically in the ratio of 68.5% to 31.5% respectively.

Based on this comparison the printed circuit design was subsequently developed for integrating an IQRF node for transmission of basic temperature data in order to monitor animal welfare while considering the monitoring of individual animals. More information can be derived from the monitoring of individual farm animals than from mass monitoring. A greater amount of variables are recorded that can be monitored and evaluated and decisions can be taken based on them as to which way to choose for moving forward and how to modify the present conditions to achieve higher yields.

Natural interference which may affect a wireless transmission occurs rather rarely, still it is important for wireless transmissions to be able to either identify such interference or replace the path of transfer. MESH systems do possess this feature and therefore are more secure in real life operation than standard wireless systems.

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REFERENCES

Behkami, S., Zain, S.M., Gholami, M. & Bakirdere, S. 2017. Isotopic ratio analysis of cattle tail hair: A potential tool in building the database for cow milk geographical traceability, *Food Chemistry* **217**, 438–444.

Bradna, J. & Malaťák, J. 2016. Flue gases thermal emission concentration during waste biomass combustion in small combustion device with manual fuel supply, *Research in Agricultural Engineering* **62**(1), 1–7.

Dong, Q., Liu, D.G. & Wright, M. 2013. Mitigating jamming attacks in wireless broadcast systems, *Wireless Networks* **19**(8), 1867–1880.

Hart, J. & Hartová, V. 2016, Development of new testers to improve quality for data transmissions in intrusion and hold-up alarm systems. In: *15th International Scientific Conference on Engineering for Rural Development*, LUA, Jelgava, pp. 523–528.

Mietzner, J., Nickel, P., Meusling, A., Loos, P. & Bauch, G. 2012. Responsive Communications Jamming Against Radio-Controlled Improvised Explosive Devices, *IEEE Communications Magazine* **50**(10), 38–46.

Milhaud, C. 2003. Ethics and animal experiments. Ethical committees in France and foreign countries, *BULLETIN DE L ACADEMIE NATIONALE DE MEDECINE* **187**(3), 559–565.

Morisse, J.P., Huonnic, D., Cotte, J.P. & Martrenchar, A. 1997. Relation between mixing solid foods and wellfare into the feed of calves. Study on three groups of 21 calves, *Point Veterinaire* **28**(184), 71–73.

Mpitziopoulos, A., Gavalas, D., Pantziou, G. & Konstantopoulos, C. 2007. Defending wireless sensor networks from jamming attacks, In: *18th International Symposium on Personal, Indoor and Mobile Radio Communications*, Vols 1–9, pp. 81–85.

Tahir, H. & Shah, S.A.A. 2008. Wireless Sensor Networks – A Security Perspective, In: *International Multitopic Conference*, pp. 189–193.

Yang, D.J., Xue, G.L., Zhang, J., Richa, A. & Fang, X. 2013. Coping with a Smart Jammer in Wireless Networks: A Stackelberg Game Approach, *IEEE Transactions on Wireless Communications* **12**(8), 4038–4047.

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The next generation of multiple temperature sensor

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Abstract. Long-term and short-term measurements of temperature at different depths in soil have always been very complicated. The solution that was used until now was measuring using soil thermometers. Measurements were done at shallow depths and generally only allowed for measuring of one temperature, and always at the one depth which was determined for the measurement (normally 5, 10, 20, 50, 100, 150 and 300 cm). These problems were relatively limiting and impractical. It was therefore necessary to devise an alternative for a simple and effective solution that would eliminate these disadvantages – it was necessary for a probe to allow temperature to be measured at different depths at one measuring point without having to change its position. A requirement simultaneously arose for the need to be able to measure temperatures at greater depths, and a multiple probe was therefore conceived consisting of a rod for dynamic penetration tests.

Key words: temperature, measurement, penetration test, sensor, soil, thermometer.

INTRODUCTION

A temperature sensor is currently the most widely used implement for measuring the temperature of solid ground, measuring the temperature on its sink bit or buried sensor network. The method of temperature measurement with a countersunk sensor bit is efficient, but it cannot be used to measure temperatures at different levels simultaneously and it is also limited by the length of the measuring rod to which the temperature sensor is attached. The temperatures are measured as standard at depths of 5, 10, 20, 50, 100, 150 and 300 cm. On the other hand, the buried sensor network enables long-term temperature measurement at different depths, but its installation is demanding. Its dismantling is also complicated. (Gonzales, 2012; Popiel, 2001)

Because of these issues a design of measuring rod development was created which would be able to measure temperature at different depths without the need for complicated installation of this measuring equipment. The proposed technical solution concerns the construction of an adjustable/extendable penetration thermometer for measuring solid ground temperatures. This construction enables temperature measurements at different depths of solid ground without the need to move the temperature sensor to different places (Popiel, 2001; Cao, 2013; Matsumoto, 2015; Hart, 2016).

MATERIALS AND METHODS

As the adjustable thermometer design is based on the technical solution of penetration rods for dynamic penetration testing, it was necessary to consider the principles and processes used within this testing when creating the design.

Dynamic penetration is a supplementary probing method in engineering and geological investigation. It is primarily used to quickly determine interfaces of layers with different geotechnical properties, establish the location and thickness of non-load-bearing and load-bearing soils, identify depth of erosion, assess homogeneity of backfills, detect the shear area, check compaction (of backfills, gravel cushions etc.), determine the thickness of made-up grounds etc (Brandl, 2006; Cao, 2013).

A 30 kg hammer is used in medium type dynamic penetrations, with a fall height of 0.5 m and a countersunk bit cross-section of 15 cm^2. Measuring instruments must conform to the requirements of CSN EN ISO 22476-2. The equipment is mobile and the set can be taken in parts also to locations that are difficult to access (slopes, foundation pits, cellars etc) (O'Loughlin, 2014; Quezada, 2014; Zhussupbekov, 2014; Bradna & Malaťák, 2016).

As a rule the penetration test is performed according to CSN EN ISO 22476-2 Geotechnical investigation and testing – Field testing – Part 2: Dynamic penetration test. Rods must be driven into the ground in a vertical direction without excessive bending, the maximum admissible incline of the rod assembly and guide rod from the vertical is equal to 2%. The speed of driving should be maintained between 15 and 30 blows per min. (pauses longer than 5 mins are recorded). The number of blows needed to drive the rod in by every 100 mm is continuously recorded. In the event of low resistance to penetration, the depth of penetration per one hammer blow is recorded. At least for each meter of penetration the torque required to turn the rods by 1.5 turns has to be recorded, or the time needed to reach the maximum moment. The measured value then serves to eliminate skin friction when evaluating results. If the number of 50 blows needed to drive the rod in by 100 mm has been reached, the test is ended. (Cao, 2013; Quezada, 2014)

The penetration assembly consists of several basic components. These parts fit together to form a large unit. They comprise a sink bit, driving rods, a pestle and a hammer with a guide rod (Gonzales, 2012; Matsumoto, 2015).

The bit (see Fig. 1), sometimes also referred to as cone, has a top angle of 90°, a diameter of 0.025 m, is used for ramming through soil and is attached to the tip of the driving rods. (Cao, 2013; Quezada, 2014)

Figure 1. Different kinds of penetration bits.

The driving rod unit has a diameter of 0.022 m and the weight of one rod is usually equal to 2.91 kg. The rods are made from high-tensile steel to reduce excessive deformation (deflation) and wear. For example, rod deflection must not exceed 1/1,000 of length. The rod unit has a scale fitted to read the needed amount of blows for a specified section (Cao, 2013; Quezada, 2014).

At the end of the driving rods a pestle is mounted (Fig. 2), also referred to as anvil or drive head. The pestle transfers the dynamic load of the hammer into the driving rods. As well as the driving rods, the pestle is also made from high-tensile steel (Cao, 2013; Quezada, 2014).

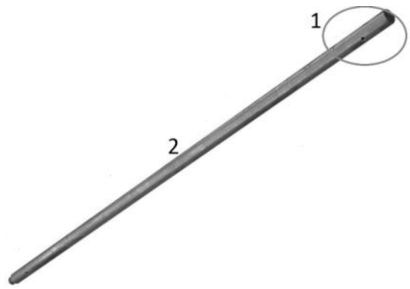

Figure 2. A pestle attached to the driving rods segment (1 – pestle, 2 – penetration rod).

The hammer with a guide rod actually functions as a large piston, hitting the pestle fastened to the driving rods. The hammer generates a constant dynamic force which acts on the pestle/anvil through its fall, in that it is guided to it by the guide rod (Cao, 2013; Quezada, 2014).

During the design work we had to meet the requirements that the thermometer should be usable in the same way as the driving rods, however a few small changes were made to integrate the temperature sensors. Therefore the probes were constructed in a manner similar to shallow depth core probes for engineering geology. The penetration assembly is also used to drive these probes in, except the bit and driving rods are replaced with a special drilling tool referred to as a 'šapa', which is used for earth sampling on the investigation site. (Cao, 2013; Quezada, 2014)

RESULTS AND DISCUSSION

The designed adjustable penetration thermometer consists of the modified penetration rod with an integrated thermometric band, with a driving bit mounted onto its lower end and an anvil at the top. A groove is made on the side of the side of the rod, where a thermometric band is integrated, consisting of temperature sensors and a bus line. The temperature sensors are placed at 10 centimetre spacing and they send data on temperature via the bus to the external assessment unit. The rods are 1,000 mm long, but according to the requirements of this dimension can be adjusted by the factory. Data collection will take place through local units or through IoT technology to transfer data directly to Cloud.

The process of measurement with an adjustable penetration thermometer (see Fig. 3) starts by driving the adjustable thermometer into the ground. A hammer or rammer can be used for striking the anvil so the rod goes in using the driving bit, which breaks through vertically into the ground. If the optimum depth is reached, a pause is made until the temperature of the sensors adjusts to the surrounding environment in order to prevent errors in measurement. Temperature stabilization on the sensor is given primarily by the used sensor. The temperature in the borehole will stabilize from about 5 to 15 min. However if a greater depth is needed, the anvil is unscrewed and an adjustable penetration thermometer is extended with another penetration rod onto which the anvil is mounted. We repeat this step as many times as needed in order to reach the optimum depth for measuring the ground temperature. After that we start collecting data from the individual temperature sensors to the external assessment unit, from where it can be further processed. The selection of rods will affect its durability. However, by default, such rods are designed for large loads, because it is high-tensile steel. For example, they are similarly constructed as rods for soil sampling. It is also possible to pick up with hydraulics and of adversely materials such as: clays soft, sandy soils and others.

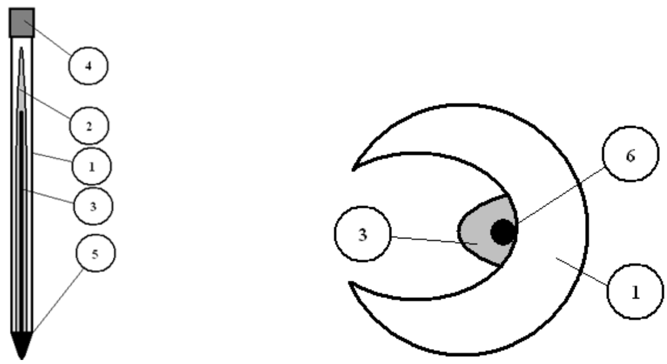

Figure 3. Adjustable penetration thermometer (1 – modified penetration rod, 2 – groove, 3 – thermometric band, 4 – anvil, 5 – bit, 6 – integrated bus).

A comparison was conducted on the cost of this device. For comparison standard temperature probes were selected. Specifically, the selected mobile monitoring device G-1 / P-100, Which has a large representation in the Czech Republic for measuring soil temperature. Comparison through a multi-criteria analysis of variants can be seen in Fig. 4 and also in Table 1 are shown the comparison value G-1 / P-100 a adjustable penetration thermometer. Selecting and setting values of weighting coefficients were dealt with experts in the art and have been adjusted according to their recommendations. For this type of analysis is the more important lower ratings of weighting coefficient. Construction of adjustable penetration thermometer is designed so to prevent stress a measuring parts and for durability. Lifetime of adjustable penetration thermometer is also dependent on the choice of material from which it is made. For our purposes, was chosen a high-tensile steel because this material is resistant to mechanical stress.

Table 1. Weighting coefficients in the multi-criteria analysis

	G-1/P-100	Adjustable penetration thermometer	Weight criterion
production costs	10 (83 EUR)	8 (95 EUR)	5
depth of use	8 (1,000 mm)	10 (1,000 mm and it can be extended)	1
recycling	6 (5,000 cycles)	10 (8,000 cycles)	3
multifunctional use	3 (1 sensor)	10 (8 sensor)	2
ease of installation	10 (without the need to pay attention to cleanliness of connections)	9 (the need to take into account the purity of connections)	4

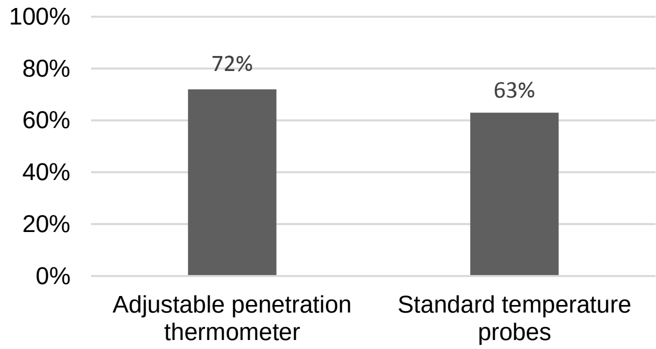

Figure 4. Comparison through a multi-criteria analysis of variants.

The author of the 'Study on Climate Conditions of Tokáň Locality' claims that taking the measurements would be easier if it was possible to measure all the quantities of his study at the same time. It is evident from his measurements (partially shown in Fig. 5) that he used four stand-alone thermometers. Therefore he had to place all the thermometers separately at the required depths. Use of an adjustable penetration thermometer would have saved him considerable time and finally also some of the funds spent on purchasing the needed measurement material (Brandl; 2006; Hostýnek, 2009).

Similar observations were also made in connection with collecting data for the article 'Energy foundations and other thermo-active ground structures' as well as 'Measurements of temperature distribution in ground'. It is therefore apparent that an adjustable penetration thermometer is a favourable alternative in similar cases, which simplifies lengthy and demanding measurements by saving time as well as financial resources (Popiel, 2001; Brandl, 2006).

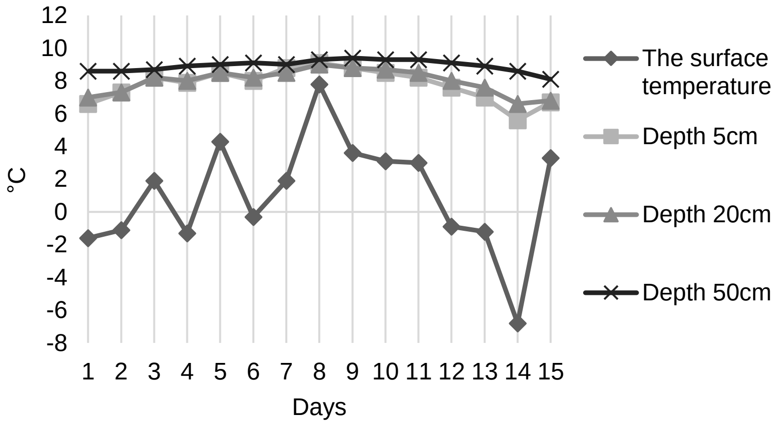

Figure 5. A Study on Climate Conditions of Tokáň Locality.

CONCLUSIONS

The extendable penetration thermometer will be appreciated in measuring ground temperatures, where it will improve the effectiveness and variability of the measurements. Thanks to its high measurement effectiveness and simple design it is also suitable for common climatology studies.

Considering that the technical solution consists in constructing an extendable penetration thermometer which is used in ground temperature measurements carried out at various depth levels at the same time, and given the requirements for a simple construction, it is necessary for the whole unit to emulate the design of the penetration rod. The penetration system technology is well-established and quite frequently used and so can be put to effective use.

Since the penetration rod designed for measurement has an integrated thermometric band placed in the groove it is sufficiently protected against critical mechanic strain, while at the same having free access to the soil around the penetration rod. This provides for effectiveness of its use, when it is only needed to drive the penetration rod to the required depth. If the optimum depth is reached, a pause is made until the temperature of the sensors adjusts to the surrounding environment in order to prevent errors in measurement, then the bus can be connected to the assessment unit, where recording of different temperatures can start at depths ranging from 10 cm to 100 cm with the use of a single rod. Naturally rods can be extended by modular pieces up to a maximum bearing depth for penetration tests. This is identified by a limit torque arising on the rods. If the driving into the ground does not stop at the right time, it may not be possible to pull the rods out of the ground.

REFERENCES

Bradna, J. & Malaťák, J. 2016. Flue gases thermal emission concentration during waste biomass combustion in small combustion device with manual fuel supply. *Research in Agricultural Engineering* **62**(1), 1–7.

Brandl, H. 2006. Energy foundations and other thermo-active ground structures. *GEOTECHNIQUE* **56**(2), 81–122.

Cao, Z.Z., Youd, T.L. & Yuan, X.M. 2013. Chinese Dynamic Penetration Test for Liquefaction Evaluation in Gravelly Soils. *Journal of Geotechnical and Geoenvironmental Engineering* **139**(8), 1320–1333.

Gonzalez, R.G., Verhoef, A., Vidale, P.L., Main, B., Gan, G.G. & Wu, Y.P. 2012. Interactions between the physical soil environment and a horizontal ground coupled heat pump, for a domestic site in the UK. *Renewable energy* **44**, 141–153.

Hart, J. & Hartová, V. 2016. Development of new testers to improve quality for data transmissions in intrusion and hold-up alarm systems. In: *15th International Scientific Conference on Engineering for Rural Development*, LUA, Jelgava, pp. 523–528.

Hostýnek, J. 2009. The study of climatic conditions Tokáň sites, Czech Hydrometeorological Institute, 43 pp. (in Czech).

Matsumoto, T., Phan, L.T., Oshima, A. & Shimono, S. 2015. Measurements of driving energy in SPT and various dynamic cone penetration tests. *Soils and Foundations* **55**(1), 201–212.

O'Loughlin, C.D., Gaudin, C., Morton, J.P. & White, D.J. 2014. MEMS accelerometers for measuring dynamic penetration events in geotechnical centrifuge tests. *International Journal of Physical Modelling in Geotechnics* **14**(2), 31–39.

Popiel, C.O., Wojtkowiak, J. & Biernacka, B. 2001. Measurements of temperature distribution in ground. *Experimental Thermal an Fluid Science* **25**(5), 301–309.

Quezada, J.C., Breul, P., Saussine, G. & Radjai, F. 2014. Penetration test in coarse granular material using Contact Dynamics Method. *Computers and Geotechnics* **55**, 248–253.

Zhussupbekov, A.Z., Alibekova, N.T., Morev, I.O. & Utepov, Y.B. 2014. Determination of bearing capacity of the precast piles by dynamic cone penetration test (DCPT), *Soil-structure interaction, underground structures and retaining* walls **4**, pp. 242–247.

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Livestock monitoring system using bluetooth technology

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Abstract. There is currently no inexpensive solution for monitoring theft of livestock. The cheapest way is to use a camera system. Whilst camera systems are able to capture theft attempts, in order to be truly effective it is necessary to permanently have a live operator available at the monitor to make evaluations. The aim was to therefore devise a system that would be used and that could identify the loss of an animal (or determine the specific animal that went missing). 'Bluetooth Beacons' were chosen after a detailed study of current technology. After closer inspection of this technology, we came to the conclusion that it is useful for this purpose with minimal cost for its application. This article would like to present concept of the method to monitoring livestock position.

Key words: ISM bands, Bluetooth Low Energy, iBacons, transmission, livestock.

INTRODUCTION

Today we can hardly manage without wireless technologies. Whether it is wireless transmission in surveillance systems, Wi-Fi networks, Bluetooth transmissions or various RC models, their transmissions are ubiquitous. All in all, they basically define the modern time and our civilization as such (Dong et al., 2013; Bisio et al., 2016).

As for the above mentioned technologies, ISM bands (industrial, scientific and medical) are mostly used for wireless transmissions. They are amply used in a variety of industrial transmissions. Officially, these bands should only be used for industrial, medical or scientific purposed. The Federal Communications Commission and the European Telecommunications Standards Institute established just the ISM bands as licence-free and given their licence-free usage they are also heavily preferred for commercial purposes (Tahir & Shah, 2008).

It is therefore favourable to use these modern technologies in the licence-free ISM bands to protect livestock in such a way that attempts at their theft are detected in time. And therefore is the aim of this article to present concept of the method to monitoring livestock position based on bluetooth technology. Although its purpose is clearly defined, following small modifications the resulting technology could also help in monitoring animal welfare (Kucera et al., 2015; Lopes & Carvalho, 2016).

MATERIALS AND METHODS

Following in-depth market research a technology conforming to exacting criteria for monitoring of livestock theft was selected. The Bluetooth technology was chosen as the technical basis for the final system for livestock monitoring (Lopes & Carvalho, 2016).

We went for the Bluetooth technology also because it uses a proprietary open standard for wireless communication connecting two and more electronic devices. The system design is based on Bluetooth BLE 4.0 version (Bluetooth Low Energy). BLE 4.0 runs in the ISM band 2.4 GHz (the same as Wi-Fi). It focuses on very low power consumption applications and it has been developed by companies associated in a group known as Bluetooth Special Interest Group (Bluetooth SIG) (Tahir & Shah, 2008; Elmasry, 2013; Bisio et al., 2016).

As a system development tool was selected a specific system based on a relatively new technology of Bluetooth SMART Beacons (iBeacons) see Fig. 1. iBeacons are used as electronic beacons for periodic transmitting information generally of any type. The principle is based on iBeacons transmitting data to smart phones, however this technology has another not yet discovered potential which can be fully utilized for the purposes of constructing the monitoring system to prevent theft of farm animals (Koppe et al., 2016; Park et al., 2016).

Figure 1. Different iBeacons types.

Of the different types of current iBeacons, EMBC01 type iBeacons which have several modes of transmission were chosen for our purposes (see Table 1). They can be set up so as to maximally save battery power while retaining sufficient reliability.

Table 1. The basic modes of transmission

Mode	Transmission range	Transmission interval	Battery lifetime
Sleep mode	-	-	> 7 years
ID Short Range	15 m	100 ms	1,5 months
ID Medium Range	30 m	500 ms	7,5 months
ID Long Range	75 m	1s	12,5 months

Basic EM Microelectronic extended and enhanced iBeacons technology by direct transmitting further information or data from iBeacons sensors and setting up individual custom application is made very easy. This feature was again in favour of our choice of this iBeacon type.

The unique parameters of this iBeacon were achieved due to two elements with an extremely low power and low supply voltage: EM9301 – Bluetooth Low Energy Controller with voltage supply from 0.8 V and EM6819 – 8bit Flash µController with DC-DC, ADC, OpAmp and EEPROM and voltage supply from 0.9 V. This iBeacon is also certified by FCC/IC/CE, it can be supplied by CR2032 Li 3V battery and is currently intended for temperatures ranging from – 20 to + 60 °C.

iBeacons basically only transmit UUID code (Universally Unique Identifier), not directly sending data that is displayed on the mobile phone. UUID (see Fig. 2) is a standard for identification of various "objects" in Linux and it is in hexadecimal format. It is mainly used for identification of different disk packs, by extension data provided by these packs (Garcia et al., 2016; Koppe et al., 2016).

62EDOE81-5CB3-425A-AEF9-3883DOE2448B

Figure 2. Example of UUID code.

The pattern of this communication between iBeacon and a mobile device is as follows (Fig. 3): iBeacon sends a UUID through the Bluetooth Low Energy technology to the mobile phone. Through its own connection to the network, the mobile phone sends the UUID code to the relevant Linux server, where it finds the required information and sends it back to the mobile device (Bisio et al., 2016).

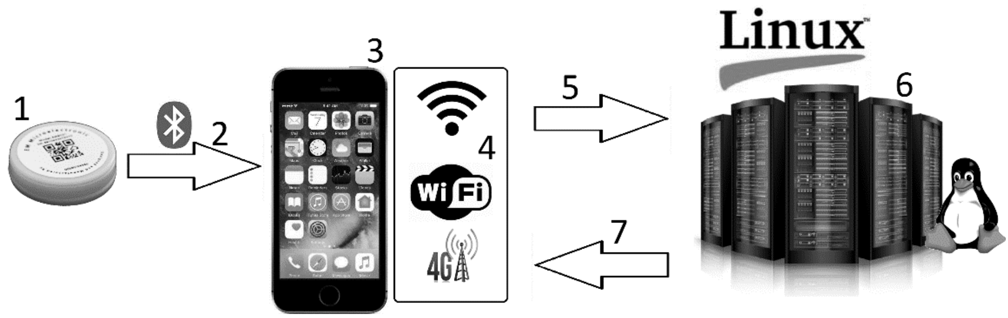

Figure 3. The pattern of information transmission initiated by iBeacon (1 – iBeacon; 2 – UUID transmission through BLE to mobile phone; 3 – mobile phone; 4 – form of mobile phone connection to the Internet; 5 – UUID transmission to Linux servers; 6 – Linux servers; 7 – transmission of required information to mobile phone).

Therefore their application potential is now to a large extent seen in Bluetooth marketing as a form of advertising, which distributes the advertising message through the Bluetooth technology. It allows for myriads of options of communication with mobile phone users, including a pocket guide to historical monuments or navigation around large exhibition centres. Given the fact that apart from direct communication with the mobile phone, it is also in touch with Bluetooth control units as seen in Fig. 4, the use of the technology is becoming increasingly variable (Tahir & Shah, 2008; Park et al., 2016).

Figure 4. Bluetooth control unit.

A small farm was chosen for the purpose of designing the system, with an adjoining pasture for cattle – see Fig. 5.

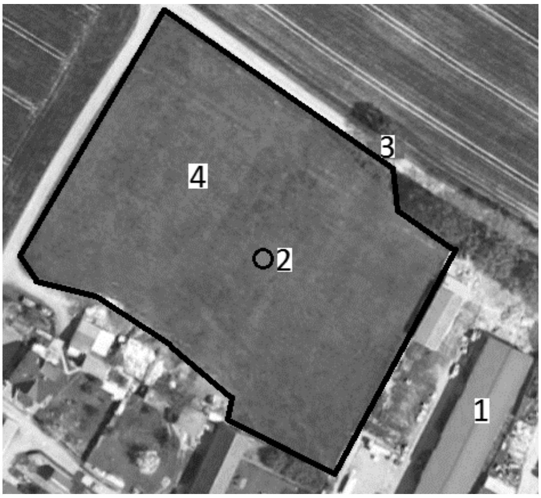

Figure 5. The chosen farm (1 – barn for housing cattle; 2 – location of centralized drinking troughs; 3 – fenced pastures; 4 – grazing area).

The pasture is 100 m long and 70 m wide. In our design of iBeacon EMBC01 setting we chose to use an option of ID Long Range mode sending data every single second. By doing that we reached the optimal range of transmission of up to 75 m, however with an effective transmission up to 50 m distance. The distance of this effective transmission is referred to as the declared distance, which is considered a distance over which the transmission should take place almost under any conditions. Thanks to the pasture size and possibility of using a Bluetooth control unit for the centralized water point in the installation, the number of Bluetooth units used was only two.

RESULTS AND DISCUSSION

Detection of an animal loss is based on a simple principle. When an iBeacon regularly sends data and the Bluetooth control unit receives regular messages of its presence from the given iBeacon, this indicates that things are in order and no alarm is launched. There was a time window determined during which an iBeacon must send a message at least once, and this was set to 5 seconds. On a standard basis it should report five times within this time, but an interference may occur thus this safeguard is set to prevent false alarms.

The designed system for livestock theft monitoring proved to be an ideal solution for inside spaces of the agricultural premises. The thick walls of the building shield wireless transmission and so it is possible to reliably identify whether an animal is inside or not.

A problem appeared when it came to outdoor grazing where animals can move beyond the determined area without raising alarm. However this distance is relatively small and theft would be identified in a short period of time. These issued are further worked on and an emphasis is now on the possibility of narrower specification (modification) of the receiving characteristic of the Bluetooth control unit to more accurately 'mark out' the guarded premises. In the future it is planned to follow-up research to apply on the aforementioned procedures.

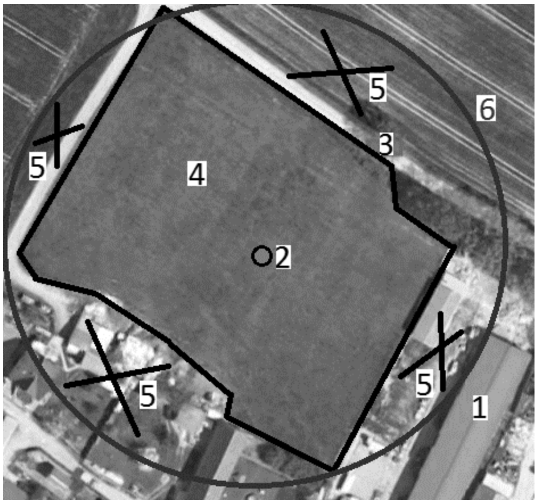

Figure 6. Chosen farm (1 – barn for housing cattle; 2 – location of centralized drinking troughs with outdoor Bluetooth control unit; 3 – pasture fencing; 4 – pasture; 5 – unmonitored area, 6 – range of iBeacons monitoring).

Although the use of RFID technology was initially considered, as described in the article on 'A new asset tracking architecture integrating RFID, Bluetooth Low Energy tags and ad hoc smartphone applications', it was given up for reasons associated with effectiveness of the detection method (Bisio et al., 2016).

As the selected method was not proven an optimal solution, the efforts to develop and modify the system of livestock monitoring must continue, since as claimed by the authors of the article 'Livestock Low Power Monitoring System', the development of systems to monitor livestock theft is a necessity today (Hartová & Hart, 2016; Lopes & Carvalho, 2016).

CONCLUSIONS

The aim of the investigation was to design a livestock monitoring system. The system design employed iBeacons technology which runs on Bluetooth Low Energy (BLE 4.0). This was complemented by Bluetooth control units intended to monitor the presence of iBeacons.

The designed system for livestock theft monitoring has been only partially successful so far. At present it is suitable for monitoring presence of animals inside buildings where their transmission is reliable. That means that if the monitored animal is inside the monitored building, its iBeacon sends data and the Bluetooth control unit smoothly receives it. However if the guarded animal leaves the monitored room, iBeacon transmission is attenuated through the walls and the Bluetooth unit stops receiving signals from the given iBeacon. After ten seconds the Bluetooth unit evaluates the alarm situation and through this obtains the information about one monitored animal being lost.

The use of this technology in outdoor areas yields only partial success at the present time. Although this technology can be partially used, there are a few dead spots in the design, where monitored animals can move being outside the area that we want to clearly restrict and monitor. Currently an emphasis is placed on the system modification to achieve monitoring of an exactly defined area without its spill-over to undesirable areas. Practice tests for proposed facilities are planned during the next follow-up research.

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REFERENCES

Bisio, I., Sciarrone, A. & Zappatore, S. 2016. A new asset tracking architecture integrating RFID, Bluetooth Low Energy tags and ad hoc smartphone applications. *Pervasive and mobile computing* **31**, 79–93.

Dong, Q., Liu, D.G, & Wright, M. 2013. Mitigating jamming attacks in wireless broadcast systems. *Wireless networks* **19**(8), 1867–1880.

Elmasry, G.F. 2013. The Progress of Tactical Radios from Legacy Systems to Cognitive Radios. *Ieee communications magazine* **51**(10), 50–56.

Garcia, G.C., Ruiz, I.L. & Gomez-Nieto, M.A. 2016. State of the Art, Trends and Future of Bluetooth Low Energy, Near Field Communication and Visible Light Communication in the Development of Smart Cities. *Sensors* **16**(11), Article Number: 1968.

Hartová, V. & Hart, J. 2016 Risk of wiring of biometric identification systems, In: *15th International Scientific Conference on Engineering for Rural Development*, LUA, Jelgava, pp. 493–497.

Koppe, E., Moldenhauer, L., Haamkens, F. & Helmerich, R. 2016. Moisture measurements in construction elements and other structures using Bluetooth Low Energy. *Bautechnik* **93**(10), 747–751.

Kucera, L., Bradna, J. & Malatak, J. 2015. Use of Molasses Stillage Utilization as Fertilizer for Organically. *Listy Cukrovarnicke a Reparske* **131**(12), 373–376.

Lopes, H.F. & Carvalho, N.B. 2016. Livestock Low Power Monitoring System, In: *IEEE Topical Conference on Wireless Sensors and Sensor Networks (WiSNet)*, pp. 15–17.

Park, H., Noh, J. & Cho, S. 2016. Three-dimensional positioning system using Bluetooth low-energy beacons. *International journal of distributed sensor networks* **12**(10), Article Number: 1550147716671720.

Tahir, H. & Shah, S.A.A. 2008. Wireless Sensor Networks – A Security Perspective, In: *international multitopic conference*, pp. 189–193.

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Experimental chamber dryer for drying hops at low temperatures

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Abstract. Hop drying takes a significant part in growers' costs of the final product processing. The current drying technology is based on drying at the drying air temperature of 55–60 °C for 6–9 hours to the final moisture content of about 10%. However, the process results in irreversible transformations and losses of, inter alia, heat labile substances contained in hops.
The experimental chamber dryer was tested at harvest in 2016. Assays hop drying were carried out at a temperature of the drying medium 40 °C. The research results in the form of an experimental new experimental chamber dryer will be used for testing of drying technologies at lower temperatures of the drying medium.
This is what will enable to preserve the quality of aroma as well as other characteristics of the components contained in hops.

Key words: hop, drying, chamber dryer, moisture.

INTRODUCTION

Besides brewing parameters there are other heat labile substances contained in hops that are important and for which the current drying temperatures in the final stage of drying are too high. For some special aroma hop varieties, whose content and composition of essential oils are key qualitative parameters, such losses result in a reduced quality of the product. Aroma hops are applied by means of so called dry hopping technique that is widespread especially in the segment of small and restaurant breweries. Based on the above it is concluded that for special hop varieties it is necessary to develop technology and technique suitable for a careful (low-temperature) drying method that would preserve to the extent possible the original composition of hops.

The chemical composition of hops depends inter alia on the variety and post-harvest treatment. On average, hops contain about 10% of water, 15% of total resins, 4% of polyphenol-type substances, 1% of essential oils, 3% of waxes, lipids, 15% of nitrogen compounds, 44% of carbohydrate compounds and 8% of mineral substances.

For the quality of hops the content of valuable brewing constituents, mainly of resins, polyphenols and essential oils, is crucial. Hop resins are responsible for the bitter flavour in beer and they are composed of a group of alpha bitter acids, consisting mainly of cohumulone, and of a group of beta bitter acids, consisting mainly of colupulone. Hops also consist of less active soft and hard resins.

Hop polyphenols or hop tannins have significant technological properties such as their precipitation effect on high and intermediate molecular weight proteins during hopping, and they also contribute to a pronounced and crispy beer taste. One of these constituents is desmethylxanthohumol (DMX).

According to the literature in the Czech Republic, no one had a problem drying hops at a lower temperature than 55 °C (Jech et al., 2011). Low-temperature drying is used with other crops and products, but not with hops (Aboltins et al., 2016). Drying hops at ambient temperature above 55 °C have been discussed by some authors (Bernášek et al., 2007). Both authors describe the drying curve and the energy consumption of hop drying, wherein the drying air has a temperature of about 60 °C. Foreign sources only describe the drying temperature of the drying medium to be 65 to 68 °C (Münsterer, 2006).

The research objective was therefore to design and assemble an experimental chamber dryer including the heater, measurement devices and accessories, allowing hop drying at temperatures below 50 °C.

In 2016, the drying process at a low temperature of the drying air (40 to 45 °C) was monitored in an adapted chamber dryer and simultaneously the hop cone quality was assessed during the process of drying in the experimental chamber dryer and in comparative measurements in operation (60 °C), in a laboratory dryer (40 and 55°) and with fresh green cones.

MATERIALS AND METHODS

The dryer is heated by electric hot air aggregate with a maximum thermal input of 18 kW, and the heated air temperature can be set by means of an indoor thermostat to 40–45 °C. The heated air is blown into the dryer by a fan. The amount of blown air is possible to regulate through a change in the fan's rotation frequency by means of a frequency converter. Above the hop layer there was a forced-draught fan placed to drive the air coming through the hop layer away (Fig. 1). This whole device is the actual design. The experimental chamber dryer is in the form of a self-supporting steel structure with inserted wooden boxes measuring 0.9 x 0.9 x 0.3 m for storing dried hops. It is possible to insert up to 3 boxes one above the other into the dryer. The weight of green hops inside one box may be approx. 20 kg (Fig. 2) (Heřmánek et al., 2016).

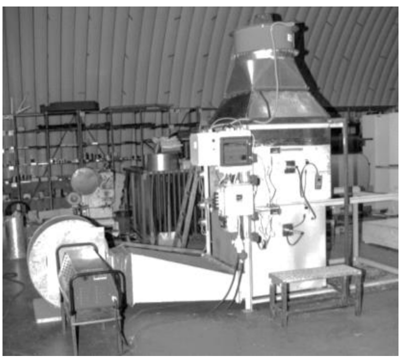

Figure 1. View of an experimental chamber dryer with a draught fan.

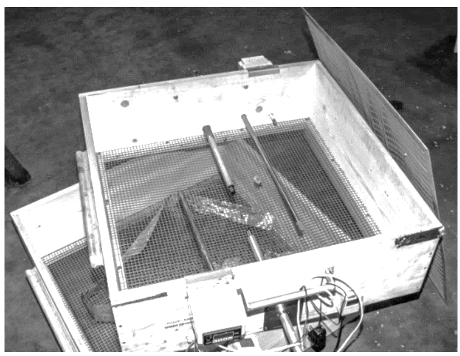

Figure 2. A wooden box.

The hop layer thickness in the experimental chamber dryer was 0.3 m following Table 1 when initiating the drying, i.e. the same as the height of the wooden box (Fig. 2). The air velocity and temperature sensors had been located approx. 0.05 m above the wooden box bottom. Data loggers had been placed in the middle of the layer of the hops being dried, evenly in the shape of a triangle.

The main objective was drying hops at low temperatures which are essential for preservation of valuable substances in hops. The temperature inside the dryer was kept within the range of 40–45 °C. This temperature was achieved by means of a hot-air aggregate and a fan controlled by a frequency converter. The drying temperature was adjusted through the change in the rotation frequency. Relevant parameters of the experimental chamber dryer are listed in Table 1.

Table 1. Parameters of the size of dryer, fans and heater

Equipment	Producer	Type	Parameter	
Chamber dryer	Chmelařství, cooperative Žatec, CZ		Dimension of box 0.9 x 0.9 x 0.3 m	Layer height 0.3 m
Hot air aggregate	Thermobile, Breda, NL	VTB 18000	Flow of air 1,000 $m^3 h^{-1}$	Temperature 40–110 °C
Fan – input	Janka Engineering, Milevsko, CZ	RSH 500	Flow of air 2500–12,500 $m^3 h^{-1}$	Species Radial, medium pressure
Fan – output	ZVVZ, Milevsko, CZ	APZC630	Flow of air 4500–10,800 $m^3 h^{-1}$	Species axial, overpressure

The values from the measuring apparatus were recorded at a pre-determined interval. Every two hours samples were taken to determine the hop moisture content by means of analyses in the laboratory of Hop Research Institute Co. Ltd., Žatec.

Following drying, the hops were left in the slat box overnight (stabilization of hops). Next day in the morning the moisture content in hops was higher, therefore further drying of samples was necessary for all varieties.

During the measurement (Heřmánek et al., 2016) we monitored:

- air temperature and relative humidity under the layer of hops – data logger COMET R0110 (Comet system, Rožnov pod Radhoštěm, CZ),
- air velocity under the layer of hops – probe GREISINGER GIA 2000/GIR 2002 (Greisinger, Würzburg, D),
- air pressure under the layer of hops – pressure gauge GREISINGER 3100 (Greisinger, Würzburg, D),
- air temperature and relative humidity over the layer of hops – data logger COMET R0110 (Comet system, Rožnov pod Radhoštěm, CZ),
- air velocity over the layer of hops – probe GREISINGER GIA 2000/GIR 2002 (Greisinger, Würzburg, D),
- temperature of blown air – thermostat FAMATEL (Famatel-CZ, Prostějov, CZ),
- energy consumption – electricity meter NOARK EDN 3412 (Noark Electric Europe, Praha, CZ),
- radial fan rotation frequency– frequency converter.

The values were recorded online. The figures show examples of the values obtained from all the sensors. The resulting values of the drying air humidity and temperature were obtained as the mean of the sensors applied.

RESULTS AND DISCUSSION

The measurement was made on the premises of Chmelařství, Cooperative Žatec, the Machinery Plant. The measurement results for the variety Vital are presented below. Regarded the fact that the measurements were carried out with Vital variety in the first year, the measured data could not be analysed statistically. The authors suppose further measurements to be carried out in the season of 2017 and compared with the values already measured.

The product input and output values are presented in Table 2.

Table 2. Input and output values for Vital variety

Parameter	Input values	Output values
weight of green hops in the box	23.8 kg	6.8 kg
hop moisture content	75.0%	12.0%

Moisture content = wet basis.

At the start of the drying process, three data loggers VOLTCRAFT DL-121-TH had been inserted into approximately half of the hop layer (Srivastava et al., 2006). Figs 3 and 4 illustrate changes over time in temperature, relative humidity and air velocity.

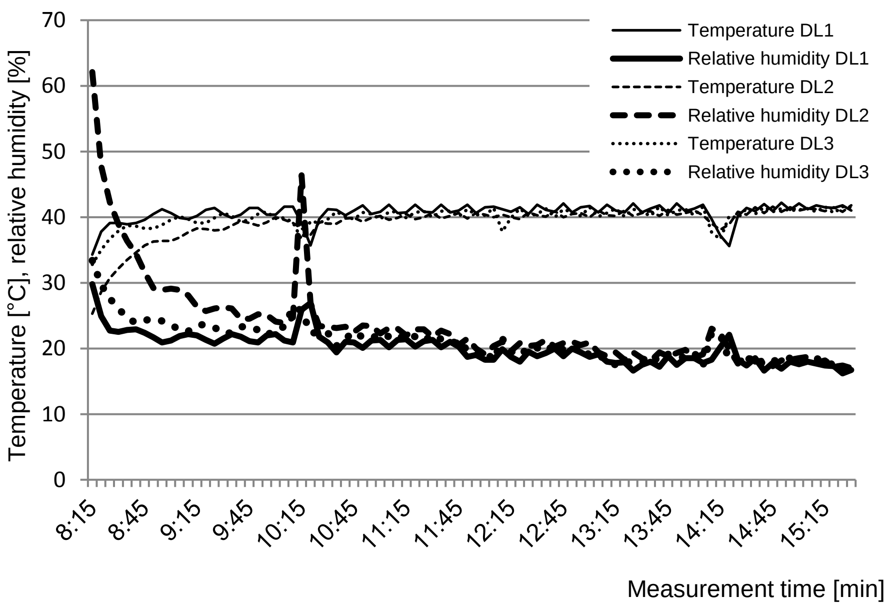

Figure 3. Dependence of the air temperature and relative humidity on the measurement time in a layer of dried hops (data loggers 1 to 3 – DL1 to DL3).

Fig. 3 depicts the changes in temperature and relative humidity prior to entering the drying slat box and over the hops that are being dried measured by means of the data loggers inserted into the hop layer. The graph clearly shows a balanced temperature pattern (approx. 40 °C) as well as relative humidity pattern (approx. 20%) under the hop layer, which confirms an optimal setting of the inlet fan rotation frequency. The values recorded for the temperature and relative humidity of the air coming out of the hop layer stabilised after approx. 3.5 h of drying. Until then the fresh green hops were influencing the gradually increasing temperature and decreasing relative humidity of the air coming through.

Fig. 4 illustrates the changes in the air velocity during drying. Both under and over the hop layer this dependence is largely unbalanced and any conclusions can be drawn only with difficulties. The air velocity depends on drying up of the hop layer and simultaneously also on the change in resistance of this layer which affects the air circulation.

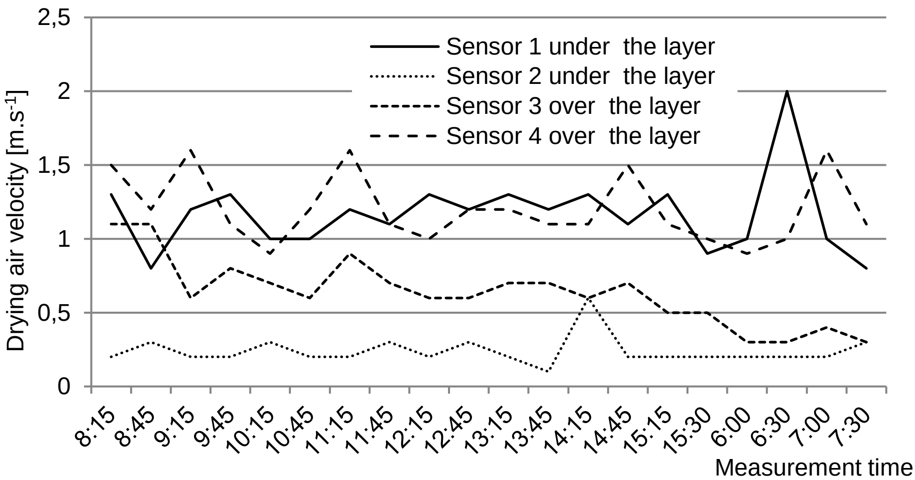

Figure 4. Air velocity during the drying process.

Dried hops were also tested in the laboratory in terms of the overall product quality. For Vital variety its qualitative parameters from the experimental chamber dryer were compared with hops of the same variety during comparative measurements in operation (60 °C), in the laboratory dryer (40 and 55 °C) and with the quality of fresh green cones.

Hop moisture was determined through gravimetric analysis in the laboratory chamber dryer of Hop Research Institute Co. Ltd., Žatec with forced air circulation according to the EBC 7.2 method (European Brewery Convention Analysis Committee, 2009). Following this method, the weighed hops are dried at a temperature of 105 °C for 1 h. Drying time for hops with moisture content over 30% shall be extended to 1.5 h. With the samples we also monitored the Hop Storage Index (HSI) which had been determined by the official EBC 7.13 spectrophotometric method from a hop toluene extract. Alpha bitter acid content was measured by means of liquid chromatography according to the EBC 7.7 method (Krofta, 2008). The measured value was then converted to an absolutely dry matrix for all the points of the drying curve.

Table 3. Results of drying monitoring in operating conditions for Vital variety

Sampling date	Alpha bitter acids (%DW)	Beta bitter acids (%DW)	DMX (%DW)	Moisture content (%)	HSI
29. 8. 2016 hop field sampling	16.02 14.39	11.31 10.65	0.52 0.48	78.1	0.208
6. 9. 2016 hop field sampling	15.96 15.48	9.56 8.74	0.51 0.46	76.0	0.216
16. 9. 2016 hop field sampling	15.58 15.62	9.32 8.63	0.39 0.38	75.1	0.231
19. 9. 2016 green harvest sample	15.40 15.55	8.71 9.16	**0.40** **0.40**	73.7	0.228
20. 9. 2016 dried harvest sample	14.67 13.87	8.57 8.09	**0.22** **0.20**	9.2	0.295

Table 4. Results of low-temperature drying monitoring for Vital variety

Drying	Alpha bitter acids (%DW)	Beta bitter acids (%DW)	DMX (%DW)	Moisture content (%)	HSI
Memmert 55 °C, 8 h	14.36	8.70	0.24	9.6	0.283
Memmert 40 °C, 10 h	16.90	9.79	0.36	37.1	0.230
Experimental chamber dryer (40 °C)	**14.07** **14.74**	**8.46** **8.92**	**0.29** **0.32**	**12.0**	**0.266**

N.B.: Memmert = laboratory dryer – producer Memmert; Department of hop chemistry Hop Research Institute Co. Ltd., Žatec.

As can be seen from Table 3, the content of chemical substances (alpha and bitter acids, Desmethylxanthohumol), moisture contents and HSI do not vary at the end of the growing season (29.8.2016–16.9.2016) nor during the harvest (19.9. 2016). After drying in a belt dryer following the traditional way of drying (65 to 68 °C), fundamental differences were measured in the content of desmethylxanthohumol (DMX), a valuable bioactive substance, highly sensitive to thermal load. Its content in green hops was 0.40% of weight, after being dried in operating conditions its content dropped by about a half (0.20; 0.22% of weight). For this reason it can be used as an indicator reflecting gentle drying.

The content of DMX after drying in the laboratory dryer (Memmert) and experimental chamber dryer under more favourable conditions in terms of temperature was substantially higher (0.29%; 0.32%). The measurement results are presented in Table 4.

CONCLUSION

The above research indicates that during drying it is necessary to monitor the content of desmethylxanthohumol (DMX), as it is a substance indicating gentle drying.

It can also be concluded that this very experimental chamber dryer is suitable for monitoring various drying technologies. At the same time this dryer will serve for further research in the field of low-temperature drying of hops.

For practical use, and further experiments will be necessary to ensure:

- optimum ripeness of hops depending on the variety,
- uniform distribution of hops within the dryer including an optimal height of the layer of hops,
- temperature of the drying medium a maximum of 40 to 45 °C,
- uniform distribution of the drying medium within the dryer,
- continuous monitoring of temperature and moisture of hops,
- continuous monitoring of temperature, humidity and velocity of the drying medium,
- control the velocity and temperature of the drying medium,
- uniform final moisture of hops between 8–10%,
- option air and moisture balancing hops,
- measurement of time and energy consumed during the process of drying,
- documentation of the measured values.

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REFERENCES

Aboltins, A. & Palabinskis, J. 2016. Fruit Drying Process Investigation in Infrared Film Dryer. *Agronomy Research* **14**(1), 5–13.

Bernášek, K., Hanousek, B., Rybka, A. & Kvíz, Z. 2007. Drying curves shape for hop cones and energy consumption during different drying air flow rate and drying temperature. In Libra, M. (eds): *3rd International Conference Trends in Agricultural Engineering 2007*, CULS Prague, pp. 57–60.

European Brewery Convention Analysis Committee. 2009. *Analytica - EBC 7.2 Moisture Content of Hops and Hop Products*, Verlag Hans Carl Getränke – Fachverlag, Nürnberg.

Heřmánek, P., Rybka, A., Honzík, I., Hoffmann, D., Jošt, B. & PODSEDNÍK, J. 2016. Construction and Verification of an Experimental Chamber Dryer for Drying Hops. In Herák D. (eds): *6-th International Conference Trends in Agricultural Engineering 2016*, CULS Prague, pp. 179–185.

Jech, J., Artim, J., Angelovičová, M., Angelovič, M., Bernášek, K., Honzík, I., Kvíz, Z., Mareček, J., Krčálová, 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-harvesting and treatment of plant material.* Profi Press s.r.o., Prague, 368 pp. (in Czech and Slovak).

Krofta, K. 2008. *Evaluation of hop quality.* Hop Research Institute Co. Ltd., Žatec, 50 pp. (in Czech).

Münsterer, J. 2006. *Optimale Trocknung und Konditionierung von Hopfen.* Bayerische Landesanstalt für Landwirtschaft, Arbeitsgruppe Hopfenbau, Produktionstechnik, Wolnzach, 26 p. (in Germany).

Srivastava, A.K., Goering, C.E., Rohrbach, R.P. & Buckmaster, D.R. 2006. *Engineering Principles of Agricultural Machines.* ASABE, 2nd Edition, Michigan, 569 pp.

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Modification of the rheological properties of honey in the honeycombs by the high frequency heating prior to honey extraction

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Abstract. This paper addresses the issue of the extraction of highly viscous honey from the honeycombs. High viscosity can be caused by many factors. In the operational practice it is mainly about the difficult conditions (cold weather), post seasonal honey extraction or honey with naturally high viscosity (honeydew honeys). The objective was to design and validate a technology that will enable to reduce the viscosity of honey in the honeycombs by the high frequency heating and increase the effectiveness of honey extraction. The experimental part is based on the high frequency heating of honey, so called dielectric heating. In this process the heating of honey occurs evenly throughout the full volume of the honeycomb. To verify the proposed procedure, several groups of samples of the capped honeycombs were selected that contained honey of different botanical origin and rheological properties. For heating of the honeycombs, a high frequency chamber was prepared in the laboratory conditions. Honeycombs were placed into the chamber and heated to the desired temperature (from 15 °C to 45 °C). During extraction, the time dependence of honey extraction on the temperature of the pre-heated honeycombs was monitored. It was proved that the high frequency heating is suitable for the pre-processing of the honeycombs; heating is quick and reduces the viscosity. As a consequence of different permittivity of honey and beeswax, the strength of the comb is not changed when the electromagnetic field conditions are set properly, the honeycomb remains compact. Measurements demonstrated the time reduction of honey extraction based on the temperature.

Key words: honey, honey extraction, high frequency heating.

INTRODUCTION

The present paper experimentally deals with the issue of the extraction of the viscous honey from the capped honeycombs. This technological operation is challenging if the honey does not have an ideal liquidity. It is when honey is extracted during adverse weather conditions or if a highly viscous honey that bees make in some seasons is extracted. The objective of this paper was to design and validate the possibility of changing the rheological properties of honey in the production conditions by heating of the whole honeycombs in order to increase the liquidity of honey. The higher temperature of honey enables the better operational processability of the honeycombs. An increase of the productivity and yield of honey from the honeycombs can be expected.

From the technological point of view, honey is a liquid which is difficult to process. Processability is influenced by its chemical composition and physical properties (Fischer & Windhab, 2011). Technologically important are the rheological properties of honey. They affect the honey processing technology, i.e. honey extraction from the honeycombs, pumping, churning, straining, filtration, mixing and filling honey into consumer packaging (Escriche et al., 2009).Rheological properties are mostly influenced by the degree of crystallization and viscosity of honey. The degree of crystallization is dependent on several factors of which the most important are the ratio of glucose and fructose and the presence of pollen grains (Escuredo et al., 2014). Honey viscosity is dependent on water content in honey, chemical composition and temperature (Gleiter et al., 2006). Water content and chemical composition of honey is determined by its botanical origin and cannot be changed in the operation conditions for honey processing. It would cause irreversible changes in the quality of honey. Given the fact that some properties (e.g. water content) are at the same time the indicators of product quality, their technological change would be in breach of the legislation (Turhan et al., 2008). On the other hand, the influence of temperature change on the viscosity of honey is technologically feasible in practice and is regularly used. The heating of honey or the heating of the honeycombs shall be performed in a friendly manner. The overheating or repeated heating may cause changes in chemical composition of honey and the quality deterioration. The quality indicator of the technologically deteriorated honey is the content of hydroxymethylfurfural (HMF). The unheated honeys contain about 10 mg per kg of HMF. The maximum allowed amount is 40 mg per kg for single–flower honeys (mixed honeys 80 mg per kg). The higher amount indicates the old age of honey or the technologically improper heating of honey.

The temperature dependence of viscosity is a logarithmic function – there is a big change in viscosity at low temperature change (Gomez–Diaz et al., 2009). Honey viscosity (regardless the botanical origin) decreases with increasing temperature and such decrease reaches its maximum at a temperature around 40 °C. In the temperature range of 10 °C to 40 °C viscosity of honey gradually decreases from 100 Pa s to 2 Pa s (Yanniotis et al., 2006). The above values show that the temperature at which the viscosity of honey is low is technologically advantageous for honey extraction from the honeycombs, mixing and other processing procedures. Technologically, there are several ways to extract honey from the honeycombs. In practice, gravitational force, pressure force or centrifugal force are used for honey extraction. In all cases, the effectiveness and efficiency of the process depend on the rheological properties of honey. Well-established practice is to extract honey by centrifugal force on honey extractors of various constructions. Extraction efficiency is dependent on centrifugal force and the properties of honey. Increasing efficiency by increasing the centrifugal force, i.e. the speed increase and the radius of rotation of the drum of the honey extractor, is limited by the strength of the beeswax comb (the risk of damage and contamination of honey by beeswax). Therefore in the production conditions for honey extraction a change in honey’s rheological properties is sometimes used prior to the uncapping of the honeycombs. It’s about the increase of temperature by the conventional heating and thus reducing viscosity, which affects the efficiency and speed of honey extraction (Oroian et al., 2013). This process is time consuming and laborious.

The proposed technology solves the problem of reduction the viscosity of honey by heating the capped honeycombs by high frequency dielectric heating. Dielectric heating and microwave heating are based on the direct transmission of the electromagnetic energy to the heated material. Compared to the conventional methods of heating the processing time is short and the heat is generated in the full volume of the heating material. For honey, as well as for the other organic materials, the heating characteristics are influenced by frequency, water content and dielectric properties of the heated material (Sosa–Morales et al., 2010). Dielectric properties of honey, i.e. relative permittivity and dielectric loss factor are a function of frequency, water content in honey (Puranik et al., 1991) and less important also temperature (Guo et al., 2011). For natural honeys, the relative permittivity decreases with increasing frequency. For the frequency range of 10 MHz to 1000 MHz the honey relative permittivity has values from 40 to 13 (Puranik et al., 1991).

This study is based on the assumption that the high frequency heats the honeycomb evenly throughout all of its volume; is faster compared to the conventional heating and friendly for the honey quality. The objective was to propose and validate a technology that will enable to reduce in adverse climatic conditions the viscosity of honey in the honeycombs by high frequency heating. This will create conditions for reduction of the overall time of the honey extraction from the honeycombs and increase the efficiency of honey extraction.

MATERIALS AND METHODS

The following procedure was used to verify the possibility of changing the rheological properties of honey in the honeycombs by warming up by high frequency heating.

Samples of the capped honeycombs from two different seasonal periods were selected. Thus, there were two groups of honey samples of different botanical origin and different rheological properties available. Honeycombs were heated to the desired temperature from 15 °C to 45 °C, always by 5 °C. The temperature of honey was increased by high frequency dielectric heating. Once the desired temperature of the honeycombs was reached, the honeycombs were uncapped, inserted into the honey extractor and were extracted to dry, i.e. to reach the complete extraction of honey. The time required to extract all honey from the honeycombs was measured.

Honeycombs

The properties of the honeycombs heated by the high frequency source were measured in two groups of the honeycomb samples. The honeycombs from the first sample came from a spring period and contained nectar honey. The honeycombs from the second sample came from a summer period and contained honeydew honey. The first and the second sample differed by the botanical origin of honey and further by its physical and chemical properties. Thus the requirement that each sample contained honey of different rheological properties was met. For both samples, the refractometric method for determining the water content was used (water content significantly influences the dielectric properties of honey). In both cases, it was confirmed that they contained mature honey. Nectar honey contained 18.2% of water, honeydew honey 18.9% of water:

1. Sample: nectar honeyfrom May 2016.
2. Sample: honeydew honeyfrom July 2016.

Honeycombs heating

The temperature of the honeycombs was increased from the original temperature of 15 °C by the high frequency dielectric heating. A device established in the laboratory conditions was used for the heating. The device is shown in Fig. 1. The device consists of a heating chamber (1) and a high frequency generator (4). The heating chamber (1) is designed as two plates (2) of dimensions of 0.3 x 0.4 m. The plates are mutually fixed at a distance d at the value of 0.1 m. For heating, the honeycomb (3) was inserted into the heating chamber (1) and the high frequency generator (4) was switched on. The heating time was calculated based on the desired temperature of heating.

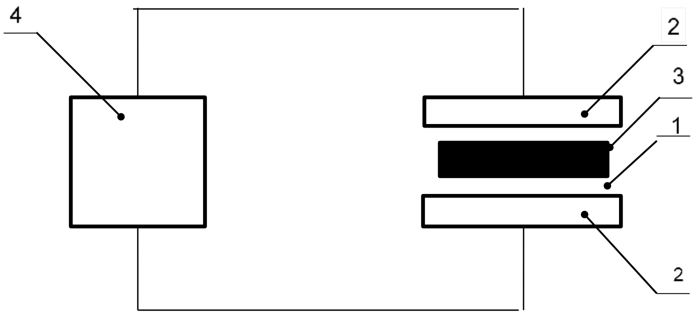

Figure 1. Connection scheme of the device for the high frequency heating of the honeycombs: 1 – heating chamber; 2 – heating surface plates; 3 – honeycombs, 4 – high frequency generator.

Operating parameters of the high frequency dielectric device (voltage, frequency) and operating conditions of heating (heating time) were calculated from the general physical equations. For the calculation, the relation between the heat output density on the side of the heated material, i.e. honeycombs (1) and the heat output density of the high frequency source, i.e. the heating device (2) was utilized.

$$Q_1 = \frac{\rho \cdot c_p \cdot \Delta T}{t} \tag{1}$$

where: ρ – density of honey; c_p – specific heat capacity of honey; ΔT – difference in temperature; t – heating time.

$$Q_2 = 2 \cdot \pi \cdot f \cdot \varepsilon_o \cdot \varepsilon_r \cdot tg\delta \cdot E_{ef}^2 \tag{2}$$

where: f – frequency; ε_o – vacuum permittivity; ε_r – relative permittivity of honey; E_{ef} – effective electric field intensity ($E_{ef} = U_{ef} \cdot d^{-1}$); d – distance between the plates; U_{ef} – voltage; $tg\delta$ – loss factor.

For calculation, honey was specified by density 1,400 kg m^{-3}, specific heat capacity 3,000 J kg^{-1} K^{-1}, loss factor 0.1 and relative permittivity of honey 17.6 at 500 MHz (Puranik et al., 1991) and original temperature 15 °C. The high frequency generator with an operating frequency 500 MHz and voltage 2,000 V was used for the heating. The frequency 500 MHz was chosen due to the possibility of using low operating voltage gradients.

Honey extraction

Honey extraction from the honeycombs was performed on a commercially produced honey extractor. Honey extractor EWG 4 Comfort of Heinrich Holtermann brand is a four-frame reversible tangential honey extractor with automatic control. During extraction, the control mechanism was adjusted so that the process corresponded to normal operational practice of honey extraction. The tangential reversible honey extractor worked in two phases. The first phase of honey extraction was conducted using low speed rotation (30 min^{-1}) to one and the other side – for 1 minute each. The second phase of honey extraction was conducted using high speed rotation (60 min^{-1}) for one and the other side – for the time necessary to extract all honey from the honeycomb.

RESULTS AND DISCUSSION

The usability of the high frequency heating of the honeycombs for the purpose of changing the rheological properties of honey was in the operating conditions measured as the time dependence of honey extraction on the temperature of the pre–heated honeycombs.

Heating of the honeycombs by the high frequency heating does not allow the usage of a suitable thermostatic control automation system for the precise adjustment of the heating temperature. The usage of the control automation system would require an installation of a thermometer sensor into honey in the heated honeycomb. The thermometer sensor has different physicochemical properties than honey and thus has a different permittivity value than the heated honey. It is heated differently from honey in the high frequency field. In order to reach the desired temperature of honey, it was necessary to measure the heating time for each selected temperature of the pre-heated honeycombs. The measurement of the heating time was carried out according to the equations (1) and (2). In order to obtain an accurate temperature of honey, control measurements by a digital needle probe thermometer were carried out. In Table 1, there are listed measured heating times of the honeycombs and temperatures measured with the thermometer after the high frequency heating. From Table 1 follows that the heating times of honey in the honeycombs are under specified conditions in the units of minutes. This suggests that the high frequency heating has at set conditions for heating of honey high efficiency. The measured heating times (in order to reach the desired temperature) and subsequently measured temperature values by control measurements show minimal deviation between desired (i.e. set) and achieved (i.e. measured) temperature of honey. This deviation moves to 2 °C. This difference is insignificant in the operating conditions.

Table 1. Measured heating times of the honeycombs for the desired temperatures and actual temperatures measured with a thermometer after the high frequency heating

		Sample number 1	Sample number 2
Temperature set [°C]	Heating time [min]	Temperature measured [°C]	Temperature measured [°C]
15	0	15	15
20	1.5	21	20.1
25	2.9	23.5	23.3
30	4.5	28.4	30.6
35	6	33.4	36.1
40	7.5	39.2	40.4
45	8.9	44	45.8

In addition, the temperature measurements at various locations of the honeycombs proved that the honeycomb is heated over the whole surface evenly. The evenness of heating the honey to a depth of the honeycombs has not been measured. The evenness of heating is given by the chosen method of heating, i.e. high frequency heating, in which the heat is generated evenly throughout the whole volume of the heated material. The evenness of heating depends on the penetration depth which is dependent on the relative permittivity, loss factor of a material and frequency. For pure honeys, the penetration depth decreased with increasing frequency linearly in log-log plot. The values of penetration depth of natural honeys in the range of 10 MHz to 1 GHz move between the range from 0.1 meter to 1 meter (Guo et al., 2011). For the honeycombs heating at a frequency of 500 MHz, which was used in the measurement, the penetration depth is sufficient.

The needle probe thermometer also measured the temperature of the beeswax, which forms the honeycombs and its caps. In this paper the concrete measured values of the temperature of the beeswax are not mentioned because they were monitored for guidance only as a secondary supplementary factor and were not accurately recorded. The honeycombs' beeswax had after the high frequency heating the temperature which was up to 8 °C lower than the reached temperature of the honey (for honeys at temperatures above 30 °C). The reason is the low permittivity of the beeswax. Beeswax has relative permittivity 3 (Prava & Ahmed, 2013). The difference in temperature reached between honey and beeswax for high frequency heating is beneficial for practice. The beeswax when heated does not change its rheological properties. It remained firm and thus the entire combs maintain their strength and dimensional stability. This is advantageous for the honey extraction from the honeycombs. The honeycombs when extracted were less damaged and the amount of beeswax in the extracted honey was lower, i.e. the extracted honey had higher purity (honey purity was assessed only subjectively).

Measured extraction times of honey at temperatures set in the interval between 15 °C to 45 °C are shown in Table 2. The temperatures indicated in Table 2. are temperatures measured by control measurements by the thermometer, i.e. the exact honey temperature reached.

Table 2. The values of honeycombs' temperature and time required to complete the extraction

Sample number 1 time [min]	Sample number 2 time [min]	Sample number 1 temperature [°C]	Sample number 2 temperature [°C]
10	12	15	15
8	10	21	20.1
6	8	23.5	23.3
6	6	28.7	30.6
4	6	33.4	36.1
2	4	39.2	40.4
2	2	44	45.8

Dependence of the measured factors shows Fig. 2. In Fig. 2 the values from Table 2 are laid out in a graph and they are interlaid with a trend connecting line. The curves thus obtained show progress of the time dependence of honey extraction on the temperature of the pre–heated honeycombs. The time figure represents the minimum time of the extraction required to extract all the honey from the honeycombs.

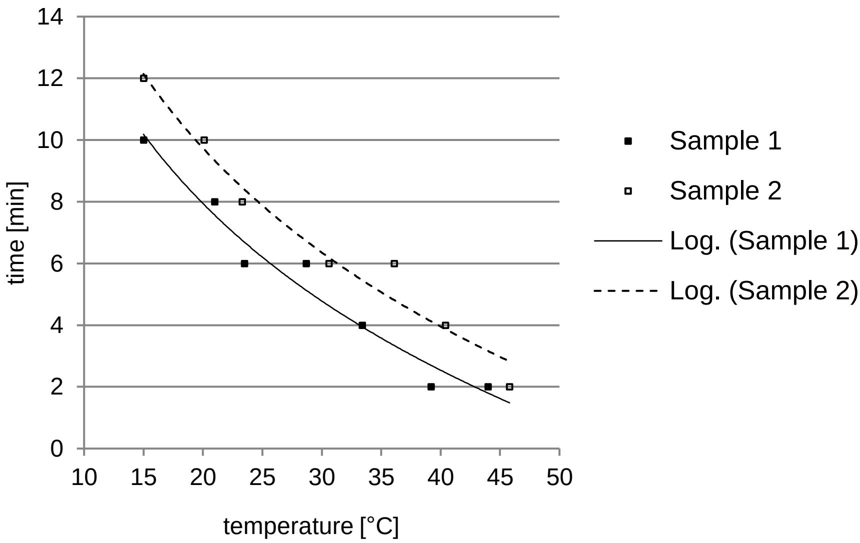

Figure 2. Dependence of honey extraction time on the temperature of the honeycombs.

The illustrated dependencies imply that the time necessary to extract honey from the honeycombs is dependent on temperature. The relationship between the time and the temperature of honey best describes logarithmic trendline of the measured values. It indicates that at a decreasing temperature i.e. temperature below 20 °C, there is a significant increase in the time required to extract the honeycomb. On the contrary, at temperatures above 35 °C, the shortening of the extraction time during increasing temperature is operationally insignificant. Technological optimum temperature for honey extraction from the honeycombs is within the temperature range of 25 °C to 35 °C. In the climatic conditions in the Central Europe, the possibility of honey extraction at these optimal temperatures is rather exceptional. This confirms the assumption of operational necessity of the honeycombs heating to the temperatures above 25 °C even during the honey extraction in the spring and summer.

The measurement proved that the course of dependency of the time required to extract honey on the temperature is similar in both samples. This means that the botanical origin of honeys and following differences in the chemical compositions of honeys have only minimal effect on the rheological properties of honeys. These results are consistent with previous research (Jehlička & Sander, 2016). Significant influence on the rheological properties has the reached temperature of honey. Botanical origin and related chemical composition impacts in each sample only mutual shift of the plotted dependencies. As follows from Fig. 2, this is a prolongation or shortening of the total extraction time of honey from the honeycomb for about 1 minute. The plotted curves indicates that the rheological properties depend mainly on the temperature and that the botanic origin of honey (chemical composition of honey) is operationally less significant factor.

From a technological point of view, the optimal temperature for the extraction of the honeycombs can be considered a temperature at which the honeycombs are extracted in a short period of time. Then, the plotted dependencies on Fig. 2 imply that extraction time depends mainly on honey temperature. It reaches its minimum at all observed samples after reaching a temperature about 30 °C. The optimal temperature for the honeycombs extraction can be considered a temperature between 25 °C to 35 °C, which corresponds to the extraction time of 4 to 6 minutes.

CONCLUSIONS

The measured values proved that the rheological properties of honey can be changed by high frequency heating. Highly productive heating can be achieved and once the honey of the optimal rheological properties is extracted then also high efficiency, i.e. to minimize the residual (unextracted) honey in the honeycombs.

The measurement was carried out only for the operating frequency set at 500 MHz, which corresponds to the relative permittivity of honey 17.6. It can be assumed that by changing the frequency used, the change in the intensity of heating will occur and thus the change of the heating time of the honeycombs. The risk of overheating of honey will increase with increasing frequency and consequently the possibility of the deterioration of honey quality. This dependence would be worthy to prove by another measurement in the future.

Furthermore, the measurement also proved a different effect of high frequency heating on honey and beeswax. Unlike the conventional method of heating, the high frequency processing causes different temperature increase in honey and beeswax. The beeswax did not change its rheological properties, remained solid and dimensionally stable. Extracted honey was not polluted by the residues of the loose honeycomb beeswax.

The monitoring of the dependency of the extraction time on temperature of the honeycomb proved that the rheological properties of honey are significantly affected by the degree of the temperature reached. The botanical origin of honey influences its rheological properties only minimally and its impact in the production conditions is negligible. Optimal rheological properties for the processing of the honey in the honeycombs are at temperature between 25 °C to 35 °C, at which point the time required to extract the honey from the honeycombs reaches its minimum.

REFERENCES

Escriche, I., Visquert, M., Juan–Borrás, M. & Fito, P. 2009. Influence of simulated industrial thermal treatments on the volatile fractions of different varieties of honey *Food Chemistry* **112**(2), 329–338.

Escuredo, O., Dobre, I., Fernández–Gonzáles, M. & Seijo, C. 2014. Contribution of botanical origin and sugar composition of honeys on the crystallization phenomenon. *Food Chemistry* **149**, 84–90.

Fischer, P. & Windhab, E.J. 2011. Rheology of food materials. *Current Opinion in Colloid & Interface Science* **16**(1), 36–40.

Gleiter, R.A., Horn, H. & Isengard, H.D. 2006. Influence of type and state of crystallization on the water activity of honey. *Food Chemistry* **96**(3), 441–445.

Gomez-Diaz, D., Navaza, J.M. & Quintans–Riveiro, L.C. 2009. Effect of temperature on the viscosity of honey. *International Journal of Food Properties* **12**(2), 396–404.

Guo, W., Liu, Y., Zhu, X. & Wang, S. 2011. Temperature–dependent dielectric properties of honey associated with dielectric heating. *Journal of Food Engineering* **102**(3), 209–216.

Jehlička, T. & Sander, J. 2016. Modification of the rheological properties of the honey in the honeycombs prior to its extraction in the production conditions. *Agronomy Research* **14**(4), 1293–1299.

Oroian, M., Amariei, S., Escriche, I. & Gutt, G., 2013. Rheological Aspects of Spanish Honeys. *Food and Bioprocess Technolog* **6**(1), 228–241.

Prava, M.L. & Ahmed, A., 2013. Study on Dielectric Behaviour of Waxes in p-band region. *Journal of Chemical, Biological and Physical Sciences (JCBPS)* **3**(4), 2907–2913.

Puranik, S., Kumbharkhane, A. & Mehrotra, S. 1991. Dielectric properties of honey–water mixtures between 10 MHz and 10 GHz using time domain technique. *Journal of Microwave Power and Electromagnetic Energy* **26**(4), 196–201.

Sosa-Morales, M.E., Valerio-Junco, L., López-Malo, A. & García, H.S. 2010. Dielectric properties of foods: reported data in the 21st Century and their potential applications. *LWT – Food Science and Technology* **43**(8), 1169–1179.

Turhan, I., Tetik, N., Karhan, M., Gurel, F. & Reyhan Tavukcuoglu, H. 2008. Quality of honeys influenced by thermal treatment. *LWT - Food Science and Technology* **41**(8), 1396–1399.

Yanniotis, S., Skaltsi, S. & Karaburnioti, S. 2006. Effect of moisture content on the viscosity of honey at different temperatures. *Journal of food engineering* **72**(4), 372–377.

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Evaluation of the inline stripping of ethanol during cyanobacteria cultivation in a bubble column bioreactor

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Abstract. Cyanobacteria are oxygenic phototrophic microorganisms capable of photosynthesis. In this redox reaction driven by light energy, carbon dioxide and water are converted into chemical energy in form of carbohydrates and oxygen. The output of this process is restricted by product inhibition from the bioethanol. Here, we evaluate a method of ethanol stripping in a bubble column for perspective use for determination of ethanol production rate of engineered cyanobacteria. The knowledge about the amount of condensation and recovery rate combined with HPLC measurement for ethanol determination can be used to specify the real amount of produced ethanol (absolute) by cyanobacteria in the used bioreactor. Stripping and recovery rate are depending on several parameter like flow rate, initial ethanol concentration, condensation temperature etc. Due to the high influence of these parameters they have to be supposed to be static regarding to the degrees of freedom.
To evaluate the system different ethanol concentration were testet for stripping and determination of recovery rate. As the stripping rate was much higher compared to the ethanol production rate with our Synechococcus elongatus PCC 7942 the medium was spiked with ethanol to varying concentrations of 0.5, 1 and 2% v/v. It could be shown that ethanol could be removed quantitatively. Removal rates of 97–98% were reached with initial ethanol concentrations of 5 g L^{-1} to 20 g L^{-1}. The results demonstrated determination of ethanol in the exhaust air stream and quantitavely recollection by cultivating engineered *Synechococcus elongatu*s in bubble column bioreactors.

Key words: Bioethanol, stripping, inline down-streaming, cyanobacteria, bubble column bioreactor.

INTRODUCTION

Renewable energies and especially biofuels play an important role to ensure energy sustainability (Savvanidou et al., 2010). Due to the increasing dependency on crude oil imports, and increasing greenhouse gas emissions, there´s an increased need for alternative ways of energy supply. Biofuels like bioethanol or biodiesel actually represent the most prominent technical option because of the possibility of blending with fossil fuels and using without major adaptations of cars (Gnansounou, 2010). Advanced biofuels, such as those made from straw, waste and algae, provide higher greenhouse gas emission savings with a low risk of causing indirect land-use change, and do not compete directly for agricultural land used for food and feed production. Therefore, the EU encourages greater research in, and development and production of advanced biofuels as they are currently not commercially available in large quantities.

The Directive (EU) 2015/1513 of the European Parliament relating on the promotion to the use of energy from renewable sources regulates the production of biofuels. The amount of biofuels and bioliquids produced from cereal and other starch-rich crops, sugars etc. grown as main crops primarily for energy purposes on agricultural land is capped to 7% of the total amount of transport fuels.

Today the so called first generation biofuels (fuels derived from sugar cane or starchy crops) are produced worldwide. Bioethanol is produced by fermentation and concentrated by distillation. The world bioethanol production was expected to reach 100 billion liters in 2016 (Kahr et al., 2013). Over the last decade, research on advanced biofuels like second generation bioethanol made great progress. The technology for biofuel production derived from straw is now available and the first production site with a capacity of 50.000 tons per year was opened in Italy in 2013 (Novozymes, 2013).

Microalgae and cyanobacteria offer great potential as platform for production of natural and high value products like pigments, proteins and biofuels. Their fast growth, low production cost regarding simple media composition in combination of using light and CO_2 to generate biomass and value products make them ideal as production systems (de Farias Silva & Bertucco, 2016; Yan et al., 2016). Additional to optimization of cultivation parameters, like light and media for high yield production, genetically engineering of these simple structured microorganisms offer additional product diversity and higher product yields. For bioethanol production with microalgae and cyanobacteria existing biochemical pathways are used for more subjective and efficient production (de Farias Silva & Bertucco, 2016). Here, integration of the genes for pyruvate decarboxylase (*pdc*) and alcohol dehydrogenase (*adh*) from *Zymomonas mobilis* enable the conversion of pyruvate to ethanol (Dexter et al., 2015). For microalgae, viability of industrial process for biodiesel production was shown but a suitable process for bioethanol has still to be found (de Farias Silva & Bertucco, 2016). In cyanobacteria different gene constructs and various promoters were tested for optimized ethanol production. Up to date, Gao et al. (2012) achieved the highest ethanol production yield with 5.5 g L^{-1}.

These prokaryotes are fast growing organisms and utilize solar energy and CO_2. First, these prokaryotes must be genetically manipulated for ethanol production. This was shown by several authors (Dexter et al., 2015; Pfannerer et al., 2016). We have modified the photosynthetic prokaryote *Synechococcus elongatus PCC 7942* using homologous recombination to introduce the pyruvate decarboxylase (*pdc*) and alcohol dehydrogenase B (*adhB*) genes of *Zymomonas mobilis* into the organism's genome. These cyanobacteria grow in fresh water, seawater or even in wastewater. Both genes were expressed under the control of the strong constitutive psbA1 promoter (encoding photosystem II protein D1).

The fermentation process of high productive engineered *Synechococcus elongatus PCC 7942* is restricted by the desired end product bioethanol (Nozzi et al., 2013). We present a method for an inline downstreaming process to strip the ethanol produced during fermentation of Synechococcus elongatus PCC 7942. The inhibiting effects of ethanol could be avoided and the product ethanol can be collected by this method at the same time. The inline stripping of ethanol from stirred tank reactors was described by Hwai-Shen (1990), Hsien-Wen (1991) and more recently by Amenaghawon (2010). It has been shown that inline stripping of ethanol can be a valid way to remove and concentrate the product from fermentation processes.

In conventional bioethanol production, ethanol is generated by yeasts in an anaerobic process without any aeration. Ethanol produced is separated at the end of the process commonly by means of rectification. We describe an inline process which allows the continous separation of the produced ethanol throughout the fermentation process in bubble column reactors. The procces can be summarized as follows: Cyanobacteria must be provided with a CO_2 as carbon source. Routinely, this is provided by flushing the fermentation reactors with compressed air.

Stripping of ethanol in general is not a new invention and was already desribed too for CO_2 stripping from high concentrations (8–9% v/v ethanol in wine) in bubble columns by Silva et al. (2015). The aim of the work was to evaluate the stripping method so far in our fermentation system to define the exact stripping conditions for fermentation of high producing (genetically modified) cyanobacteria.

We have utilized a commercial bubble column reactor for fermentation of bioethanol from *Synechoccus elongatus* and examined the stripping of the ethanol produced by the bacteria. As a result, a stable fermentation process can be designed which prevents the inhibition of the Cyanobacteria by the toxic ethanol.

MATERIALS AND METHODS

Cultivation of *Synechococcus elongatus PCC 7942*

Wildtype *Synechococcus elongatus PCC 7942* was used for fermentation to evaluate inline stripping process with added ethanol in different concentrations in a bubble column bioreactor. Pre culture was incubated in 100 mL Erlenmeyer flasks on 20 m LBG11 medium as described by CCAP (Culture Collection of Algae and Protozoa) for 48 hours. For agitation a Gerhard Laboshake THO 500 was used. Incubation conditions were 34 °C, 150 rpm at PAR of 100 μmol m^{-2} s^{-1}. Bubble column bioreactor was inoculated with 100 mL of preculture.

Fermentation: For fermentation a bubble column bioreactor was used (Fig. 1). The reactor consists of a circular glass tube, working vol. 1,000 mL to 1,300 mL (length 540 mm, diameter 60 mm). Temperature was adjusted to 24 °C, PAR was 100 μmol m^{-2} s^{-1}. The reactor was flushed with compressed, sterile filtered (0.2 μm, PA) air from the bottom. The flow rate V varied from 0.5 L^{-1} to 2.0 L^{-1}. Experimental conditions for the examination of stripping effects are shown in Table 1.

Stripping experiments

Ethanol stripped from the medium through flushing was cooled via a Dimroth condenser, connected to a Thermo Fisher Lauda 600 + 610 thermostat (Fig. 1). Temperature of cooling water was 5 °C. The production rate of ethanol by the modified *Synechococcus elongatus* can`t yet be predicted exactly at the actual state. In addition the ethanol in the system applied is not recovered completely as shown later (Fig. 5). So an exact mass balance is difficult to generate. Therefore a non ethanol producing wild type of *Synechococcus elongatus* was used an the fluid was spiked with ethanol of varying concentrations of 0.5, 1 and 2% v/v. Experimental conditions for the examination of ethanol stripping effects are shown in Table 1.

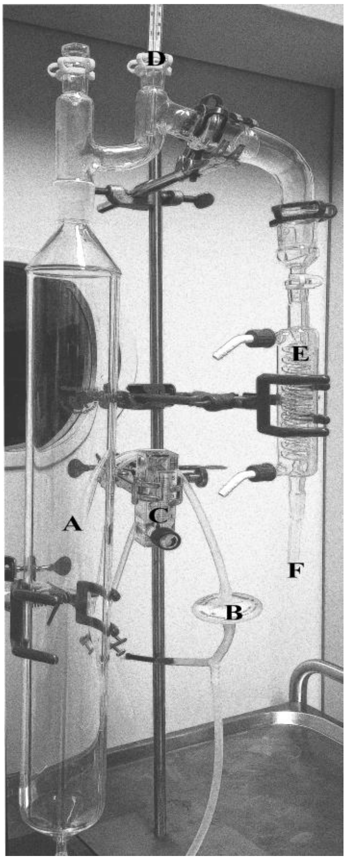

Figure 1. Bioreactor including inline ethanol stripping; A: bubble column reactor; B sterile filter disc for aeration; C: flow meter; D: thermometer; E: Dimroth condenser connected to Thermo Fisher Lauda FB 600+610; F condensate connected to volumetric device; (image post processed for better visualization).

Table 1. Experimental conditions for examination of ethanol stripping effects

Series	cEtOH at Start	Air Flow rate
1	2% v/v	2 L^{-1}
2	1% v/v	2 L^{-1}
3	0.5% v/v	2 L^{-1}
4	1% v/v	1 L^{-1}
5	1% v/v	0.5 L^{-1}

Ethanol Determination per HPLC

Ethanol concentration in the stripped condensate was determined by HPLC, using an Agilent Technologies 1200 Series connected via Agilent 35900 AD converter to a refractive index detector from Jasco (RI 2031plus). As chromatographic column a Varian Metacarb 87 H (length 300 mm, diameter 7.8 mm) at 65 °C was applied. Sulfuric acid (c = 5 mmol L^{-1}) as eluent with an isocratic flow rate of 0.8 mL min^{-1} was used. The injection volume was set to 80 µL. For calibration, the method of external standard was used in a range from 10 to 200 mg L^{-1} ethanol (VWR, p.a., < 99,9%). For low target concentrations between 5 and 10 mg L^{-1} of ethanol, the quantification was performed with the standard addition method. The data acquisition was performed per refractive index detection with the software Agilent Chemstation V 03.04 b.

RESULTS AND DISCUSSION

To evaluate the inline stripping process of ethanol in a bubble column bioreactor a cultivation of cyanobacteria Synechococcus elongatus PCC 7942 wildtype was performed. Different air flow rates and initial ethanol concentrations were used, the recovery rate of ethanol was determined.

Table 1 shows the experimental conditions for the different sets of experiments. Ethanol was added to the medium up to 2% (w/v) (Table 1), different air flow rates (between 0.5 and 2 L min^{-1}) were tested. These concentrations are much higher than actually reached with Synechococcus elongatus PCC 7942 (Pfannerer et al., 2016) but are regarded as a target which should be achievable with further genetic optimization of the strain. The process was monitored for 8 days:

In the first series of experiments a fixed air flow rate of 2 L^{-1} and ethanol concentrations of 0.5, 1 and 2% (v/v) were examined. The removal of ethanol increased exponentially by increased initial ethanol concentrations (Fig. 2). After 96 h of incubation ethanol was below 0.1% v/v ethanol for all three initial concentrations. The specific removal is not directly depending on the actual concentration of ethanol in the bioreactor. Therefor the method is working for any initial ethanol concentration.

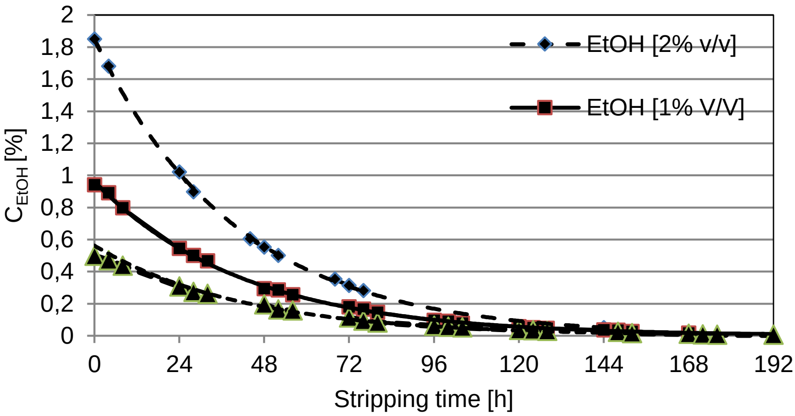

Figure 2. Ethanol removal from bioreactor in dependency on initial ethanol concentration. Conditions: air flow rate 2 L min^{-1}, Temp. bioreactor 24 °C, initial ethanol concentration 0.5%, 1%, 2%.

The specific ethanol removal rate (ethanol removed in g L^{-1} d^{-1}) from the reactor is shown in Fig. 3. The daily removal rate is about 10 g L^{-1} d^{-1} at ethanol concentrations of approximately 10 g L^{-1}. This corresponds to 0.4 g L^{-1} per hour. The important consequence of this finding is the fact that the ethanol production rate of the cyanobacteria may be 0.4 g L^{-1} per hour or lower if the ethanol concentration may not exceed this (possibly toxic) concentration (Dexter & Fu, 2009).

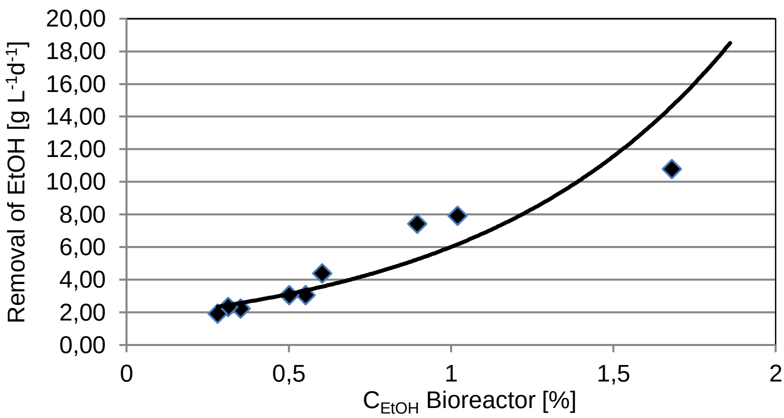

Figure 3. Specific **e**thanol removal rate dependent on actual ethanol concentration in the bioreactor. Conditions, airflow rate 2 L min^{-1}, temp. Bioreactor 24 °C, initial ethanol concentration 2%.

Fig. 4 shows the influence of different air flow conditions on the stripping of the ethanol. In all experiments the starting ethanol concentration was 1% ethanol (v/v). At an airflow rate of 2.0 L min^{-1} (which is definitely more than needed for the supply of Synechococcus elongatus PCC 7942 with carbons source and also higher than needed for turbulence in the bioreactor) the ethanol concentration fell below 0.3% (v/v) after 48 h of incubation and fell under 0.02% after 144 h. The ethanol removal at an air flow rate of 0.5 L min^{-1} is definitely too low to ensure not toxic effects of ethanol produced by a high productive strain of Synechococcus elongatus PCC 7942. An ideal air flow rate have to be fitted to the ethanol productivity of the engineered strain and its sensitivity against the end product ethanol. Fig 4. shows respectively, ethanol production could be determined in any experiments using bubble column bioreactors.

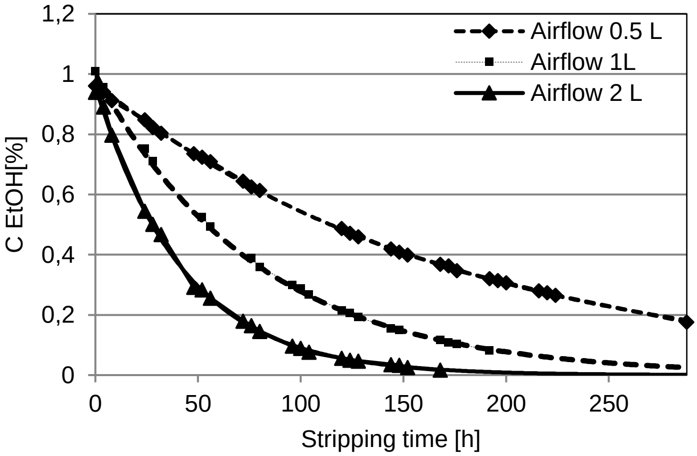

Figure 4. Ethanol concentration versus stripping time from bioreactor. Conditions, airflow rate 0.5, 1, 2 L min^{-1}, Temp. bioreactor 24 °C, initial ethanol concentration 1%.

CONCLUSIONS

Stripping of ethanol constantly throughout the fermentation process using bubble column bioreactors is a suitable and certainly cost effective technique for the separation of ethanol produced by cyanobacteria. More than 97% can be removed ad moderate volumetric air flow rates which are anyway needed for a bubble column bioreactor. So the end product inhibition of a high productive engineered strain by the ethanol is avoided. A challenge which has to be solved is the modest recovery rate of the ethanol. The stripped ethanol was collected via low temperature condensation. Experiments were performed with variation of flow rate and ethanol concentration. Elimination rates of 97–98% were reached with initial ethanol concentrations of 20 g L^{-1} respectively 10 g L^{-1}. The daily removal rate of about 10 g L^{-1} d^{-1} at ethanol concentrations 1% and of 20 g L^{-1} d at ethanol concentrations 2% ethanol (v/v) should be high enough for state of the art ethanol concentrations (Woods et al., 2012). The important consequence of this finding is the fact that the ethanol production rate of the cyanobacteria can reach 0.4–0.8 g L^{-1} per hour without reaching an inhibiting ethanol concentration. A major finding is that aerated column reactors are not all suitable for kinetic studies of biological ethanol production.

The experiments show a further and very important consequence. If laboratory and pilot scale fermentations for the production of ethanol in bubble column reactors are carried out, the measurement of the ethanol concentration within the medium is more or less useless, because the ethanol produced is stripped out. A possibly low production will be faked. To circumvent the problem the measurement of the ethanol stripped in the air flow (for example by means of IR detection) is obligatory. In experiments with agitated flasks the amount of ethanol produced must be examined in the head space.

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REFERENCES

Amenaghawon, N.A. 2010. Evaluation of Ethanol Stripping from Fermenters. Master *Thesis Imperial College London.* Department for Chemical Engineering and Chemical Technology accessed 17.1.2017.

CCAP (Culture Collection of Algae and Protozoa), Dunstaffnage Marine Laboratory, Oban, Argyll, PA37 1QA, UK *https://www.ccap.ac.uk/media/documents/BG11.pdf*. accessed 18.1.2017.

Novozymes. 2013. Crescentino biofuel facility *http://www.novozymes.com/en/news/image/crescentino-grand-opening* accessed 24.3.2017.

ICLEI Local Governments for sustainability 2016. The Paris Climate Package: A Basic Guide for Local and Subnational Governments *http://e-lib.iclei.org/wp-content/uploads/2016/05/COP21-Report-web.pdf* accessed 18.1.2017.

de Farias Silva, E.C. & Bertucco, A. 2016. In Bioethanol from microalgae and cyanobacteria. A review and technological outlook. *Process Biochemistry* **51**(11), 1833–1842. DOI: 10.1016/j.procbio.2016.02.016.

Dexter, J., Armshaw, P. & Sheahan, C. 2015 The state of autotrophic ethanol production in Cyanobacteria. *Journal of Applied Microbiology* **119**(1),11–24.

Dexter, J. & Fu, P. 2009 Metabolic engineering of cyanobacteria for ethanol production 2857–864 *Energy & Environmental Science* **2**, 857–864.

Gao, Z., Zhao, H., Li, Z., Tana, X. & Lu, X. 2012. Photosynthetic production of ethanol from carbon dioxide in genetically engineered cyanobacteria. *Energy Environ. Sci.* **5**, 12.

Gnansounou, E., 2010. In Production and use of lignocellulosic bioethanol in Europe: Current situation and perspectives. *Bio resource Technology* **101**, 4842–4850.

Hwai-Shen, L. & Hsien-Wen, H. 1990. Analysis of gas stripping during ethanol fermentation – I. In a continuous stirred tank reactor. *Chemical Engineering Science* Volume **45**(5), 1289–1299.

Hwai-Shen, L. & Hsien-Wen, H. 1991. In Analysis of gas stripping during ethanol fermentation-II. A combined product-substrate inhibition case *Chemical Engineering Science* **46**(10), 2551–2565.

Kahr, H., Wimberger, J., Schürz, D. & Jäger, A. 2013. Evaluation of the Biomass Potential for the Production of Lignocellulosic Bioethanol from Various Agricultural Residues in Austria and Worldwide. *Energy Procedia* **40**(20), 146–155.

Pfannerer, F., Krennhuber, K., Jäger, A. & Kahr, H. 2016. New Constructs for ethanol production via Cyanobacteria. *Agronomy Research* **14**(1), 174–180.

Nozzi, N., Oliver, J. & Atsumi, S. 2013. In Cyanobacteria as a Platform for Biofuel Production. *Front Bioeng Biotechnol.* 1: 7. *https://doi.org/10.3389/fbioe.2013.00007 accessed 13.1.2017*.

C.R. Silva, C., Esperança, M., Cruz, A., Moura, L. & Badino, A. 2015. Stripping of ethanol with CO2 in bubble columns: Effects of operating conditions and modelling. *Chemical Engineering Research and Design* **102**, 150–160.

Savvanidou, E., Zervas, E. & Tsagarakis, K.P. 2010. In Public acceptance of biofuels. *Energy Policy* **38**, 3482–3488.

The European parliament and the council of the European Union 2015. Derective (EU) 2015/1513 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL *Official Journal of the European Union.*

Woods, P., Kramer, D. & Chance, R. 2012. In The Algenol DIRECT TO ETHANOL® Process *https://energy.gov/sites/prod/files/2015/07/f24/chance_bioenergy_2015.pdf* accessed 18.1.2017.

Yan, N., Fan, C., Chen, Y. & Hu, Z. 2016. The Potential for Microalgae as Bioreactors to Produce Pharmaceuticals. *International journal of molecular sciences* **17**(6), 1–24, 962; doi:10.3390/ijms17060962.

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Effect of different air velocities on convective thin-layer drying of alfalfa for livestock feeding

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Abstract. Alfalfa (*Medicago sativa*) is widely used as forage which has very high feeding value. The aim of this paper is to inform about the experimental and theoretical investigations of alfalfa drying in thin layer. Special device for convection drying with air flow passing through material from bottom through supporting trays with sieve by constant temperature was used for drying when air velocity was 0.7 m s^{-1}, 1 m s^{-1}, 1.2 m s^{-1} and 2.0 m s^{-1}. The results were compared with natural convection drying by the same temperature, but with the 0 m s^{-1} air velocity. The increased air velocity for convection influenced drying process positively. The results show that the differences between the drying with air velocities 1.2 m s^{-1} and 2 m s^{-1} are very small, therefore 1.2 m s^{-1} could be realised as an optimum. The evaluation of measurement results was focused on curves of drying rate, changes in water content and changes of moisture depending on the time and their mutual relations. Experimental data create the background for calculation of main parameters useful for description and modelling of the drying process, which can be helpful e.g. for decision of optimum drying time. Drying alfalfa for hay by forced convection shortened the drying time as compared with natural convection two and a half times. Drying alfalfa for haylage by forced convection shortened the drying time as compared with natural convection even four times.

Key words: air, drying time, forced drying, moisture, natural drying.

INTRODUCTION

Alfalfa (*Medicago sativa*) is used because of its high protein content and highly digestible fibre for high-producing dairy cows, beef cattle, horses, sheep, and goats. Alfalfa is most often harvested and conserved as hay, but can also be made into haylage or silage. The differences are according to the moisture (dry matter DM content).

DM is one of fundamental characteristics in conservation of alfalfa (Bebb, 1990; Maloun, 2001). The DM content in fresh plants varies depending on the weather and on phenophases (age) in a wide range from 11 to 25%. At the younger vegetation DM content of alfalfa is lower, which requires long drying, but there is also a lower fibre content and improved digestibility of forage. During the conservation it is necessary to increase the amount of dry matter at least 35% (preferably 40%) for the production of silage (suitable technological process using horizontal or tower silos).

For the production of haylage (silage with higher DM) it is necessary to increase DM content to 45% (in horizontal or tower silos), for production of round bale wrapped in foil to DM content from 45 to 65%. DM content of 75–85% allows storage of forage in round bales without using the packaging film (under shelter) or in hayloft for longer periods. In the production of uncoated hay bales it is needed to prevent mould growth by increased DM content at least to 75%.

For the production of quality hay should be achieved DM 75–85%, which requires drying time 2–4 days of favourable weather. High-quality alfalfa hay should be green, soft to the touch, with a high proportion of leaves, smelling well and without admixtures. Moisture level should not be higher than 15%.

Drying time and temperature together with the moisture influences the quality of the final dry fodder. Low temperatures have positive influence on quality of biological materials, but require longer processing time. There are many different applications of drying for the agricultural (Jokiniemi et al., 2012; Aboltins & Palabinskis, 2013; Jokiniemi et al., 2014) purposes. Problems of natural drying applied to drying of special plants are solved also in some scientific publications, e.g. (Aboltins & Kic, 2016).

The increased air velocity for convection or suitable material preparation can influence the drying process positively. But too high air velocity, needed to accelerate the drying process, can cause problems with losses of light particles particularly at the final stage of drying when forage has low water content and thus low density of small particles. In practice, sometimes DM is not sufficient in the production or storage of hay, haylage or silage, or on the contrary, DM is too high which can cause higher losses of fodder. DM is an important determinant of intake by animals (Pond & Pond, 2000). The attention of alfalfa drying under artificial conditions is paid in different scientific publications, e.g. (Adapa et al., 2004; Osorno & Hensel, 2012).

The aim of this work is to bring some new experimental and theoretical investigations of alfalfa drying by forced convection with air flows of different air velocities going from bottom through trays with layer of fodder up.

MATERIALS AND METHODS

The laboratory measurements were carried out at the Faculty of Engineering CULS Prague during summer weather conditions in August. The technical equipment used for the experiments was forced convection system of own design (Fig. 1) (Kic & Liska, 2012; Kic & Aboltins, 2013), which consists of four vertical drying chambers.

Each of the drying chambers – a space in which was placed perforated tray with sample – allows independent measurements during drying at different flow rates of drying air. The airflow delivered by fan of 120 mm diameter is controlled by fan revolutions.

To research the drying kinetics, alfalfa samples which were cut up into a particle length from 2 to 5 cm, were placed in a thin layer about 50 mm on sieve tray with mesh 3 x 4 mm of total area approximately 20,400 mm^2. Initial weight of one sample on one tray was approximately 120 g. The forced drying was with air velocity in drying chambers 0.7 $m\ s^{-1}$, 1 $m\ s^{-1}$, 1.2 $m\ s^{-1}$ and 2.0 $m\ s^{-1}$. The results were compared with natural convection drying by the same temperature, but with the 0 $m\ s^{-1}$ air velocity.

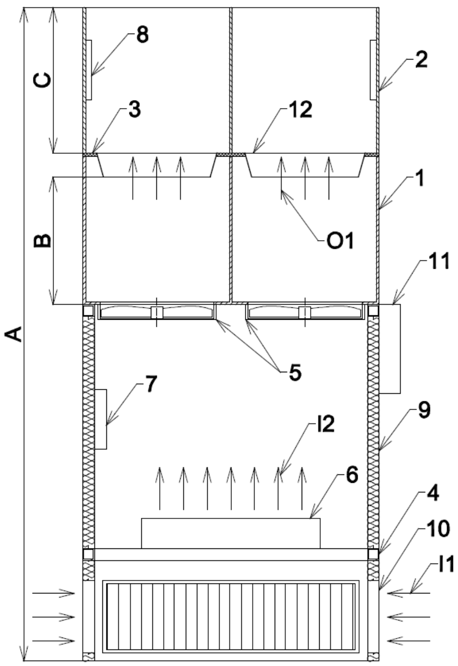

Figure 1. Apparatus used for alfalfa drying: 1 – lower drying chamber; 2 – upper drying chamber; 3 – underlay; 4 – structure; 5 – fans; 6 – air heating; 7 – sensors; 8 – sensors; 9 – thermal insulation; 10 – inlet air; 11 – control panel; 12 – perforated tray with measured alfalfa; I1 – inlet of fresh air; O1 – air passing through perforated tray with measured alfalfa; A – overall height, B – height of the lower chamber; C – height of the upper chamber.

Air speed was measured by anemometer CFM 8901 Master with resolution 0.01 m s^{-1} and accuracy ± 2% of final value. Air temperature and humidity was measured by the sensor FHA646-E1C connected to the data logger ALMEMO 2690-8. The average temperature of drying air was 27 ± 0.6 °C and relative humidity 49 ± 1.8%.

The moisture content in the alfalfa samples was identified by gravimetric measurement in regular time intervals. Samples were weighed during the drying on the digital laboratory balance KERN-440-35N with maximum load weight 400 g and with resolution 0.01 g and values were recorded. Each measuring tray was weighed during the first 1 hour every 15 min, later during the next 2.5 hours every 30 min and after that every 60 min. The total drying time 144 h was adapted to the need for a determination of lowest moisture content, which can be achieved by convective drying. An example of alfalfa samples before and after forced drying is on the Fig. 2.

Figure 2. Alfalfa samples on sieve tray before (left) and after (right) drying by forced convection.

The DM content in alfalfa samples was identified by gravimetric measurement using an MEMERT UNB-200 air oven under temperature 105 °C. Samples were weighed on a Kern 440-35N laboratory balance in regular time intervals. The total drying time was adapted to the need for a determination of the equilibrium moisture.

The following main parameters are calculated from the measured values of all alfalfa samples. Water content u is defined as the ration of the weight of water m_W contained in a solid to the weight of dry solid m_S, expressed in the equation (1):

$$u = \frac{m_W}{m_S} \tag{1}$$

where: u – water content, g g^{-1}; m_W – weight of water, g; m_S – weight of dry matter, g.

Moisture w is the ratio of the weight of water m_W contained in a solid to the mass of the humid solid $m = m_S + m_W$, expressed in the equation (2):

$$w = \frac{m_W}{m} 100 \tag{2}$$

where: w – moisture, %.

Changes of water content du during the time difference dt describe the drying rate N expressed in the equation (3):

$$N = \frac{du}{dt} \tag{3}$$

where: N – drying rate, g $g^{-1}min^{-1}$; t – time, min.

The obtained results of drying rate N were processed by Excel software and some suitable parameters have been verified by statistical software Statistica 12 (*ANOVA* and *TUKEY HSD Test*).

Different superscript letters (a, b) mean values in common are significantly different from each other in the rows of the tables (*ANOVA; Tukey HSD Test; $P \leq 0.05$*), e.g. if there are the same superscript letters in all the rows it means the differences between the values are not statistically significant at the significance level of 0.05.

RESULTS AND DISCUSSION

The kinetics of alfalfa drying process caused by forced and natural convection with air velocities (0 m s^{-1}, 0.7 m s^{-1}, 1 m s^{-1}, 1.2 m $s^{-1}$and 2 m s^{-1}) is described by the curves calculated according to the equations (1), (2) and (3) in the Figs 3–8. The whole convection drying time 144 h was sufficient to the maximal drop of water content which can be achieved by convection of air temperature 27 °C and relative humidity 49%.

The Fig. 3 shows that all air velocities of forced drying including the smallest one (v = 0.7 m s^{-1}) in comparison with natural convection (v = 0 m s^{-1}) reduced the time of drying considerably. The small differences between the drying courses of forced drying with air velocities (0.7 m s^{-1}, 1 m s^{-1}, 1.2 m s^{-1}, 2 m s^{-1}) during the first 5 drying hours are more obvious if the curves are presented on the Fig. 4.

The course of moisture w during the first 100 h of convection drying is presented on the Fig. 5. The decrease of moisture is significantly slower in the case of natural convection (v = 0 m s^{-1}) than with forced convection. The differences between the drying courses of forced drying with air velocities (0.7 m s^{-1}, 1 m s^{-1}, 1.2 m s^{-1}, 2 m s^{-1}) are very small.

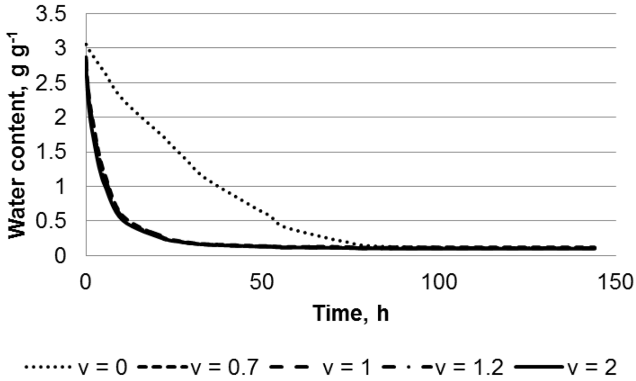

Figure 3. Water content u of all 5 alfalfa samples during 144 h of convection drying with air velocities 0 m s^{-1}, 0.7 m s^{-1}, 1 m s^{-1}, 1.2 m s^{-1} and 2 m s^{-1}.

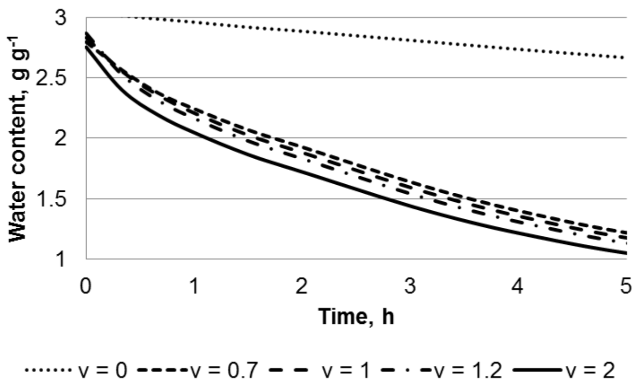

Figure 4. Water content u of all 5 alfalfa samples during the first 5 h of convection drying with air velocities 0 m s^{-1}, 0.7 m s^{-1}, 1 m s^{-1}, 1.2 m s^{-1} and 2 m s^{-1}.

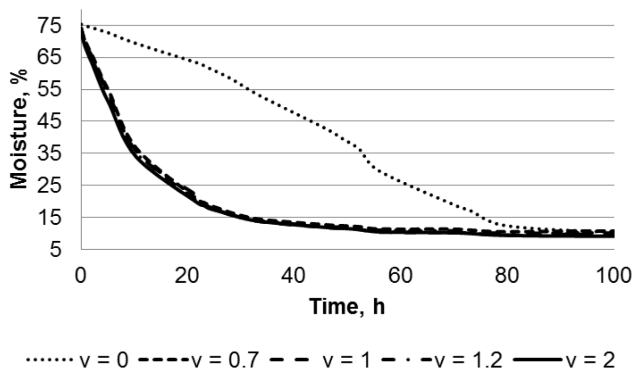

Figure 5. Moisture w of all 5 alfalfa samples during 100 h of convection drying with air velocities 0 m s^{-1}, 0.7 m s^{-1}, 1 m s^{-1}, 1.2 m s^{-1} and 2 m s^{-1}.

The course of drying rate N during the first 5 h of convection drying is presented on the Fig. 6. The highest drying rate of all 5 alfalfa samples is during the first hour. To see better the differences influenced by the air velocity, the drying rate only from the first 60 minutes is presented on the Fig. 7.

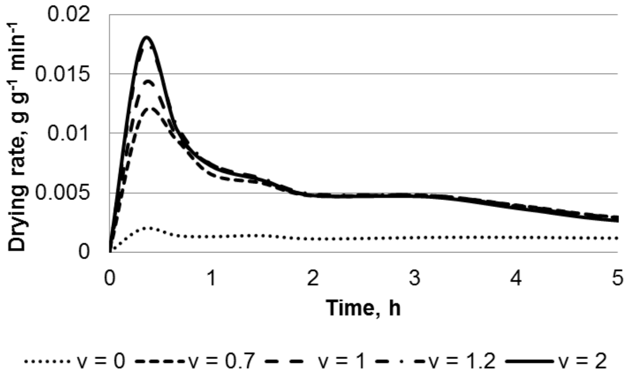

Figure 6. Drying rate N of all 5 alfalfa samples during 5 h of convection drying with air velocities 0 m s^{-1}, 0.7 m s^{-1}, 1 m s^{-1}, 1.2 m s^{-1} and 2 m s^{-1}.

The biggest drying rate was achieved during the first 30 min. According to the Fig. 7 the difference between the drying rate with air velocity 1.2 m s^{-1} (N = 0.0172 g g^{-1} min^{-1}) and 2 m s^{-1} (N = 0.0178 g $g^{-1}min^{-1}$) is rather small. It is obvious that the drying rate with natural convection (N = 0.0019 g $g^{-1}min^{-1}$) is very low also during the first hour.

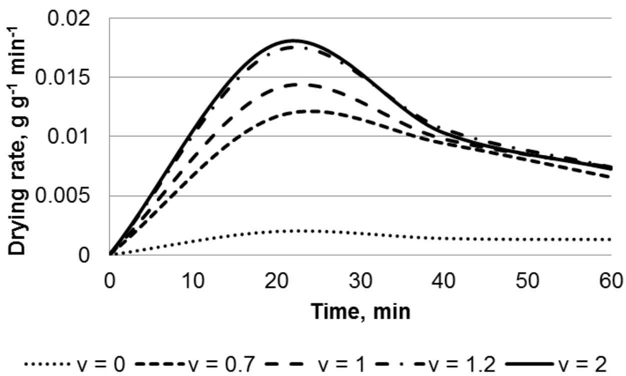

Figure 7. Drying rate N of all 5 alfalfa samples during 1 h of convection drying with air velocities 0 m s^{-1}, 0.7 m s^{-1}, 1 m s^{-1}, 1.2 m s^{-1} and 2 m s^{-1}.

Calculated results of drying rate N were evaluated statistically. The big difference between the initial drying rate during the first 30 minutes and subsequent drying phases strongly affects and distorts the results of mean values, standard deviations and statistical assessment of the mutual differences between them.

The results of the statistical evaluation of drying rate N during the first hour and 5 hours are presented in the Tab. 1. The positive effect of forced convection is obvious during the first hour of drying. The difference between the drying rate of natural convection (v = 0 m s^{-1}) and the other drying rates by forced convection is statistically significant.

Differences between the drying rates of two highest velocities (1.2 m s^{-1}, 2 m s^{-1}) and other drying rates are statistically significant during the first 5 hours of drying. According to the statistic evaluation of drying rates for longer time, the differences between all drying rates of all velocities in this respect are not statistically significant; therefore they are not presented in the Table 1.

Table 1. The drying rates N of all 5 alfalfa samples during 1 hour and 5 hours of convection drying with air velocities 0 m s^{-1}, 0.7 m s^{-1}, 1 m s^{-1}, 1.2 m s^{-1} and 2 m s^{-1}. Different letters (a, b) in the superscript are the sign of high significant difference (*ANOVA; Tukey HSD Test; $P \leq 0.05$*)

Air velocity	N (1 hour)	N (5 hours)
	g g min^{-3} ± SD	g g min^{-3} ± SD
v = 0 m s^{-1}	0.0014 ± 0.0004^{a}	0.0014 ± 0.0002^{a}
v = 0.7 m s^{-1}	0.009 ± 0.002^{b}	0.0062 ± 0.002^{a}
v = 1 m s^{-1}	0.01 ± 0.002^{b}	0.0068 ± 0.003^{a}
v = 1.2 m s^{-1}	0.012 ± 0.004^{b}	0.007 ± 0.003^{b}
v = 2 m s^{-1}	0.012 ± 0.004^{b}	0.007 ± 0.004^{b}

SD – Standard deviation.

Rather interesting is the dependence of drying rate N on water content u presented in the Fig. 8, describing both very important parameters of drying process. The best relation between the drying rate and water content is achieved if the water content is high and with higher air velocity of forced drying. The difference between the drying with air velocities 1.2 m s^{-1} and 2 m s^{-1} is rather small.

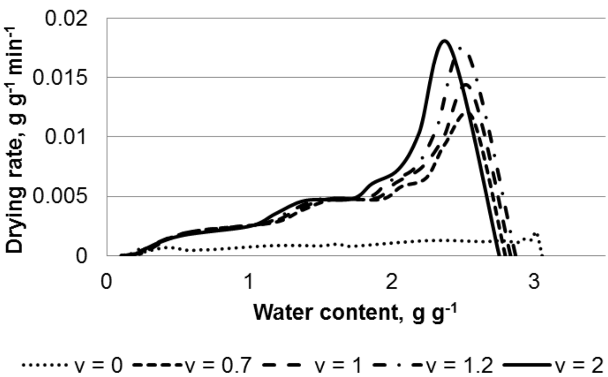

Figure 8. Drying rate N of all 5 alfalfa samples as a function of water content u during convection drying with air velocities 0 m s^{-1}, 0.7 m s^{-1}, 1 m s^{-1}, 1.2 m s^{-1} and 2 m s^{-1}.

From a practical perspective, it is possible determine from the measured and calculated results that to achieve relative humidity 15% (appropriate for hay) by forced convection drying of alfalfa in air of 27 °C the drying time is about 30 h. The achievement of these parameters by forced convection is in all cases of tested air flow velocities. In the case of natural convection with zero velocity it would be required drying time approximately 75 h.

To achieve relative humidity 55%, which corresponds to a request for storage in the form of alfalfa haylage (DM 45%), it is sufficient 8 hours of drying by forced convection; in the case of drying by natural convection with zero velocity it would require 30 h.

CONCLUSIONS

This research is useful for verification of influence of different air velocities on the drying process of alfalfa in thin layer.

It has been found that the forced convection has a strong and positive influence on drying time in comparison with free drying by natural convection. The differences between the results of drying with air velocities 1.2 m s^{-1} and 2 m s^{-1} are very small, therefore 1.2 m s^{-1} could be realised as an optimum. Higher air velocity could cause losses of small dry particles especially at the end of drying process.

In order to achieve the suitable moisture of alfalfa for different conservation applications with economic benefits, the optimization of drying time should be provided and respected.

Future research in this area of research should be focused on the study of other factors influencing the drying process especially in different air temperatures, partly described and expressed by drying coefficient.

REFERENCES

Aboltins, A. & Palabinskis, J. 2013. New types of air heating solar collectors and their use in drying agricultural products. *Agronomy Research* **11**, 267–274.

Aboltins, A. & Kic, P. 2016. Research of some medical plants drying process. In: *15th International Scientific Conference Engineering for Rural Development*. Latvia University of Agriculture, Jelgava, pp. 1145–1150.

Adapa, P.K., Schoenau, G.J. & Arinze, E.A. 2004. Fractionation of alfalfa into leaves and stemps using a three pass rotary drum dryer. *Biosystems Engineering* **91**, 455–463.

Bebb, D.L. 1990. *Mechanised livestock feeding*. BSP professional books, Oxford, 209 pp.

Jokiniemi, T., Mikkola, H., Rossner, H., Talgre, L., Lauringson, E., Hovi, M. & Ahokas, J. 2012. Energy savings in plant production. *Agronomy Research* **10**, 85–96.

Jokiniemi, T., Jaakkola, S., Turunen, M. & Ahokas, J. 2014. Energy consumption in different grain preservation methods. *Agronomy Research* **12**, 81–94.

Kic, P. & Liska, R. 2012. *Apparatus for drying loose or bulk materials.* Utility model No. 23841. Industrial property Office, Prague, 5 pp. (In Czech)

Kic, P. & Aboltins, A. 2013. Convective drying of poultry manure by different air speeds. In Vartukapteinis, K.: *12th International Scientific Conference Engineering for Rural Development*. Latvia University of Agriculture, Jelgava, pp. 121–125.

Maloun, J. 2001. *Technological equipment and main processes in the production of fodder*. CULS, Faculty of Engineering, Prague, 201 pp. (In Czech)

Osorno, F.L. & Hensel, O. 2012. Drying homogeneity of grass mixture components in a rotary drum. *Drying Technology* **30**, 1931–1935.

Pond, W.G. & Pond, K.R. 2000. *Introduction to animal science*. John Wiley & sons, inc. New York, 687 pp.

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Influence of air-conditioning on dust level in drivers' cabin during the harvest of grain

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Abstract. The period of grain harvest is characterized by dry and hot summer weather. During the grain harvest is generated large amount of dust which significantly influences surroundings, but mainly drivers are exposed to dust pollution. The aim of this paper is to present results of microclimatic research focused on dust pollution in drivers' cabin of tractors and combine harvesters of different construction used for harvest of grain. The machinery selected for this research includes the old but also very modern tractors and combine harvesters which are equipped with air conditioning. In the frame of this research the concentration of air dust was measured by exact instrument DustTRAK II Model 8530 aerosol monitor. Using the special impactors the PM_1, $PM_{2.5}$, PM_4, PM_{10} size fractions were also measured. Obtained results of measurements were evaluated and concentrations of different size of dust particles were analysed. Results of different indoor conditions measured in new and old machinery are generalized.

Key words: combine harvesters, grain dust, indoor of cab, measurement, tractors.

INTRODUCTION

Dust level is one of the factors that affect the global environment in which people, animals and plants spend entire life. The protection of people against high dust levels is solved mainly in terms of working conditions in mines, quarries, factories, workshops, transport systems and other workplaces where is the technological dust is produced. The problems of dust pollution is studied many scientific articles and papers.

The attention to dust is paid in many research works, e.g. Skulberg et al. (2004), Bouillard et al. (2005), Mølhave (2008), Boac et al. (2009), Mølhave et al. (2009), Buchholz et al. (2011), Nõu & Viljasoo (2011), Eherlich et al. (2013), Traumann et al. (2013), Traumann et al. (2014), Kic (2015), Kic (2016). The methodology and the results of measurements correspond to the research topic, especially to factors that are specific to studied space. There are studied e.g. the impact of outdoor particulates transferred into the indoor space, the impact of processed and handled material, the influence of floor surface, the influence of sports equipment, particles released from special plastic materials used indoor, dust produced in animal farms etc.

In agriculture, there is among other environmental problems a large amount of organic dust during the grain harvest and by handling in storing, cleaning, processing and packaging. The aim of this paper is to show the results of measurements of dust during the harvest of grain. Concentration of dust was measured outdoors near the fields where it was harvested grain by combine harvesters and where tractors were driving around. It has also been measured directly in the driving cabs of tractors and harvesters.

Problems of drivers comfort are one of very important factors to which producers of different vehicles pay attention. Microclimate composition rate is an important index factor affecting contentment of drivers in the cabin. Some publication have shown the effects of inappropriate working conditions on fatigue, which significantly applies to prolonged driver's working hours mainly to professionals. A suitable microclimate is necessary and the systems must ensure as it is one of the most important safety features of the vehicles (Zewdie & Kic, 2015; Zewdie & Kic, 2016a; Zewdie & Kic, 2016b; Zewdie & Kic, 2016c).

MATERIALS AND METHODS

This research work and measurements were carried out in agricultural company situated in the south part of Czech Republic. For research measurements were chosen harvesters and tractors, which differ in equipment for ventilation and air conditioning.

The combine harvester Fortschritt E 517 (CH1) is outgoing but still at use; the combine harvester which is not air-conditioned, but equipped with forced ventilation creating overpressure in the cabin and with filtration of the inlet air. It is compared with a modern combine harvester Massey Ferguson MF BETA Paralel (CH2), equipped with comfort air-conditioner (AC).

The tractor Zetor 7045 (TR1) is an old Czech brand, but still widely used in the country. Ventilation is only through opened windows during the summer. It is compared with a modern tractor Case (TR2), equipped with comfort AC.

According to the type of material, dust has specific characteristics to which respond the properties. According to Act Government Regulation No. 361/2007 Coll. the type of dust produced by the cereals has irritating effects (grain and straw). For this type of dust the prescribed Occupational Exposure Limits (OEL) is permissible exposure limit of total grain and straw dust concentrations 6,000 $\mu g\ m^{-3}$.

Measured dust is not aggressive, therefore, as a criterion for comparative evaluation of the measured values can be also used the limit level of outdoor dust. According to the Air Protection Act No. 201/2012 PM_{10} limit value in 24 hours is 50 $\mu g\ m^{-3}$, 1 year limit value is 40 $\mu g\ m^{-3}$ and 1 year limit value $PM_{2.5}$ is 25 $\mu g\ m^{-3}$. The 90 data of dust concentration for total dust as well as of each fraction size in each measured place were collected.

RESULTS AND DISCUSSION

Principal results of dust measurement are summarized and presented in the Tables 1–3 and Figs 1–4. Table 1 shows the results of dust measurement of external environment at a distances D1 = 400–600 m, D2 = 200–400 m, D3 = 20–40 m from working combines, and at a distance of D4 = 10 m of hayloft, where straw is stored in big bales.

The results indicate that the OEL values of 6,000 $\mu g\ m^{-3}$ were never exceeded. Far away from the harvest place in distances D1 and D2 the limits applicable to the external environment were not exceeded. Near the harvesters in distance D3 the values of PM_{10} and $PM_{2.5}$ were sometimes slightly exceeded. The highest concentrations of dust were measured near the storage of straw D4. The measured total concentration of dust was very high and also measurement $PM_{2.5}$ exceeded the limit value of 25 μg m^{-3}.

Table 1. Total dust concentration and concentration of dust fractions PM_{10}, PM_4, $PM_{2.5}$ and PM_1 in in external conditions at distances D1, D2, D3 and D4

Place	Total	PM_{10}	PM_4	$PM_{2.5}$	PM_1
	μg m^{-3} ± SD	μg m^{-3} ± SD	μg m^{-3} ± SD	μg m^{-3} ± SD	μg m^{-3} ± SD
D1	20.6 ± 7.9	20.3 ± 9.0	14.6 ± 3.5	14.5 ± 3.9	13.4 ± 2.6
D2	29.4 ± 8.0	29.1 ± 7.4	24.2 ± 1.1	22.6 ± 1.0	20.9 ± 0.4
D3	51.1 ± 46.3	50.4 ± 47	37.3 ± 22.4	24.3 ± 10.2	12.5 ± 2.4
D4	238.5 ± 213.3	42.3 ± 8.0	33.8 ± 1.1	33.0 ± 1.8	32.5 ± 2.7

SD – Standard deviation.

The Fig. 1 presents graph of a size distribution of dust particles in outside air. The main parts (65%) of dust in the external air in distance D1 are the particles smaller than 1 μm (PM_1) and 28% are the particles bigger than 4 μm and smaller than 10 μm. The air contains the biggest dust particles in very low percentage (1% of the particles bigger than 10 μm). The situation in the external air in distance D2 is very similar, PM_1 is 71% and 17% are particles bigger than 4 μm and smaller than 10 μm. The air contains the biggest dust particles in very low percentage (1% of the particles bigger than 10 μm).

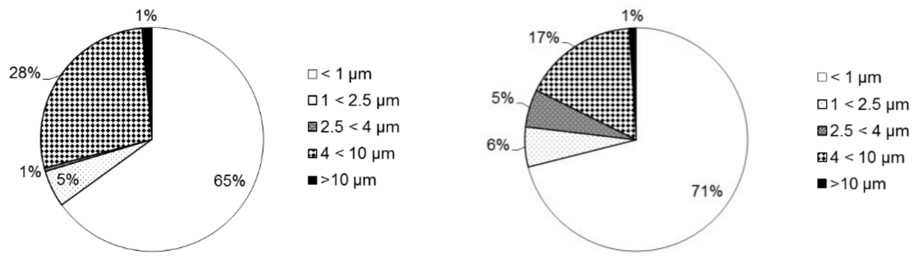

Figure 1. Percentage of dust fractions in the outside air in distances D1 (left) and D2 (right).

The Fig. 2 presents graph of the size distribution of dust particles in outside air in distances D3 and D4. The size distribution of dust in the external air in distance D3 is rather uniform, only the content of the biggest dust particles in very low (1% of the particles bigger than 10 μm). The situation in the external air in distance D4 is very different. There are 82% of the biggest dust particles and 14% the smallest PM_1.

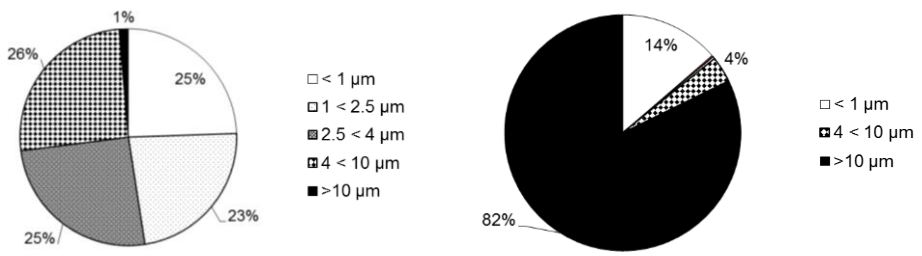

Figure 2. Percentage of dust fractions in the outside air in distances D3 (left) and D4 (right).

The results of measurement show that the eternal air in big distances from the fields with combine harvesters and tractors contains mainly small dust particles and the highest concentration of big dust particles is near to the source of pollution (D4).

Table 2 shows the results of measurement in the cabins of combine harvesters CH1 (E 517) and CH2 (Massey Ferguson). Results show a significant effect of air filtration in ventilation and air conditioning on clean air in the cab. The limit values for PM_{10} or $PM_{2.5}$ were never exceeded. Both combine harvesters have ventilation with forced air supply and pressure filtration. The results showed that the total dust level in the new modern harvester CH2 was approximately 6 times lower than in the older combine CH1 without air-conditioning. There are not smallest particles PM_1 in CH2.

Table 2. Total dust concentration and concentration of dust fractions PM_{10}, PM_4, $PM_{2.5}$ and PM_1 in cabins of combine harvesters CH1 a CH2 (AC)

Place	Total	PM_{10}	PM_4	$PM_{2.5}$	PM_1
	$\mu g\ m^{-3} \pm SD$	$\mu g\ m^{-3} \pm SD$	$\mu g\ m^{-3} \pm SD$	$\mu g\ m^{-3} \pm SD$	$\mu g\ m^{-3} \pm SD$
CH1	22.4 ± 8.3	22.3 ± 7.2	15.3 ± 2.7	11.9 ± 1.9	8. 8 ± 2.4
CH2	5.1 ± 2.9	2.6 ± 1.3	2.2 ± 1.7	2.0 ± 0.6	0 ± 0

SD – Standard deviation.

The Fig. 3 presents the graph of the size distribution of dust particles inside the cabins of combine harvesters. Dust in CH1 without AC contains main parts (39%) of dust the particles smaller than 1 μm (size fraction PM_1) and 31% are the particles bigger than 4 μm and smaller than 10 μm. The air in CH2 with AC contains 49% of the particles bigger than 10 μm and 39% bigger than 1 μm and smaller than 2.5 μm.

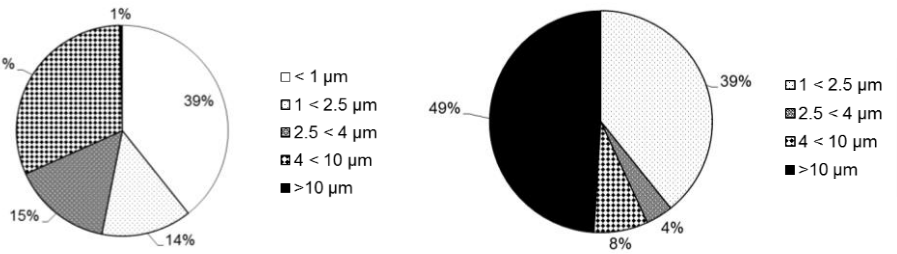

Figure 3. Percentage of dust fractions in the cabins of combine harvesters CH1 (left) and CH2 (AC) (right).

Table 3 shows the results of measurements in the driving cabs of tractors TR1 (Zetor 7045) and TR2 (CASE). The results show a very strong influence of air filtration on air purity. The internal environment of the tractor TR1 has been improved only by ventilation through open windows. The dust concentration was therefore very high and has exceeded the limit values for external environment PM_{10} and $PM_{2.5}$. Concentration of dust inside the tractor TR2 (CASE) equipped with AC with air filtration was very low.

Table 3. Total dust concentration and concentration of dust fractions PM_{10}, PM_4, $PM_{2.5}$ and PM_1 in cabins of tractors TR1 a TR2 (AC)

Place	Total	PM_{10}	PM_4	$PM_{2.5}$	PM_1
	$\mu g\ m^{-3} \pm SD$	$\mu g\ m^{-3} \pm SD$	$\mu g\ m^{-3} \pm SD$	$\mu g\ m^{-3} \pm SD$	$\mu g\ m^{-3} \pm SD$
TR1	282.4 ± 233.0	243.9 ± 171.2	64.4 ± 11.8	62.5 ± 7.4	62.2 ± 20.6
TR2	34.5 ± 14.5	9.2 ± 0.7	9.2 ± 0.6	9.1 ± 0.5	8.1 ± 0.2

SD – Standard deviation.

The Fig. 4 presents the graph of the distribution of dust size of particles inside the cabins of tractors. Dust in TR1 without AC contains 22% of dust particles smaller than 1 µm (size fraction PM_1) and 63% are the particles bigger than 4 µm and smaller than 10 µm. 14% are the particle bigger than 10 µm. Air in TR2 with AC contains 73% of the particles bigger than 10 µm and 24% smaller than 1 µm.

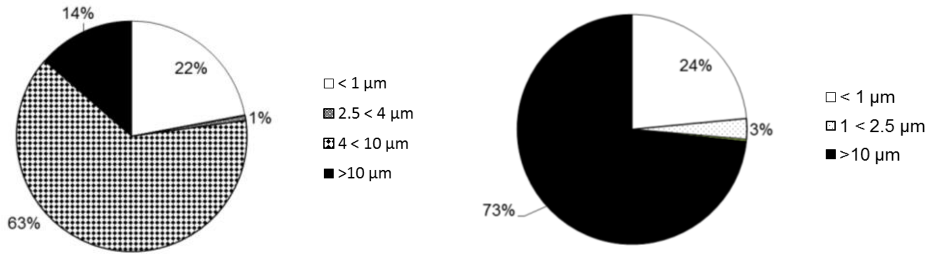

Figure 4. Percentage of dust fractions in the cabins of tractors TR1 (left) and TR2 (AC) (right).

CONCLUSIONS

The results of dust measurements have shown that the work and function of machines and manipulation with cereals during the harvest of grain and straw significantly increased the concentration of dust pollution near the source of the dust (harvesting, handling and transportation). Very high level of total dust concentration and also high concentrations of dust fractions is dangerous for the human health, mainly because of a lot of allergens. Dust concentration decreases with increasing distance from the place of harvest. The spread of dust into the environment is greatly influenced by wind speed and direction.

The created overpressure in driving cabins equipped with a pressurisation system and a dust filtration of all supplied fresh air has a positive impact on the indoor environment in driving cabs of tractors and combine harvesters, which is reflected especially in today's modern harvesters and tractors. The purity of the air in terms of dust in them is lower than inside other conventional indoor spaces as dwellings, schools and similar buildings.

REFERENCES

Act Government Regulation No. 361/2007 Coll. Laying down the conditions for the protection of health at work. Changes: 9/2013 Coll. (in Czech).

Act No. 201/2012 Coll. Air Protection Act. (in Czech).

Boac, J.M., Maghirang, R.G., Casada, M.E., Wilson, J.D. & Jung, Y.S. 2009. Size distribution and rate of dust generated during grain elevator handling. *Applied Engineering in Agriculture* **25**(4), 533–541.

Bouillard, L., Michel, O., Dramaix, M. & Devleeschouwer, M. 2005. Bacterial contamination of indoor air, surafaces, and settled dust, and related dust endotoxin concentrations in healthy office builgings. *Ann. Agric. Environ. Med*. **12**, 187–192.

Buchholz, S., Krein, A., Junk, J., Gutleb, A.C., Pfister, L. & Hoffmann, L. 2011. Modelling, measuring, and characterizing airborne particles: Case studies from southwestern Luxembourg. *Critical reviews in environmental science and technology* **41**(23), 2077–2096.

Ehrlich, C., Noll, G., Wusterhausen, E., Kalkoff, W.D., Remus, R. & Lehmann, C. 2013. Respirabile Crystalline Silica (RCS) emissions from industrial plants – Results from measurements programmes in Germany. *Atmospheric Environment* **68**, 278–285.

Kic, P. 2015. Dust pollution in university offices. *Agronomy Research* **13**(3), 759–764.

Kic, P. 2016. Microclimatic conditions in the poultry houses. *Agronomy Research* **14**(1), 82–90.

Mølhave, L. 2008. Inflammatory and allergic responses to airborne office dust in five human provocation experiments. *Indoor air* **18**(4), 261–270.

Mølhave, L., Pan, Z., Kjærgaard, S.K., Bønløkke, J.H., Juto, J., Andersson, K., Stridh, G., Löfstedt, H., Bodin, L. & Sigsgaard, T. 2009. Effects on human eyes caused by experimental exposures to office dust with and without addition of aldehydes or glucan. *Indoor air* **19**(1), 68–74.

Nõu, T. & Viljasoo, V. 2011. The effect of heating systems on dust, an indoor climate factor. *Agronomy Research* **9**(1), 165–174.

Skulberg, K., Skyberg, K., Kruse, K., Eduard, W., Djupesland, P., Levy, F. & Kjuus, H. 2004. The effect of cleaning on dust and the health of office workers: an intervention study. *Epidemiology* **15**(1), 71–78.

Traumann, A., Reinhold, K. & Tint, P. 2013. The model for assessment of health risks of dust connected with wood manufacturing in Estonia. *Agronomy Research* **11**(2), 471–478.

Traumann, A., Kritsevskaja, M., Tint, P. & Klauson, D. 2014. Air quality as an important indicator for ergonomic offices and school premises. *Agronomy Research* **12**(3), 925–934.

Zewdie, R. & Kic, P. 2015. Selected factors affecting microclimatic conditions in driver's cabin. In: *14th International Scientific Conference Engineering for Rural Development*. Latvia University of Agriculture, Jelgava, pp. 61–66.

Zewdie, R. & Kic, P. 2016a. Microclimate conditions and stress factors effecting farm machine operators during harvest. In: *15th International Scientific Conference Engineering for Rural Development*. Latvia University of Agriculture, Jelgava, pp. 25–30.

Zewdie, R. & Kic, P. 2016b.Transport route segments and stress effect on drivers. *Agronomy Research* **14**, 269–279.

Zewdie, R. & Kic, P. 2016c. Microclimate in drivers cabin of combine harvesters. In: *6th International Scientific Conference on Trends in Agricultural Engineering.* Faculty of Engineering, CULS, Prague, 2016. pp. 723–748.

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Development and implementation of data collection technologies for digital mapping of soil electric conductivity

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Abstract. One of the main preconditions for the introduction of soil protection measures and sustainable use of a soil is to strengthen the knowledge base about the specific habitats characteristics with high spatial resolution and adequate interventions to these properties. One of the most common sensors used to describe the level of soil variability are devices that measure the electric conductivity of the soil.
Platform for the electrical conductivity measuring has been developed and implemented into the standard combined machines for the tillage and seeding, using an existing work tools as part of the platform. Within the field work the series of measurements was conducted with this machine and platform and data of electrical conductivity were collected. On the same field as a reference method electrical conductivity was measured by an electromagnetic induction probe EM38 MK2. Compared data from the measuring platform and the EM38 MK2 probe showed a high correlation value. The experiments demonstrate the possibilities of technical solutions of soil conductivity measurement implementation on tillage and seeding machines where by a modification of selected tillage and seeding machines together with incorporation of sensors directly onto the work tools is possible to obtain measuring platform that enables data collection directly during operation of the machine on the field.

Key words: Soil electric conductivity, soil mapping, soil sensor.

INTRODUCTION

Precision agriculture technology has been introduced several years ago. Despite all the potential of this technology, there are still many problems that hinder their higher usage and adoption. Implementation of precision agriculture implies somewhat high level of expertise and technical skills of the users. Most farmers, however, sees this approach as too complex. As also shown in studies from the USA, Great Britain, Denmark and Germany, it is one of the reasons for the low diffusion of technology of precision agriculture compared to the assumptions (Reichardt et al., 2009). The same was concluded in 2005 by McBratney et al., who states that precision farming is still developing, but not as fast as expected 5 years ago. The development of appropriate decision support systems and systems for performing accurate decisions remains a major obstacle to the adoption of the technology. The main idea of precision agriculture is based on the belief that the variability of conditions for plant growth is one of the main contributions to the differences in yields and therefore also different inputs under different soil conditions could be a way to approach the situation. Number of growers already has, for example, yield data from several seasons. However, the effectiveness of the decision–making process can be guaranteed only when we receive high quality information on the spatial variability of soil, which limits yield in certain parts of the field. Lack of knowledge which information is significant and economically acceptable is the most limiting factor (Adamchuk, 2007). The high price for the sampling and laboratory analysis supports the deployment of sensors which will evaluate required soil properties; such as during towing of sensors over plot (Adamchuk et al., 2004; Viscarra Rossel et al., 2011). Variable sampling applications require significant amount of samples, but where there is a possibility the hand sampling should be replaced by an autonomous or semi–autonomous data collection. Regarding the measurement of field variability, sensors on agricultural machines can deliver the best accessible spatial and temporal information (Heege, 2013). Deployment of geophysical instruments or implementation of sensory equipment to commonly used machines will enable an overall reduction in costs of data collection, sampling network optimization, time savings and reduce demands on workers. Corwin & Lesch (2003) or Terrón et al. (2011) confirms that the conductivity measurement of soil becomes one of the most widely used techniques for field variability mapping for the needs of precision agriculture technologies and farmers can use the measurement for fast and accurate characterization of soil environment (Doerge, 2001). Measurement of the electrical conductivity of the soil is suitable for detection of many soil parameters and variables description (Fortes et al., 2015; Moral et al., 2010) or yields potential prediction (Johnson et al., 2003). Indirect measurement of soil properties thus have many promising applications, which should be further developed and improved.

The purpose of the measurements was to determine whether it is possible to install the soil electrical conductivity platform into commonly offered tillage and seeding machine for purpose of measurement and data collection between field operation, cultivation and seeding.

METHODS AND MATERIALS

The measurement and verification of the measurement electronics was done on the field, which manages agriculture company ZD Dolany (geographical coordinates: 50°22'48"N, 15°57'40"E). Field experiments were carried out during seeding of spring wheat. The soil is *Haplic Luvisol* (FAO, 2014). The highest part of the field is at the northern part an altitude of 325 m a.s.l. and further field is sloped to the lowest altitude 29 m a.s.l. Field acreage was 14.2 ha (see Fig. 1).

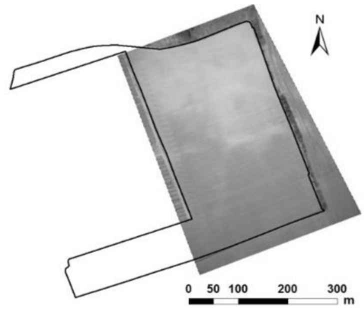

Figure 1. Aerial picture of the experimental plot, which was taken after sowing by unmanned aircraft.

Scheme of sampling patterns and moving trajectories illustrated Fig. 2.

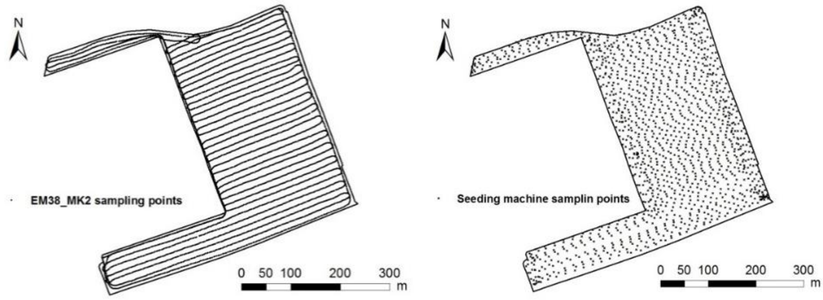

Figure 2. Sampling patterns and moving trajectories of EM38 MK2 device (left) and sampling points collected during seeding (right).

The most commonly used electrical and electromagnetic sensors for field–scale on–the–go measurements are electrical resistivity (ER) and electromagnetic induction (EMI) (Corwin & Lesch 2005). ER and EMI measure the electrical conductivity of the bulk soil, which is referred to as the apparent soil electrical conductivity (EC_a).

Measuring electronics, which use principles of electrical resistivity measurements, was installed on a modular seeding machine Farmet Falcon (Farmet a.s., Ceska Skalice, Czech Republic) with working width of 6 m. Electrical Resistivity method could be described as a galvanic contact method. As electrodes the discs tiller of first section were used. These discs were electrically isolated from the machine frame through rubber segments. Disc allowed contact with the soil during the work only. The speed during the measurement with EM38 MK2 probe was about 2.8 m s^{-1} and the speed of the seeding machine about 3.4 m s^{-1}. Speed sets corresponded to normal operating speed at which proper work of tools was ensure. That movement speed affects especially the density of sampling. Electrodes connection was done according to article of Milsom (2003), where the mentioned connections are known as Wenner array. Connecting corresponds to the diagram in Fig. 3, where the individual discs formed a pair of voltage (V) and current (I) electrodes. Distance between electrodes (a) was 0.25 m. Outputs from electrodes were stored onto measuring units together with the GPS position. Storage interval was 5 sec. Measuring device was developed on Department of Agriculture Machines and Department of Machine Utilization, CULS Prague.

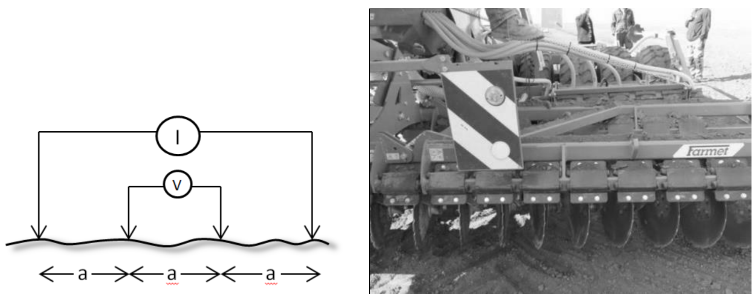

Figure 3. Connection of electrodes on the seeding machine Falcon and front disc section of seeding machine, which were used as electrodes.

To obtain a validation set of measurements of electrical conductivity from platform which was installed on seeder, the measurement using reference probe EM38 MK2 (Geonics Limited, Ontario, Canada) on the same date was carried out as well. Probe EM38 MK2 is a commercially sold product utilizing noncontact electromagnetic induction measurements. The validation data were measured in the vertical mode of probe in spacing of 12 m between parallel lines. Data were stored together with GPS position and storage interval was 1 sec.

Software ArcGIS 10.2 (ESRI, Red lands, USA), Statistica 12 (StatSoft, Inc., Tulsa, OK, USA) and tools GS+ for Windows (Gamma Design Software, LLC, Michigan, USA), Microsoft office (Microsoft Corporation, Redmond, USA) were used.

RESULTS AND DISCUSSION

Two sets of ER and EMI data were processed using statistical and geostatistical methods. In order to get accurate data and to eliminate measuring errors, several modifications on the initial EC_a values were performed before next processing. The majority of errors, when measuring EC_a with galvanic contact method by seeding machine Falcon, occurred when the machine started a new line. Thus, values especially on headlands were removed from the data set. These values were eliminated by trimming the marginal points recorded. Values larger or less than three times of the standard deviation from the mean value were also excluded from the initial data set. The time series were smoothened during the subsequent modification. A simple running average method was applied to smooth the time series of all measurements using following equation:

$$\hat{Y}_t = \frac{1}{3}(Y_{t-1} + Y_t + Y_{t+1}) \tag{1}$$

where: Y are original values at time t.

The descriptive statistics of EC_a data set is shown in Table 1. The range of values expressed as the maximum and minimum as well as variation coefficient illustrates the variability of the individual data sets. Asymmetry from the normal distribution is described as a coefficient of asymmetry. The normality condition is met, if the interval of inclination lies between -2 and 1 (Lopez–Granados, 2002). A normal distribution is demonstrated by low values of skew. On the other hand normality is not limiting condition for geostatistical evaluation.

As Kolář & Kužel (1998) reported, the soil belongs to the most variable environments. In order to implement variable application and interventions it is necessary to describe the variability of the field (Piers and Nowak, 1999). Standard deviation and the variance are useful measures for describing the spread of a set of measurements. Describe the variability around the mean and variance is related to the geostatistical parameters. Suitable indicator for the comparison of the variability level is the coefficient of variation (*CV*). *CV* expresses dispersion in the relative terms. It is useful for comparing the variation of different data sets of observations of the same property (Webster & Oliver 2007). Measures indicate a higher degree of variability in the data set obtained by seeding machine Falcon.

Table 1. Descriptive statistics of data set

Variable / Property	EC_a EM38 MK2 0–1 m	EC_a Falcon 6
Mean value (mS m^{-1})	34.2	31.9
Median	33.5	27.4
Standard deviation	9.5	20.7
Variance	90.3	428.5
CV (%)	27.8	53.7
Skew	0.17	0.51
Minimum	12.6	5.7
Maximum	56.8	83.4
N	5,294	1,088

In order to find out spatial relationships between tested values and calculation of variogram parameters the experimental variograms were built and substituted by model variograms in the next step. Model variograms were fitted for both files and parameters Nugget (C_0), Sill ($C_0 + C$) and Range (A_0) were calculated. The spatial relation itself is expressed as a portion of the nugget (C_0) in the sill value ($C_0 + C$). The spherical model of the variogram of EC_a values with nugget was chosen. Parameters of model variogram were taken off (Table 2). Based on the values of A_0 may be estimated mutual spatial dependence of the data.

Table 2. Parameters of model variogram for soil electric conductivity values

Variable / Property	EC_a EM38 MK2 0–1m	EC_a Falcon 6
Nugget C_0 ((mS $m^{-1})^2$)	2.7	108.7
Sill $C_0 + C$ ((mS $m^{-1})^2$)	46.8	275.2
Range A_0 (m)	98.8	69.7
R^2	0.99	0.91
RSS	29.7	2,445
$C_0/C_0 + C$ (%)	5.7	39.4
Model	Spherical	Spherical

The measurement errors as well as the variability character can influence the values of nugget (Lopez-Granados et al., 2002). Division of spatial relations into classes is described e.g. in Cambardella & Karlen (1999) and Lopez–Granados et al., (2002). Following criterion $C_0/C_0 + C < 25\%$ indicates a strong spatial relationship for the tested files of EC_a measured by EM38 MK2. The values of EC_a measured by Falcon showed medium strong spatial dependence ($C_0/C_0 + C$ from 25 to 75%). Medium spatial dependence of data could be caused by higher distances between measured points. *Ordinary Kriging* interpolation method was used for spatial interpolation of measured values. Part of the assessment process was also validation of the interpolation by *Cross–Validation* method. Estimated values which were collected after this process were correlated with measured values. The correlation coefficient *R* should be equal to 1 in an ideal case. Coefficients of correlation for the data sets are shown in Table 3. The lower value of the correlation coefficient was found for the values of conductivity which were measured by the seeding machine Falcon. There was impacted by lower levels of spatial dependence of data.

Table 3. Comparison of measured and predicted data

Variable / Property	EC_a EM38 MK2 0–1 m	EC_a Falcon 6
coefficient of correlation *R*	0.99	0.59

On the basis of regression and correlation analysis, the significance of variogram modelling for the subsequent interpolation was proved. Reliable conductivity maps are presented in Fig. 4. For the purpose of data set comparison, when the points do not have identical coordinates, both maps were resampled to the grid of 5 x 5 meters and data from both sets were paired. This steps enable comparison and assessment of values recorded from the sensors.

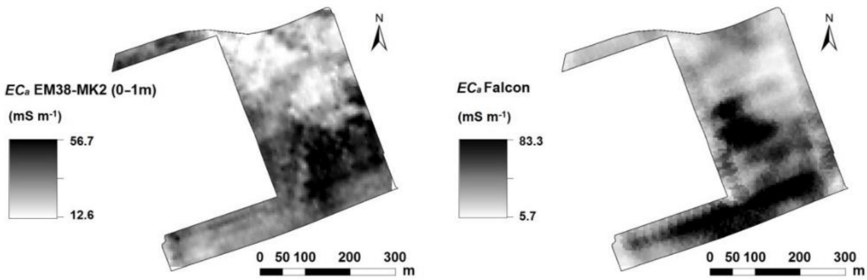

Figure 4. Maps of kriged estimates.

Presented resampling of data sets allowed a mutual comparison. Regression and correlation analysis was used for the comparison. The comparison and evaluation of these two data sets were carried out by means of regression and correlation analysis. Fig. 5 shows the results of this analysis. In the legend of the chart, it is also possible to read determination and correlation coefficient values ($R^2 = 0.40$ and $R = 0.63$ respectively), including significance test ($p < 0.05$).

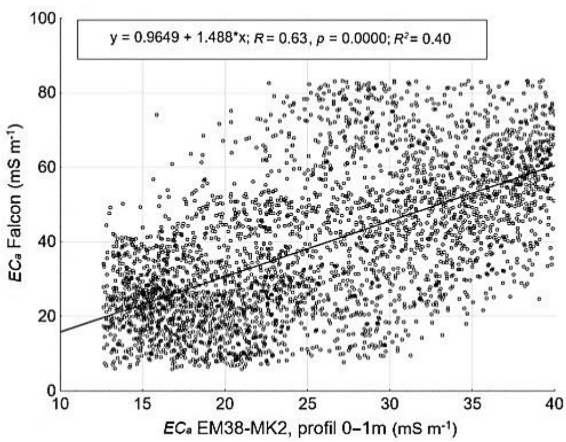

Figure 5. Relationship between data from sensor installed in the seeding machine Falcon and outputs from EM38 MK2.

In the case of implementation of individual approach on the field, its parts, creating application maps or zones there are usually three factors which must be considered: the information which will be used as the basis for the creation of a zones the information processing procedures (ie. classifications) and how many zones should be created (Fridgen et al., 2004). Proximal sensors provide important results to create a sampling plan (Corwin & Lesch 2010). As Steinberger et al. (2009) refer that modern farm machinery with installed sensors could collect a large amount of data during field operation. On the other hand, communication and compatibility is the main limiting factor.

The monitoring systems and sensors implemented to the tillage and seeding machines seems like very attractive option in relation with the use of the sensor technology. Telematics' monitoring systems in the combination of GPS navigation offers a number of very valuable information. The mere knowledge of the position will allow to monitor the agricultural technology usage (deployment location and work inspection). If the more information are added to the machine position (such as: fuel consumption, slipping or pulling force) the data which can indirectly give evidences about the variability of soil environment or the economic balance of the partial areas of land with few additional costs could be obtained. Development of machines and mobile technologies will continue and this technology offers a wide area for variable applications and service in farming (Xin et al., 2015).

CONCLUSION

The rapid development of sensor technology and data processing, which frequently contribute to the efficient and sustainable agricultural production, along with the development of the internet and telecommunications are nowadays the key innovative processes. The research activities are supported by the following research hypotheses: 1) The sensors used for soil properties measuring are based on a relatively simple measurement principles and the implementation in machines for tillage and seeding is real. 2) The introduction of machines which are able to collect the soil variability data during field work, can deliver an important tool for the development and advancement of the precision agriculture technologies. Currently, the data collection associated mainly with individual and independent activity that requires additional entrance on the field, acquisition costs of the measuring device and time for data collection. This solution is based on the idea that the machine and field operations will also become the source of data. Outputs from measuring platform and sensors, which was installed on the seeding machine showed a significant correlation with the data from sensor EM 38, which is placed on a standard. The data collection will be processed concurrently with the work of machines, at high density of measurement and the actual soil conditions.

ACKNOWLEDGEMENTS. The project was supported by the Grant Agency of the Czech University of Life Sciences Prague (CIGA No. 20163005).

REFERENCES

Adamchuk, V.I. 2007. Development of On–the–Go Soil Sensor Systems. In: *1st Global Workshop on High Resolution digital soilsensing and mapping.* Sydney, Australia.

Adamchuk, V.I., Morgan, M.T. & Lowenberg–Deboer, J.M. 2004. A model for agroeconomic analysisi of soil pH mapping. *Precision Agriculture* **5**, 109–127.

Cambardella, C.A. & Karlen, D.L. 1999. Spatial analysis of soil fertility parameters. *Precision Agriculture* **1**, 5–14.

Corwin, D.L. & Lesch, S.M. 2005. Apparent soil electrical conductivity measurements in agriculture, *Computers and Electronics in Agriculture* **46**, 11–43.

Corwin, D.L. & Lesch, S.M. 2010. Delineating site–specific management units with proximal sensors. In: *Oliver M.A. (Ed.) Geostatistical applications for precision agriculture,* Springer Netherlands, pp. 139–165.

Corwin, D.L. & Lesch, S.M. 2003. Application of Soil Electrical Conductivity to Precision Agriculture: Theory, Principles and Guidelines. *Agronomy Journal* **95**(3), 455–471.

Doerge, T. 2001. Fitting soil electrical conductivity measurements into the precision farming toolbox. In: *Wisconsin Fertilizer, Aglime and Pest Management Conference*. Madison, pp. 16–18.

FAO. World reference base for soil resources 2014. 2014, FAO, Rome.

Fortes, R., Millán, S., Prieto, M.H. & Campillo, C. 2015. A methodology based on apparent electrical conductivity and guided soil samples to improve irrigation zoning. *Precision Agriculture* **16**(4), 441–454.

Fridgen, J.J., Kitchen, N.R., Sudduth, K.A., Drummond, S.T., Wiebold, W.J. & Fraisse, C.W. 2004. *Management Zone Analyst (MZA):* Software for subfield management zone delineation. *Agronomy Journal* **96**, 100–108.

Heege, H.J. 2013. *Precision in crop farming. Site specific concepts and sensing methods: applications and results.* Dordrecht: Springer, 356 pp.

Johnson, C.K., Mortensen, D.A., Weinhold, B.J., Shanahan, J.F. & Doran, J.W. 2003. Site – Specific Management Zones Based on Soil Electrical Conductivity in a Semiriad Cropping System. *Agronomy Journal* **95**, 303–315.

Kolář, L. & Kužel, S. 1998. *Heterogeneity of soil properties. In Resonable use of fertilizers*, KAVR, CULS Prague, pp. 76–83, (in Czech).

Lopez–Granados, F., Jurado–Expósito, M., Atenciano, S., Garcia–Ferrer, A., Sánchez De La Orden, M. & Garcia–Torres, L. 2002. Spatial variability of agricultural soil parameters in southern Spain. *Plant Soil* **246**, 97–105.

McBratney, A., Whelan, B., Ancev, T. & Bouma, J. 2005. Future Directions of Precision Agriculture, *Precision Agriculture* **6**, 7–23.

Milsom, J. 2003. *Resistivity methods. Field Geophysics, third edition.* John Wiley & Sons Ltd, 232 pp.

Moral, F.J., Terrón, J.M. & Marques Da Silva, J.R. 2010. Delineation of management zones using mobile measurements of soil apparent electrical conductivity and multivariate geostatistical techniques. *Soil and Tillage Research* **106**, 335–343.

Pierce, F.J. & Nowak, P. 1999. Aspects of precision agriculture. *Advances in agronomy* **67**, 1–85.

Reichardt, M., Jürgens, C., Klöble, U., Hüter, J. & Moser, K. 2009. Dissemination of precision farming in Germany: acceptance, adoption, obstacles, knowledge transfer and training activities. *Precision Agriculture* **10**, 525–545.

Steinberger, G., Rothmund, M. & Auernhammer, H. 2009. Mobile farm equipment as a data source in an agricultural service architecture. *Computers and electronics in agriculture* **65**(2), 238–246.

Terrón, J.M., Marques Da Silva, J.R., Moral, F.J. & Alfonso, García–Ferrer 2011. Soil apparent electrical conductivity and geographically weighted regression for mapping soil. *Precision Agriculture* **12**5), 750–761.
Viscarra Rossel, R.A., Adamchuk, V.I., Sudduth, K.A., Mckenzie, N.J. & Lobsey, C. 2011. Chapter Five – Proximal Soil Sensing: An Effective Approach for Soil Measurements in Space and Time. *Advances in Agronomy* **113**, 243–291.
Webster, R. & Oliver, M.A. 2007. *Geostatistics for environmental scientists/ 2nd Edition*. John Wiley & Sons, 330 pp.
Xin, J., Zazueta, F.S., Vergot, P., Mao, X., Kooram, N. & Yang, Y. 2015. Delivering knowledge and solutions at your fingertips: strategy for mobile app development in agriculture. *Agric. Eng. Int. CIGR J.,* Special issue 2015: 18th World Congress of CIGR, 317–325.

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Determination of poultry house indoor heating and cooling days using degree-day method

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Abstract. In poultry production, degree-day values are used as fundamental design parameters considered among others in determining the extent of heating and cooling of poultry housing. In this study, heating and cooling data values for each of broiler production period were determined using the degree-day method. The total length of the experiment was 123 days which corresponds to 3 growing periods. The inside and outside air temperatures of the poultry house were measured using air temperature data loggers positioned at different points and heights within and outside broiler house. Knowledge of heating and cooling day values is important as it necessitates the provision and maintenance of ideal bird's production conditions and ensuring the economic viability of the enterprise through optimized energy consumption.

Key words: Broiler, energy, production period, temperature.

INTRODUCTION

Poultry, has recently become one of the a largest growing agricultural commodity in Turkey. The country is the world's 10th largest poultry producer, processing about 1.900 million tonnes in 2014 (USDA, 2015) and aims to be the one of the top three producers of world in the next decade. This can be achieved through not only planning the appropriate genetic breeding programs, but also ensuring availability of suitable environmental conditions (indoor and outdoor) during birds rearing process.

Improved environmental control of poultry houses plays a significant role in ensuring and maintaining effective poultry production. In order to ensure maintenance of optimal indoor environmental conditions, poultry houses must be properly designed in the farmstead, due consideration need to be given to environmental factors (Barre, 2012), such as temperature (Charles, 1986; Kic, 2016), relative humidity (Longhouse et al., 1968; Xin et al., 1994), movement of the air (Drury, 1966; Luck et al., 2014), ventilation (Miragliotta et al., 2006; Cemek et al., 2016) and intensity of light (Araújo et al., 2015; Patel et al., 2016).

The control of poultry houses' indoor environmental conditions requires careful consideration of the energy input which depends on numerous parameters, such as species, method of breeding, thermal characteristics of the building, internal microclimate, external microclimate. Failure to accurately take note of the energy input has serious repercussions on the cost of production. Degree-days (DDs), on the other hand, provide a simplified avenue to energy estimation for both heating and cooling requirement determination. The DDs method uses less input data, and can be used as a quick assessment tool for decisions relating to design, such as, levels of insulation assumptions about infiltration, building thermal capacity, (CIBSE TM41, 2006).

Heating degree days (HDDs) and cooling degree days (CDDs) mathematical formulations that reflects are the amount of energy needed to heat or cool a building to a known optimal temperature, considering the extent of hotness or coolness of the outside temperature. A ‘degree day’ indicates that the daily average outdoor temperature was one degree higher or lower than some known benchmark temperature of that particular day. The sum of the number of HDDs or CDDs over a year is roughly proportional to the annual amount of energy that is required to heat or cool a building in that particular location (Quayle & Diaz, 1980). Thus, HDDs and CDDs are rough surrogates for how climate change is likely to affect energy use for heating and cooling.

In this study, inside and outside temperatures were measured using data loggers. The broiler house HDD and CDD values for each production period (in summer, winter and end of the spring) were determined using the degree-day method. Energy requirements for heating and cooling can be determined by using these data and can provide producers with indications on whether raising broiler chickens in the region is economical.

MATERIALS AND METHODS

Materials

The study was conducted in a commercial broiler house during three production periods (in summer, winter and end of the spring) located in Samsun province (Northern Hemisphere, Latitude 41°70’, Longitude 36°30’), northern Turkey. The broiler house, with a capacity of 20,000 birds, with a width of 14 m, length measuring 90 m, and ceiling height of 4.40 m (Fig. 1). Sawdust was used as a litter material within the broiler house. Feeding, watering, lighting, heating and ventilation were operated automatically. The roof and sidewalls of the poultry house is made of sandwich panels (5. mm), while the floor is constructed using lean concrete XPS construction materials. The broiler house was equipped with seven large (diameter 1.38 m) and five small exhaust fans (diameter 0.92 m). The house had sixty-six air inlets measuring 32.50 × 52.50 cm, placed along with the side walls of the building. The heating system comprised an external heat source with a dual-tube system.

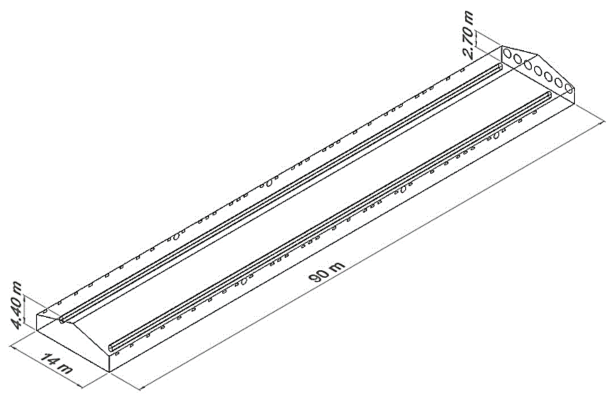

Figure 1. Broiler house dimensions.

Feeding dates, production period and number of the birds housed during the experiment is given Table 1.

Table 1. Feeding dates, production period and number of the birds housed during the experiment

Growing period no	Feeding dates	Production period	The number of birds
1	23.04.2016–03.05.2016	End of the spring	19,360
2	12.07.2016–22.08.2016	Summer	18,400
3	13.10.2016–23.11.2016	Winter	18,000

Methods

To monitor indoor temperature distribution, fifty-nine automatically operated temperature data loggers (NDI 320B) were used (Fig. 2). These air temperature data loggers have a resolution of ±0.1 °C with a 30-minute data capturing interval. The data loggers were positioned in broiler house to capture indoor air temperature data at three heights namely birds (0.25 m), human (1.80 m) and roof heights (2.50 m) as shown in Fig. 3. Air temperature measurements were recorded automatically at an interval of 30 minutes by these data loggers. An outdoor air temperature was monitored by a data logger that was placed beneath the outside eaves of the building for protection against direct sunlight and rain.

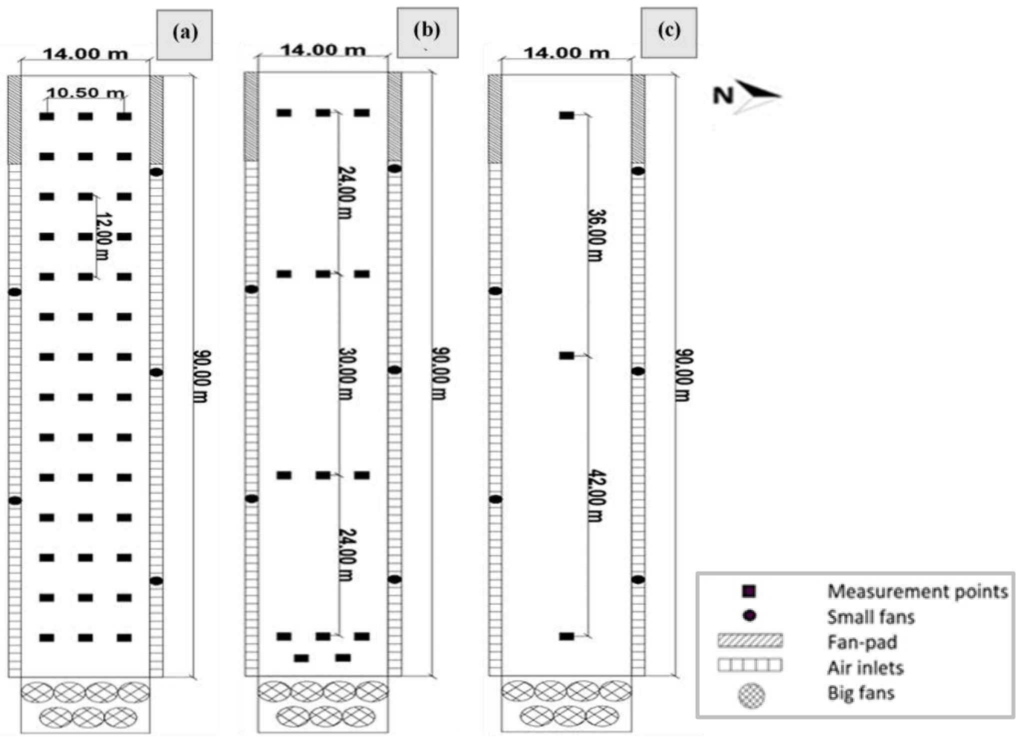

Figure 2. Broiler house measurement points (a) birds' height, (b) human height, (c) roof height.

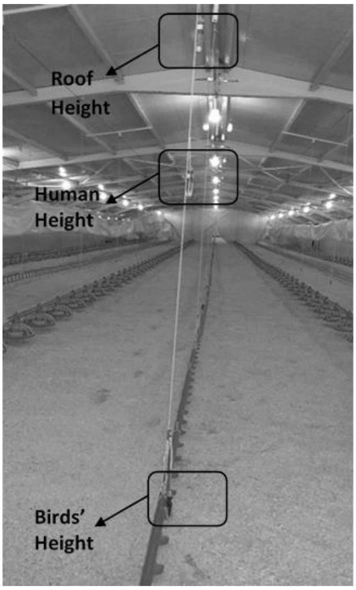

Figure 3. Measurement levels in the broiler house.

To determine HDD and CDD values, base temperature values dependent on broilers' weekly growth development were used for the six-week periods under study (Table 2) (Lindley & Whitaker, 1996).

Table 2. Recommended weekly base temperature for broiler chicken

Weeks	Base temperature, °C
1	31.00
2	29.00
3	25.00
4	23.50
5	22.50
6	20.50

Degree days (DDs) method

Degree days' values represent a simplified representation of outdoor air-temperature data. The DDs method has found common use in areas that estimate and target energy consumption for heating and cooling as a key parameter. This method has successfully been used in residential, commercial, and industrial buildings, greenhouses, livestock facilities, and storage facilities mainly for determining energy requirements for heating and cooling (Yildiz & Sosaoglu, 2007).

HDDs are a measure of by what amount (in degrees), and for which period (in days), outside air temperature was lower than a specific 'base temperature'. Calculations concerning energy requirement for purposes of heating the building generally make use of HDDs.

CDDs are a measure of how much (in degrees), and for how long (in days), outside air temperature was higher than a specific base temperature. They are used to measure the demand for energy needed to cool buildings.

HDDs and CDDs are calculated by summing the temperature differences between a known specific base temperature and the average daily outside dry-bulb temperature for a given time period (weekly, monthly and annual) (Eto, 1988). HDD and CDD values in each production period are calculated using Eqs 1 and 2 (Buyukalaca et al., 2001; Christenson et al., 2006; Atilgan et al., 2012; Yucel et al., 2014):

$$For\ T_{out} < T_{base}, \qquad HDD = \sum_{i=1}^{n} (T_{base} - T_{out}) \tag{1}$$

$$For\ T_{base} < T_{out}, \qquad CDD = \sum_{i=1}^{n} (T_{out} - T_{base}) \tag{2}$$

Where HDD and CDD are the cumulative sum of the heating and cooling degree-days for n days, n is the total number of days in the period, T_{base} is the base temperature recommended for the broiler chicken and T_{out} is the average outdoor air temperature. These equation indicates that only positive values are summed.

RESULTS AND DISCUSSION

The results of long time measurements of indoor and outdoor temperatures in three growing periods are presented in Table 3. These results show that measurement temperatures are closer to ideal temperatures for chickens.

Table 3. Average values and standard deviation of the indoor and outdoor temperatures in three growing periods

Growing period no	Inside temperature (°C ± SD)	Outside temperature (°C ± SD)
1	25.71 ± 2.85	17.00 ± 3.89
2	26.06 ± 2.92	22.43 ± 2.04
3	25.12 ± 3.99	14.11 ± 1.74

SD – Standard deviation.

The heating and cooling degree-day values for 3 growing periods were calculated using equations 1 and 2 (Table 4).

As shown in the Table 3, it is expected that maximum heating requirement observed in winter period emanating from the very low outdoor temperatures. The lower the average daily outdoor air temperature, the more the HDDs resulting more energy consumption during this period. The opposite is true of cooling requirement during summer. The higher the average daily air outdoor temperature, the more CDDs occur necessitating higher cooling energy requirement through ventilation.

Table 4. The heating degree-day and cooling degree-day values for different production periods

Temperature	31		29		25		23.5		22.5		20.5	
Growing period no	HDD	CDD	HDD	CDD	HDD	CDD	HDD	CDD	HDD	CDD	HDD	CDD
1	126.3	--	67.3	--	57.9	--	53.8	--	53.1	--	4.5	16.9
2	51.9	--	54.1	--	15.1	--	5.7	2.8	4.7	7.6	3.8	8.0
3	99.9	--	93.4	--	75.6	--	68.8	--	71.1	--	59.1	--

The daily average inside temperature (T_{in}), outside temperature (T_{out}) and base (suggested) inside temperature (T_{base}) of poultry house are presented in Fig. 4. As shown in Fig 4 (a, b), T_{in} is lower than T_{base} during the first and second weeks of production, indicating that the poultry house was not adequately heated. On the other hand, during the third, fourth and sixth weeks, T_{in} is greater than T_{base}, implying that the broiler house was not optimally cooled. During winter production period, high level of heating is required during the first, second, fifth and sixth weeks because of the average indoor temperatures are lower than recommended temperatures. Conversely, during the third and fourth weeks, the house is need to be cooled (Fig. 4, c). The smaller the difference between the indoor and base temperatures, the more energy will be saved. In other words, the lower the average daily outside temperature, the more heating degree-days and the greater consumption of fuel. In general, three production periods are examined, it can be said that indoor temperatures are close to recommended temperatures.

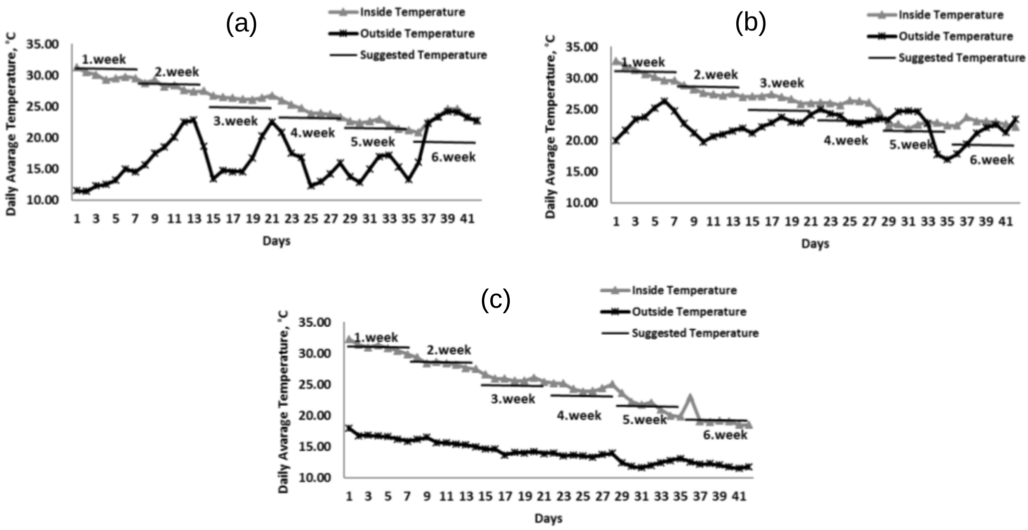

Figure 4. The daily average inside temperature, outside temperature and suggested inside temperature of poultry house (a, end of the spring; b, summer; c, winter).

CONCLUSIONS

In this study, heating degree-days and cooling degree-days were calculated for Samsun province during three broiler rearing periods. Knowledge of the number of HDDs and CDDs in a poultry house allows an engineer to plan and design appropriate type of equipment and materials which should be installed to provide adequate heating and cooling to broiler facilities. Furthermore, calculated HDDs and CDDs offers producers opportunity to reliably predict energy consumption. Apart from the technical benefits mentioned above, a well-designed broiler house also carries a positive benefit on broiler performance and welfare, feed efficiency and overall economic operation of the facility.

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REFERENCES

Araújo, F.E., Garcia, R.G., Nääs, I.A., Lima, N.D.S., Silva, R.B.T.R. & Caldara, F.R. 2015. Broiler Surface Temperature and Behavioral Response under Two Different Light Sources. *Revista Brasileira de Ciência Avícola* **17**(2), 219–226.

Atilgan, A., Yucel, A. & Oz, H. 2012. Determination of heating and cooling day data for broiler housing: Isparta case. *Journal of Food, Agriculture & Environment* **10**(3 & 4), 353–356.

Barre, H. 2012. *Environmental and functional engineering of agricultural buildings.* Springer Science & Business Media.

Büyükalaca, O., Bulut, H. & Yılmaz, T. 2001. Analysis of variable-base heating and cooling degree-days for Turkey. *Applied Energy* **69**(4), 269–283.

Cemek, B., Kucuktopcu, E. & Demir, Y. 2016. Determination of spatial distribution of ammonia levels in broiler houses. *Agronomy Research* **14**(2), 359–366.

Charles, D.R. 1986. Temperature for broilers. *World's Poultry Science Journal* **42**(03), 249–258.

Christenson, M., Manz, H. & Gyalistras, D. 2006. Climate warming impact on degree-days and building energy demand in Switzerland. *Energy Conversion and Management* **47**(6), 671–686.

CIBSE TM41. 2006. *Degree-Days: Theory and Application.* Chartered Institution of Building Services Engineers (CIBSE).

Drury, L.N. 1966. Air velocity and broiler growth in a diurnally cycled hot environment. *Trans. ASAE* **9**(3), 329–332.

Eto, J.H. 1988. On using degree-days to account for the effects of weather on annual energy use in office buildings. *Energy and Buildings* **12**(2), 113–127.

Kic, P. 2016. Microclimatic conditions in the poultry houses. *Agronomy Research* **14**(1), 82–90.

Lindley, J.A. & Whitaker, J.H. 1996. *Agricultural buildings and structures*. American Society of Agricultural Engineers (ASAE).

Longhouse, A.D., Ota, H., Emerson, R.E. & Heishman, J.O. 1968. Heat and moisture design data for broiler houses. *Transactions of the ASAE* **11**(5), 694–700.

Luck, B.D., Davis, J.D., Purswell, J., Kiess, A.S., Hoff, S.J. & Olsen, J.W. 2014. Effect of measurement density on characterizing air velocity distribution in commercial broiler houses. *Trans. ASABE* **57**(5), 1443–1454.

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

Patel, S.J., Patel, A.S., Patel, M.D. & Patel, J.H. 2016. Significance of Light in Poultry Production: A Review. *Advances in Life Sciences* **5**(4), 1154–1160.

Quayle, R.G. & Diaz, H.F. 1980. Heating degree day data applied to residential heating energy consumption. *Journal of Applied Meteorology* **19**(3), 241–246.

USDA. 2015. *United States Department of Agriculture*, *Foreign agricultural service,* Broiler meat selected countries summary.

Xin, H., Berry, I.L., Tabler, G.T. & Barton, T.L. 1994. Temperature and humidity profiles of broiler houses with experimental conventional and tunnel ventilation systems. *Applied Engineering in Agriculture* 10**(**4), 535–542.

Yildiz, I. & Sosaoglu, B. 2007. Spatial distributions of heating, cooling, and industrial degree-days in Turkey. *Theoretical and Applied Climatology* **90**(3), 249–261.

Yucel, A., Atilgan, A., Oz, H. & Saltuk, B. 2014. *The determination of heating and cooling day values using degree-day method: Tomato plant example.* Infrastruktura i Ekologia Terenów Wiejskich, (IV/1).

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Impact of clearfelling on dissolved nitrogen content in soil-, ground-, and surface waters: initial results from a study in Latvia

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Abstract. Conventional forest management has traditionally been targeted to enhance provisioning ecosystem services. Recently, however, awareness about the effect of forest management on other groups of ecosystem goods and services has been raised at the European and global levels. A number of initiatives addressing the evaluation and mitigation of the impact of forest management operations on biodiversity, soil quality, nutrient cycling, and water quality have been reported. In 2011, the development of a monitoring system to assess the impact of forest management on biodiversity and environment in the state forests of Latvia was initiated in the Latvian State Forest Research Institute 'Silava'. A number of studies to obtain experimental data and to test potential monitoring methods were implemented during this project. Among other activities, three research objects related to the quantification of changes in nutrient cycling after clearcut with whole-tree harvesting and stem-only harvesting were established. Data on changes in nutrient concentrations in soil solution, ground water, and surface waters, and on nutrient input through precipitation, are presently available for one year before and two years after clearfelling. Significant increase of dissolved nitrogen concentration in soil solution, as well as differences between stem-only and whole-tree harvested plots emerged only in the second year after harvesting. No significant increase of the dissolved N in the streams was observed, compared to the reference period. Ground vegetation recovery, amount of slash, soil properties and processes in the buffer zone are among those factors influencing the N leaching most, and these will be investigated further.

Key words: forest management, water, dissolved nitrogen content.

INTRODUCTION

In recent years, there has been a growing scientific and political awareness of various goods and services provided by the world's ecosystems. Forests, among other ecosystem types, deliver a wide range of ecosystem goods and services, with timber, energy-wood, non-wood forest products, biodiversity, carbon sequestration, and clean water being among those mentioned most often (e.g., Krieger, 2001; Powell et al., 2002; Fisher et al., 2009; EUSTAFOR & Patterson, 2011; Wunder & Thorsen, 2014).

Each intervention in the ecosystem processes simultaneously alters several ecosystem functions and consequently affects the delivery of various ecosystem goods and services. Conventional forest management (FM) has traditionally been targeted to use and enhance provisioning services. Recently, however, awareness about the effect of FM on other groups of ecosystem goods and services has been raised on the European and global levels (Nasi et al., 2002; FAO, 2010; EUSTAFOR & Patterson, 2011; Miura et al., 2015). At the same time, the worlds' forests are confronted with growing pressure due to the need to reduce fossil fuel usage. Also in Latvia, wood biomass utilization for energy purposes is predicted to increase substantially in the future. According to the National Renewable Energy Action Plan, Latvia's overall objective is to increase the share of energy produced from renewable energy sources in gross final energy consumption from 32.6% in 2005 to 40% in 2020 (Latvian Ministry of Economics, 2010). There are several potential methods to meet the increasing demand for energy wood; one of those is increased utilization of forest biomass. Intensified biomass harvesting potentially includes removal of branches, treetops, and stumps during clearcutting, thinning, drainage system renovation, and other silvicultural activities.

Clearfelling, especially whole-tree harvesting, may have adverse effects on several ecosystem services. A number of studies suggest that forest harvesting may cause a decline of water quality both in groundwater and surface waters (e.g., Ahtiainen, 1992; Kubin, 1998; Ahtiainen & Huttunen, 1999; Gundersen et al., 2006; Laudon, 2009; Miettinen et al., 2012). Mechanical disturbance of the forest floor may increase the potential for nitrate and potassium leaching to ground- and surface waters, as well as that of other pollutants, for example, mercury (Olsson & Staaf, 1995; Porvari et al., 2003, Nieminen, 2004; Munthe & Hultberg, 2004; Laurén et al., 2005; Gundersen et al., 2006; Bishop et al., 2009). Leaching of nutrients from harvested sites can lead to particular problems of eutrophication and acidification, causing major ecosystem damage to streams, rivers and lakes (Carpenter et al., 1998; Ahtiainen & Huttunen, 1999; Gundersen et al., 2006; Kreutzweiser et al., 2008). Concern has also been expressed about long-term nutrient depletion and loss of soil fertility, especially in N-limited ecosystems (Bengtsson & Wikström, 1993; Rolff & Ågren, 1999; Merganičová et al., 2005; Thiffault et al., 2011). Forest harvesting, particularly the removal of logging residues and stumps, affects ground vegetation and fauna (e.g., Olsson & Staaf, 1995; Bengtsson et al., 1998; Gunnarson et al., 2004; Åstrom et al., 2005). Thus, forest utilization clearly leads to changes in ecosystem processes and subsequently may alter provision of practically all ES groups, as these are directly dependent on ecosystem processes (Maes et al., 2013). Results related to the impact of forest harvesting on future forest productivity and leaching of nutrients and pollutants to adjacent water ecosystems are, however, site- and scale-dependent and rather contradictory (Futter et al., 2010; Wall, 2012; De Wit, 2014).

Most available data on the effects of forest management on water quality originate from Finland and Sweden, but due to dissimilar soil and hydrological conditions, results and conclusions obtained there may not necessarily be applicable in Latvian conditions. Soils of Latvia, compared to other soil regions, provinces and states have a wide range of distinct specific traits, mainly determined by diverse parent material (Nikodemus et al., 2009). Latvia, together with Lithuania, Estonia, parts of Poland, Russia and Belarus, as well as large area of the Baltic Sea, including island of Gotland, is a part of Baltic artesian basin, multilayered and complex hydrogeological system. Intense confined aquifer discharge is an important factor influencing nutrient cycling in Latvian forests (Dzilna, 1970; Virbulis et al., 2013). 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, this situation being essentially different from that in Fennoscandia (Indriksons & Zalitis, 2000; Zālītis, 2006; Indriksons, 2010; Zālītis, 2012). The continuous nutrient supply by confined aquifer discharge waters explains high and stable long-term productivity of forest stands established on drained organic soils. Evidence exists that if horizontal water flow and soil aeration is maintained at these drained areas, forest productivity is enhanced also at adjacent nutrient-poor dry mineral sites.

In 2011, the development of a monitoring system to assess the impact of forest management on biodiversity and the environment in the state forests of Latvia was initiated in the Latvian State Forest Research Institute 'Silava'. A number of studies to obtain experimental data relevant for Latvian conditions and to test potential monitoring methods were implemented during this project. Among other activities, research objects for the quantification of changes in nutrient cycling after clearcut with whole-tree harvesting and stem-only harvesting were established in the Kalsnava forest district research forests. Aim of this study was to test whether different types of clearfelling have significant and different impact on soil and water chemistry, forest regeneration and development of ground vegetation. This particular paper summarizes the first results on nitrate, ammonium, organic and total nitrogen concentration changes in soil solution, ground water, and surface waters, and nitrate, ammonium, organic and total nitrogen input through precipitation one year before and two years after clearfelling in pine and spruce forests in Latvia. We hypothesized that:

- clearfelling will result in significant increase of dissolved N-compounds in soil-, ground and streamwater;
- the concentration of dissolved N-compounds in the soil water will differ significantly between plots with stem-only and whole-tree biomass removal.

MATERIALS AND METHODS

The study area is located in experimental forests of Kalsnava Forest district, eastern part of Latvia (56°40–44´N, 25°50–54´E) (Fig. 1). Climate is continental; according to meteorological data from Jaunkalsnava meteorological station 10 km distant, the annual precipitation amount was 1,023 mm in 2012, 590 mm in 2013 and 823 mm in 2014, with largest share (61–74%) falling as rain from April to October. Mean annual air temperature was 4.4 °C in 2012, 5.1 °C in 2013 and 5.0 °C in 2014.

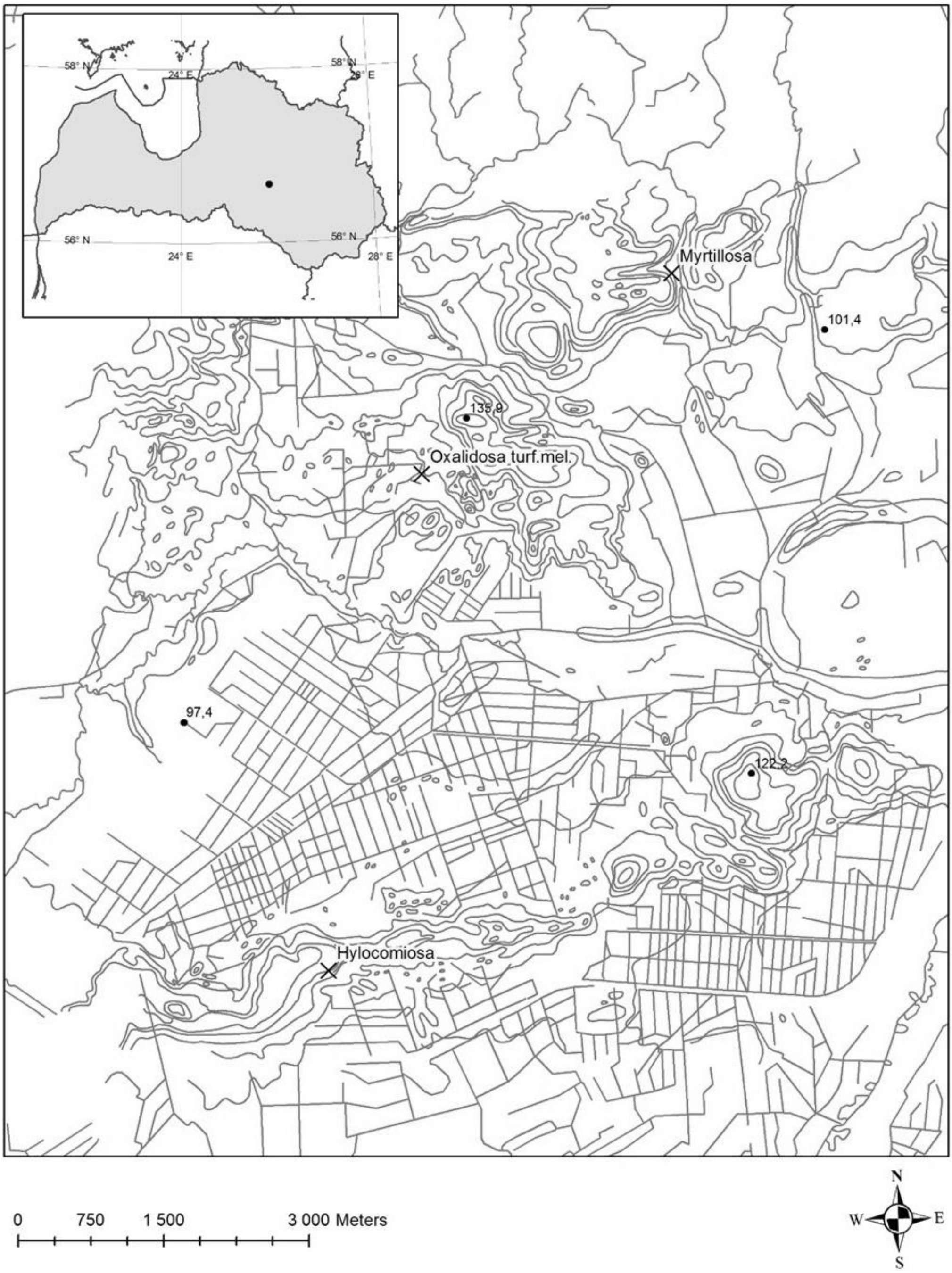

Figure 1. Location of the study sites.

Research was carried out at three sites: two were located on mineral soils (*Myrtillosa* and *Hylocomiosa* site type, dominant tree species *Pinus sylvestris* L.) and one on drained peat soil (*Oxalidosa turf. mel.* site type, dominant tree species *Picea abies* (L.) Karst.). Drainage was carried out in 1960. The sites were located on slopes (5° in *Oxalidosa turf.mel.*, 15° in *Hylocomiosa* and *Myrtillosa*), with bufferzone in the lower part (Fig. 1). Site description is presented in Table 1 and Table 2.

Table 1. Description of the study sites

Site	Dominant tree species	Mean diameter, cm	Mean height, m	Basal area, m^2 ha^{-1}	Standing volume before felling, m^3 ha^{-1}
Hylocomiosa	*Pinus sylvestris* L.	34	31	35.3	541.3
Oxalidosa turf.mel.	*Picea abies* L. (Karst.)	31	25	17.4	315.0
Myrtillosa	*Pinus sylvestris* L.	31	26	21.2	270.9

Table 2. Soil description of the study sites

Site	Soil type (WRB)	Soil texture (FAO)	Depth of O horizon, cm	Depth of H horizon, cm	Total C content, g kg^{-1} (O horizon/0–40 cm/40–80 cm)	Total N content, g kg^{-1} (O horizon/0–40 cm/40–80 cm)
Hyloco-miosa	*Folic Umbrisols* (*Albic, Hyperdystric, Arenic*)	Sand	0–10	n.a.	545.4/7.8/3.9	15.5/0.2/0.2
Oxalidosa turf.mel.	*Rheic Histosols* (*Eutric, Drainic*)	Sand	0–3	3–95	555.4/104.6/46.1	22.1/5.6/2.4
Myrtillosa	*Albic Arenosols* (*Dystric*)	Sandy loam	0–5	n.a.	422.1/7.2/2.9	11.3/0.3/0.1

At each site, three sampling plots were established: whole tree harvesting (WTH, only above-ground biomass harvested), stem-only harvesting (SOH) and control (C). Size of the plot varied from 3.00 to 3.75 ha. Suction tube lysimeters (lysimeter cup made of porous ceramic – 92% pure Al_2O_3 and body of trace metal-free PVC) at 2 depths (30 and 60 cm), open precipitation collectors, and groundwater wells were installed at all sampling plots to collect soil water, wet precipitation, and groundwater samples. Three pairs of lysimeters (30 and 60 cm), and one precipitation collector per sample plot were installed in autumn 2011. Already existing groundwater wells (established in the sites in 2006) were used for groundwater sampling but some of those were dry or did not correspond to site layout (slope) therefore groundwater sampling was possible only in the SOH and WTH plots of the *Hylocomiosa* site, and in the C and WTH plots of the *Myrtillosa* site. Groundwater table level was 10.1 m in *Hylocomiosa* site and 20.9 m in *Myrtillosa* site. Water samples were also taken from small streams bordering *Hylocomiosa* and *Oxalidosa turf. mel*. sites. Water samples were collected twice per month during the vegetation season in 2012 (reference period), 2013, and 2014 (first and second years following clearcutting). In the summer some of the lysimeters were sometimes dry but there was always at least one sample per plot per sampling time. Precipitation samples taken in the clearcut after felling are referred to as bulk precipitation, while those sampled under tree canopy are referred to as throughfall samples.No bulk precipitation samples were taken in the reference period, as the closest open area was located too far from the sites. Clearfelling was performed in early spring 2013 with harvester, timber was extracted and logging residues were removed with forwarder, following ‘business as usual’ principle. During harvest the soil was frozen, and no damage to the soil due to the movement of machinery was observed. At the whole-tree harvested plots all above-ground part of the tree was harvested (in practice this means that approximately 70% of tree tops and branches were removed). At the stem-only harvested plots only the stemwood was removed and logging residues were evenly scattered throughout the plot.

The following chemical parameters were measured in the water samples: pH determined according to LVS ISO 10523:2012; ammonium nitrogen (NH_4-N) determined using manual spectrometric method according to LVS ISO 7150/1:1984; nitrate nitrogen (NO_3-N), nitrite nitrogen (NO_2-N) and dissolved total nitrogen (DTN) determined using FORMACS^{HT} TOC/TN Analyzer (ND25 nitrogen detector) according to LVS EN 12260:2004. Dissolved organic nitrogen (DON) was calculated by subtracting NO_3-N, NO_2-N and NH_4-N concentrations from DTNconcentration. Preservation and handling of water samples were done according to ISO 5667-3:2012. Water samples were filtered using borosilicate glass fiber filters without a binder before determination of NH_4-N, NO_3-N and DTN. Limitof detection (LOD) forNH_4-N is 0.008 mg L^{-1} (9.4% of results below LOD), LOD for NO_3-N is 0.018 mg L^{-1} (4.4% of results below LOD) andLOD for DTN is 0.06 mg L^{-1} (0.4% of results below LOD).

Statistical differences in the monitored chemical parameters of precipitation, groundwater and surface water between study sites as well as significance of changes in monitored chemical parameters due to harvestingwere analyzed with Wilcoxon rank sum test with continuity correction. Statistical differences in monitored chemical parameters of precipitation, groundwater and surface water between different years (significant differences from reference period before harvesting) within each site were analyzed with Wilcoxon signed rank test with continuity correction. We used results of repeated-measures analysis of variance and Tukey’s honestly significant difference (HSD) test to assess the significance of treatment means (within each site) of monitored chemical parameters in soil solution. There were no statistically significant differences in pH, nitrate, ammonium, organic nitrogen and total nitrogen concentration in soil solution between 30 cm and 60 cm depth within each study site and year; consequently, we combined data from both soil solution sampling depths in a single statistical analysis. We used a 95% confidence level in all analyses. Data analysis was conducted in program R (R Core Team, 2015) for Linux.

RESULTS AND DISCUSSION

Precipitation

There were no statistically significant differences in pH, concentration of NO_3-N, NH_4-N, DON and DTN in throughfall and bulk precipitation between the study sites, but we found significant impact of harvesting on mean pH and ammonium concentration in precipitation reaching the ground if the data from all three sites were combined. Bulk precipitation pH values at the clearcut areas were significantly ($p = 0.015$) more alkaline compared with mean throughfall pH values at the control plots at all study sites (Table 3).

Table 3. Mean precipitation pH before (2012) and after (2013–2014) clearfelling in study period (April-October) at the study sites

Study site	Before harvesting	After harvesting	
	Forest	Clearcut	Control
Hylocomiosa	6.6 ± 0.2	6.8 ± 0.2	6.4 ± 0.1
Oxalidosa turf.mel.	6.5 ± 0.2	6.8 ± 0.2	6.5 ± 0.1
Myrtillosa	6.8 ± 0.3	6.9 ± 0.2	6.4 ± 0.2
Mean	6.6 ± 0.1	6.8 ± 0.1*	6.5 ± 0.1

*Significant differences between treatment and control after harvesting.

We detected significantly higher (p = 0.023) mean ammonium concentration in bulk precipitation at clearcut areas compared to throughfall precipitation at control plots after felling. Also a higher nitrate concentration in bulk precipitation at clearcut areas compared to throughfall precipitation at control plots was observed, but no significant differences between nitrate as well as DTN concentration in bulk and throughfall precipitation (in clearcut and control) were detected after felling. It should be noted that nitrate, ammonium, and total nitrogen concentration also decreased in throughfall of the control plots compared with the mean values in the study period before harvesting. After harvesting, DON concentration in throughfall was significantly higher than that in the bulk precipitation at *Hylocomiosa* and *Oxalidosa turf.mel.* sites (p = 0.001 in both cases). The same was true if precipitation data from all three sites were combined (p = 0.000) (Table 4).

At all plots, the N deposition was higher in the first year of the study due to higher throughfall amounts. In Latvia, 2012 was the second wettest year of the 21st century. The adsorption of N (both ammonium and nitrate) from wet deposition by tree canopies in the boreal zone has been demonstrated in several studies, and, at low levels of N deposition, N concentration in the throughfall is smaller than in the bulk precipitation (e.g., Hyvärinen, 1990; Nieminen, 1998; Kristensen et al., 2004). Opposite results are reported for areas with high N deposition (e.g., Kopáček et al., 2009; Drápelová, 2012). Also Nieminen (1998) observed increased nitrate concentration in throughfall compared to bulk precipitation in an area where N deposition was higher than the average for Finland. At our plots annual N deposition may be considered low to moderate (below or slightly above 5 kg ha^{-1}), and our results show slightly higher nitrate and ammonium concentrations in throughfall (but no significant differences). According to Cornell et al (2003), the contribution of the organic component to dissolved total nitrogen in precipitation in Europe is on average 23 ± 8%. At our sites, the DON proportion in the dissolved total nitrogen concentration ranged from 12.5 ± 3.22% to 16.2 ± 7.90% at clearcut plots and from 20.2 ± 7.75% to 54.3 ± 6.53% at control plots. Canopy functions as the source of DON, consequently DON concentration in the bulk precipitation was significantly lower at all study sites. No significant DON concentration differences from the reference period were observed, as these are not correlated with the mean annual precipitation (Michalzik et al., 2001). Despite the fact that DON contribution is highly variable and site specific, it is an important component of atmospheric nitrogen deposition.

Table 4. Mean concentration and annual input of nitrate, ammonium, dissolved total nitrogen and dissolved organic nitrogen with precipitation before (2012) and after (2013–2014) clearfelling in study period (April–October) at the study sites

Study site	Before harvesting		After harvesting			
	Forest		Clearcut		Control	
	Content, mg L^{-1}	Input, kg ha^{-1} yr^{-1}	Content, mg L^{-1}	Input, kg ha^{-1} yr^{-1}	Content, mg L^{-1}	Input, kg ha^{-1} yr^{-1}
NO_3-N						
Hyloco-miosa	0.52 ± 0.17	1.83	0.27 ± 0.08	1.61	0.18 ± 0.07*	0.80
Oxalidosa turf.mel.	0.59 ± 0.13	2.46	0.23 ± 0.05*	1.15	0.18 ± 0.04*	0.75
Myrtillosa	0.71 ± 0.23	2.32	0.27 ± 0.08*	1.00	0.24 ± 0.06*	1.00
Mean	0.60 ± 0.10	2.20 ± 0.19	0.26 ± 0.04*	1.25 ± 0.18	0.20 ± 0.03*	0.85 ± 0.08
NH_4-N						
Hyloco-miosa	0.29 ± 0.12	1.00	0.27 ± 0.10	1.67	0.13 ± 0.06	0.43
Oxalidosa turf.mel.	0.42 ± 0.13	1.60	0.23 ± 0.06	1.24	0.16 ± 0.11	0.55
Myrtillosa	0.30 ± 0.17	0.77	0.31 ± 0.13	1.46	0.22 ± 0.10	0.81
Mean	0.34 ± 0.08	1.12 ± 0.25	0.27 ± 0.06**	1.46 ± 0.12	0.17 ± 0.05*	0.60 ± 0.11
DTN						
Hyloco-miosa	1.18 ± 0.53	3.74	0.59 ± 0.18	3.58	0.53 ± 0.13	2.24
Oxalidosa turf.mel.	1.71 ± 0.68	5.93	0.51 ± 0.11*	2.63	0.64 ± 0.14*	2.82
Myrtillosa	1.87 ± 1.05	6.14	0.62 ± 0.17	3.10	0.56 ± 0.17*	2.37
Mean	1.59 ± 0.43	5.27 ± 0.77	0.58 ± 0.08*	3.10 ± 0.27	0.58 ± 0.08*	2.48 ± 0.18
DON						
Hyloco-miosa	0.36 ± 0.26	0.91	0.05 ± 0.02**	0.31	0.22 ± 0.03	1.01
Oxalidosa turf.mel.	0.70 ± 0.50	1.87	0.05 ± 0.01**	0.24	0.30 ± 0.03	1.52
Myrtillosa	1.01 ± 0.70	3.05	0.04 ± 0.02	0.24	0.11 ± 0.03	0.57
Mean	0.69 ± 0.29	1.94 ± 0.62	0.05 ± 0.01**	0.26 ± 0.02	0.21 ± 0.02	1.03 ± 0.27

*Significant differences from reference period/ **Significant differences between treatment and control.

Changes in pH and nitrogen content in soil water

Mean annual soil solution pH at C, SOH and WTH plots of all three sites before and after harvesting, as well as significant differences, are shown in Table 5. Gradual pH value decrease in the soil water after felling was observed nearly at all harvested plots, reaching significant levels at *Myrtillosa* SOH plot (p = 0.000) and *Oxalidosa turf.mel*. WTH plot (p = 0.001) in the second year after treatment.

Table 5. Mean soil solution pH at the study sites

Site	Treatment	pH		
		2012	2013	2014
Hylocomiosa	C	7.7 ± 0.1	7.4 ± 0.1	7.4 ± 0.1
	SOH	6.8 ± 0.3	6.8 ± 0.2*	6.2 ± 0.2*
	WTH	6.5 ± 0.3	6.7 ± 0.1*	6.1 ± 0.2*
Myrtillosa	C	6.3 ± 0.2	6.7 ± 0.1	6.7 ± 0.1
	SOH	6.8 ± 0.2	6.1 ± 0.1*	*5.2 ± 0.1**
	WTH	7.2 ± 0.3	6.7 ± 0.1**	6.7 ± 0.1**
Oxalidosa turf.mel.	C	7.3 ± 0.1	*7.5 ± 0.1*	7.4 ± 0.1
	SOH	7.5 ± 0.1*	7.7 ± 0.1	7.5 ± 0.1
	WTH	6.8 ± 0.1*/**	6.1 ± 0.2*/**	*5.4 ± 0.2*/***

*Significant differences between treatment and control/ **Significant differences between treatments/ Significant differences from reference period are indicated in italics.

The mean soil water pH value differences between treatments and control varied considerably depending on the year, plot and site (Fig. 2).

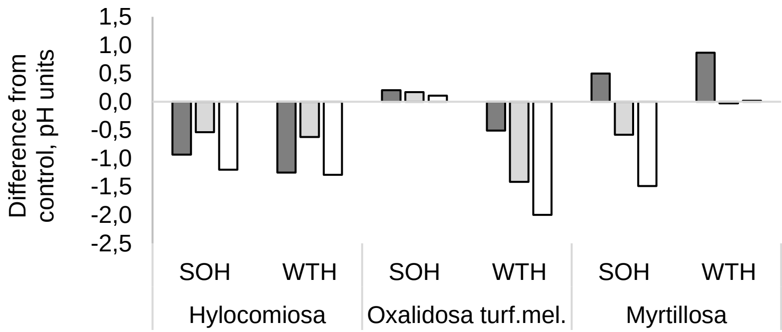

Figure 2. Mean pH value difference from control at the study sites. WTH – whole-tree harvesting; SOH – stem-only harvesting. Error bars show combined standard errors. Dark grey – 2012, light grey – 2013, white – 2014.

These were significant in 2013 and 2014 at SOH (p = 0.034 and p = 0.000, respectively) and WTH plots (p = 0.014 and p = 0.000, respectively) of *Hylocomiosa* and at SOH plot of *Myrtillosa* (p = 0.000 in both years after harvesting), in 2012 at SOH plot of *Oxalidosa turf. mel.*(p = 0.015) but in all study years – at WTH plot of *Oxalidosa turf.mel.* (p = 0.000 in all three years). Significant soil water pH differences between whole-tree harvested and stem-only harvested plots were observed at *Myrtillosa* and *Oxalidosa turf.mel.* sites, both in 2013 and 2014 (p = 0.000 in all cases).

Mean annual plot NO_3-N and NH_4-N concentration at C, SOH and WTH plots of all three sites before and after harvesting, as well as significant differences, are shown in Table 6. Already prior to clearfelling, significant mean NO_3-N concentration differences between treatment and control plots were observed at *Myrtillosa* (p = 0.000 at WTH) and *Oxalidosa turf.mel.* (p = 0.037 at SOH and p = 0.026 at WTH) sites (Table 6). In 2013, the first year after felling, the soil water nitrate nitrogen concentration actually decreased at most plots, except SOH and WTH of *Myrtillosa* and WTH of *Oxalidosa turf.mel*. In the second year after harvesting, the soil water nitrate nitrogen concentration further decreased at all control plots (significantly at both sites on mineral soils; $p = 0.000$) but started to increase at both harvested plots of *Hylocomiosa* ($p = 0.016$ at SOH and $p = 0.002$ at WTH), SOH plot of *Myrtillosa* ($p = 0.000$) and WTH plot of *Oxalidosa turf.mel.*($p = 0.037$). At these plots also the difference from the control plot was most pronounced (Fig. 3). On the contrary, significant nitrate nitrogen decrease compared to the reference period was observed at SOH plot of *Oxalidosa turf.mel.*in 2014 ($p = 0.000$). No significant nitrate concentration differences between clearcut with whole-tree harvesting and clearcut with stem-only harvesting were observed at *Hylocomiosa* site but such differences were found at *Myrtillosa* site in 2012 ($p = 0.014$) and 2014 ($p = 0.000$) and at *Oxalidosa turf.mel.*site in 2013 and 2014 ($p = 0.000$) (Table 6).

Table 6. Mean nitrate and ammonium concentration in soil solution at the study sites

Site	Treat-ment	NO_3-N, mg L^{-1}			NH_4-N, mg L^{-1}		
		2012	2013	2014	2012	2013	2014
Hyloco-miosa	C	1.76 ± 0.15	*0.38 ± 0.14*	*0.11 ± 0.04*	0.05 ± 0.02	0.11 ± 0.07	0.65 ± 0.58
	SOH	1.81 ± 0.30	1.66 ± 0.38	*5.49 ± 0.61**	0.05 ± 0.01	0.23 ± 0.10	0.39 ± 0.11
	WTH	2.07 ± 0.36	1.51 ± 0.47	*6.46 ± 0.61**	0.04 ± 0.01	0.08 ± 0.03	0.43 ± 0.18
Myrtillosa	C	0.58 ± 0.08	*0.13 ± 0.02*	*0.10 ± 0.03*	0.04 ± 0.01	0.02 ± 0.004	0.03 ± 0.01
	SOH	1.01 ± 0.09	2.98 ± 0.47*	*5.82 ± 0.61**	0.05 ± 0.01	0.02 ± 0.01	0.23 ± 0.07
	WTH	1.82 ± 0.36$^{*/**}$	1.99 ± 0.33*	1.10 ± 0.26$^{*/**}$	0.05 ± 0.01	0.02 ± 0.01	0.02 ± 0.01**
Oxalidosa turf.mel.	C	1.06 ± 0.23	0.84 ± 0.18	0.80 ± 0.19	0.06 ± 0.01	*0.02 ± 0.01*	*0.02 ± 0.01*
	SOH	3.10 ± 0.50*	*1.41 ± 0.36*	*0.96 ± 0.31*	0.05 ± 0.01	0.03 ± 0.01	*0.02 ± 0.004*
	WTH	3.87 ± 1.69*	7.62 ± 1.24$^{*/**}$	*10.72 ± 1.59*$^{*/**}$	0.12 ± 0.04**	0.15 ± 0.04$^{*/**}$	0.31 ± 0.08$^{*/**}$

*Significant differences between treatment and control/ **Significant differences between treatments/ Significant differences from reference period are indicated in italics.

NH_4-N concentration in the soil water was similar at all plots during the reference period (2012). Significant difference between treatment and control was observed only at WTH plot of *Oxalidosa turf.mel.* in 2013 and 2014 ($p = 0.000$) (Table 6, Fig. 3). Significant difference between plot with whole-tree harvesting and plot with stem-only harvesting was observed only at *Oxalidosa turf.mel.* site ($p = 0.000$ both in 2013 and 2014), but in this case ammonium concentration in the soil water at WTH plot was significantly higher already before treatment in 2012 ($p = 0.016$). No significant differences from the reference period were observed at both sites on mineral soils but significant decrease of ammonium concentration was detected at *Oxalidosa turf.mel.* site, at the control plot in 2013 and 2014 ($p = 0.000$) and at the SOH plot in 2014 ($p = 0.005$).

DTN concentration in the soil water tended to increase with the time but significant differences from the reference period were observed only at SOH ($p = 0.007$) and WTH

(p = 0.006) plots of *Hylocomiosa* in 2014. Quite contrary, at the SOH plot of *Oxalidosa turf.mel.* the total dissolved N concentration in the soil water in 2013 and 2014 was significantly lower than in 2012 (p = 0.011 and p = 0.003, respectively) (Table 7). Significant differences between treatment and control plots were observed at SOH and WTH plots of both sites on mineral soils (p = 0.021), as well as at the WTH plot of *Oxalidosa turf.mel.* (p = 0.000 in 2013 and 2014). It has to be noted, however, that significant differences between WTH and control plots of *Myrtillosa* and *Oxalidosa turf.mel.* existed already in the reference period (p = 0.001 and p = 0.007, respectively) (Fig. 3). In 2014, at the *Myrtillosa* WTH plot the DTN concentration in the soil water was significantly lower than at the SOH plot of the same site (p = 0.000). The opposite was true for the same plots in the reference period (p = 0.025) and for the *Oxalidosa turf.mel.* site in 2013 and 2014 (p = 0.000).

Table 7. Mean dissolved total and organic nitrogen concentration in soil solution at the study sites

Site	Treat-ment	DTN, mg L^{-1}			DON, mg L^{-1}		
		2012	2013	2014	2012	2013	2014
Hyloco-miosa	C	1.86 ± 0.22	1.03 ± 0.30	1.43 ± 0.70	0.03 ± 0.01	0.41 ± 0.12	*0.46 ± 0.10*
	SOH	3.23 ± 0.68	3.17 ± 0.53*	*9.36 ± 1.12**	0.93 ± 0.87	1.35 ± 0.39	3.38 ± 0.76
	WTH	2.20 ± 0.36	2.17 ± 0.45	*11.09 ± 1.64**	0.09 ± 0.03	0.86 ± 0.17	*4.59 ± 1.32**
Myrtillosa	C	0.68 ± 0.07	0.38 ± 0.04	0.89 ± 0.50	0.06 ± 0.03	0.20 ± 0.04	0.26 ± 0.05
	SOH	1.10 ± 0.10	3.73 ± 0.52*	*7.84 ± 0.73**	0.03 ± 0.01	0.72 ± 0.18*	*1.70 ± 0.27*
	WTH	1.90 ± 0.37$^{*/**}$	2.35 ± 0.34*	1.74 ± 0.33**	0.04 ± 0.01	0.33 ± 0.07	*0.50 ± 0.11***
Oxalidosa turf.mel.	C	2.96 ± 0.49	2.42 ± 0.29	2.56 ± 0.27	2.24 ± 0.40	2.01 ± 0.19	1.78 ± 0.16
	SOH	5.47 ± 0.99	*2.87 ± 0.41*	*2.57 ± 0.46*	2.32 ± 0.58	1.63 ± 0.22	1.59 ± 0.20
	WTH	8.37 ± 2.51*	12.27 ± 2.23$^{*/**}$	15.16 ± 1.62$^{*/**}$	5.42 ± 2.30*	6.37 ± 1.50$^{*/**}$	4.38 ± 0.50$^{*/**}$

*Significant differences between treatment and control/ **Significant differences between treatments/ Significant differences from reference period are indicated in italics.

In the reference period, DON concentration in the soil water was highest at WTH plot of *Oxalidosa turf.mel.*site, and the difference from control was significant (p = 0.040). Dissolved organic N concentration at the WTH plot of *Oxalidosa turf.mel.* remained significantly higher than at the control site also in 2013 and 2014 (p = 0.000). Also at SOH plot of Myrtillosa in 2013 and WTH plot of Hylocomiosa in 2014 DON concentration was significantly higher than at the control plots (p = 0.043 and p = 0.027, respectively). Dissolved organic N concentration in the soil water at both sites on mineral soil tended to increase after the harvesting; significant increase compared to the reference period were observed in the second year after harvesting at SOH and WTH plots of Myrtillosa (p = 0.000 and p = 0.009, respectively), WTH plot of *Hylocomiosa*

(p = 0.049), but also at control plot of *Hylocomiosa*. In 2014, soil water DON concentration at SOH plot of *Myrtillosa* was significantly higher than that at WTH plot of the same site (p = 0.023). The opposite was true for harvested plots of *Oxalidosa turf.mel.*, both in 2013 and 2014 (p = 0.000) (Table 7, Fig. 3).

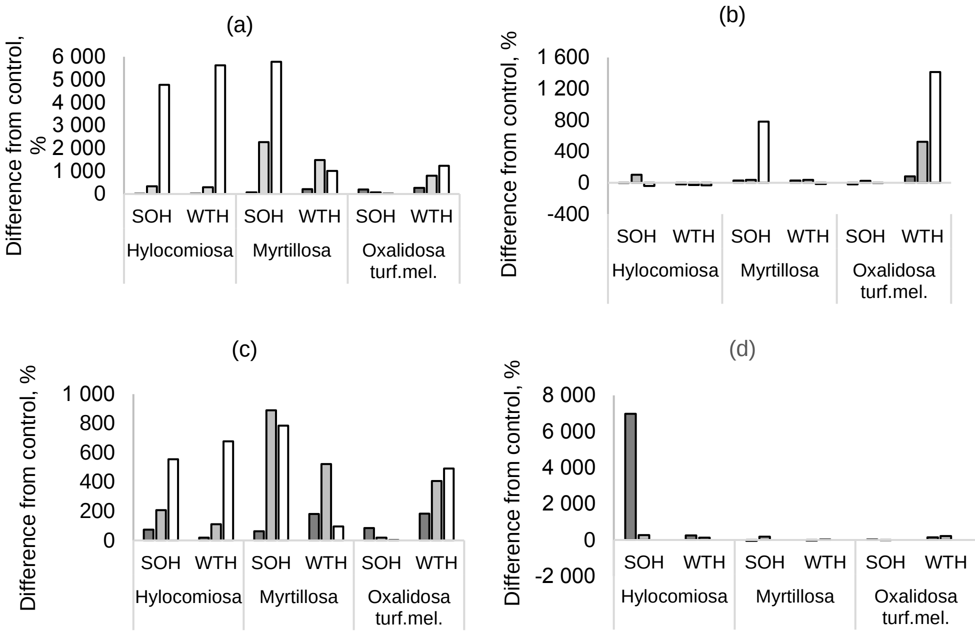

Figure 3. Nitrate (a), ammonium (b), dissolved total nitrogen (c) and dissolved organic nitrogen (d) concentration difference (%) from control in soil solution at the study sites. Dark grey – 2012, light grey – 2013, white – 2014.

High nitrate concentrations in the soil water may suggest high potential for leaching losses of nitrogen. Nieminen (1998) reported increase of the ammonium concentration in soil water in the first year after clearfelling but no statistically significant DON or nitrate differences. At our sites no significant changes of nitrate, ammonia or DON concentration in the soil water at the harvested plots were observed in 2013, except significant decrease of nitrate at the SOH plot of *Oxalidosa turf.mel*. In 2014, elevated N concentrations in the soil solution were detected at several but not all plots. Differences between harvested and control plots were more explicit in the second year after harvesting. Ring (1996, 2004) explains elevated nitrate N content with increased nitrification. Also our results suggest this, since nitrate concentrations were elevated at those plots where pH was lowered. Previous results suggest that there may be a considerable time lag following harvest before significant changes of N content in the soil water are demonstrated (Ring, 1996; Löfgren et al., 2009; Futter et al., 2010). Concentration increase of inorganic N compounds in the soil water after felling may be caused by higher mineralization rate of organic matter due to soil disturbance, changed microclimate and availability of logging residues, increased runoff and disrupted nitrogen uptake by vegetation (Gundersen et al., 2006; Löfgren et al., 2009). Data on this are, however, not consentient, e.g., Palviainen et al. (2004) concluded that logging residues may cause significant N immobilization with no net release during the first years after harvesting. Bergholm et al. (2015) also suggested that immobilization of N by stump and root necromass may be of importance. Evidence on positive relationship between the site productivity or N deposition and nitrogen leaching is repeatedly reported (e.g., Wiklander et al., 1983; Bredemeier et al., 1998; Rothe & Mellert, 2004). A few studies on richer Norway spruce sites found increasing nitrate concentrations in soil water immediately after clear-cut (Berdén et al., 1997; Hedwall et al., 2013). Leaching of inorganic N after clear-cutting normally lasts for 5-8 years, with a peak after 1–2 years (Huber et al., 2004; Ring, 2004; Futter et al., 2010; Hedwall et al., 2013). The peak concentration of NO_3-N in the soil solution can vary from below 0.5 mg L^{-1} (Berdén et al., 1997) to 30 mg L^{-1} (Huber et al., 2004). As our sites represent medium fertility conditions and the N deposition is low, it can be expected that concentration of N compounds in the soil water may still increase in the following years. We hypothesized that soil solution N concentration would differ in clearcuts with all above-ground biomass and stem-only biomass removed. Indeed, we found significant differences between SOH and WTH plots at both our sites that differed most in site productivity, but the pattern of difference was opposite. At the *Oxalidosa* (more productive) site concentration of all N compounds was higher at the WTH plot, both in 2013 and 2014. At the *Myrtillosa* (less productive) site concentration of all N compounds was higher at the SOH plot, and significant differences were demonstrated only in 2014. Ring et al (2001) found no significant effect of brash removal on soil solution N concentration 5 years after felling. At our plots, the differences between treatments may still increase in the following years. Model simulations performed by Laurén et al. (2005) suggested that most important sinks of N after clearfelling are immobilization by the soil microbes, uptake by ground vegetation and sorption to soil. Stem-only biomass removal with brash left on site may suppress the ground vegetation, and this is most likely an important factor influencing soil water N content at the *Myrtillosa* site on poor sandy soil where soil microbial activity and soil sorption capacity is low.

Changes in pH and nitrogen content in groundwater

Due to the reasons explained in the Material and Method, groundwater sampling was possible only at the SOH and WTH plots of the *Hylocomiosa* site and at the C and WTH plots of the *Myrtillosa* site. In the reference period, mean NO_3-N concentration in the groundwater was the highest at SOH plot of *Hylocomiosa* and lowest at control plot of *Myrtillosa*. Significant difference was observed only between SOH and WTH plots of *Hylocomiosa* in 2012 ($p = 0.027$). In 2013 and 2014, the nitrate nitrogen concentration in groundwater decreased at all plots, and the difference from the reference period was significant in all cases ($p < 0.022$) (Table 8, Fig. 4).

Groundwater NH_4-N concentration in the reference period was highest at the SOH plot of *Myrtillosa* and lowest at the WTH plots at both sites, but significant differences were observed only between the SOH and WTH plots of *Hylocomiosa* ($p = 0.043$). Also, the ammonium concentration in ground water decreased after felling; the difference from the reference period was significant at the WTH plot of *Hylocomiosa* ($p = 0.035$) and at the C plot of *Myrtillosa* ($p = 0.028$) in 2013, and at the SOH plot of *Hylocomiosa* ($p = 0.014$), as well as at the C and WTH plot of *Myrtillosa* in 2014 ($p = 0.010$ and $p = 0.005$, respectively) (Table 8, Fig. 4).

DTN concentration at all plots was highest in the reference period. Significant differences were detected between the SOH and WTH plots of *Hylocomiosa* in 2013 ($p = 0.038$), but difference was not significant in 2014. At all plots, there was a significant total nitrogen concentration difference from the reference period in both 2013 and 2014 ($p < 0.002$).

DON concentration in groundwater tended to decrease after harvesting, significant decrease compared to the reference period was observed at WTH plot of *Hylocomiosa* in 2013 ($p = 0.024$) and at all sampled plots in 2014 – SOH and WTH of *Hylocomiosa* ($p = 0.013$ and $p = 0.042$, respectively) and C and WTH plots of *Myrtillosa* ($p = 0.005$ and $p = 0.017$, respectively). Significant differences between plots of the same site were detected only at *Myrtillosa* site in 2014, with groundwater DON concentration significantly higher at the harvested than at the control plot ($p = 0.001$) (Table 8, Fig. 4).

Table 8. Mean pH, nitrate, ammonium, dissolved total nitrogen and dissolved organic nitrogen concentration in groundwater at the study sites

Site	Treatment	2012	2013	2014
pH				
Hylocomiosa	SOH	8.0 ± 0.1	7.9 ± 0.1	8.0 ± 0.1
	WTH	8.0 ± 0.1	7.8 ± 0.2	8.1 ± 0.1
Myrtillosa	C	7.9 ± 0.1	8.1 ± 0.1**	8.0 ± 0.1
	WTH	7.7 ± 0.1	8.0 ± 0.1**	8.0 ± 0.1**
NO_3-N, mg L^{-1}				
Hylocomiosa	SOH	1.07 ± 0.018	0.20 ± 0.04**	0.08 ± 0.03**
	WTH	0.59 ± 0.20*	0.12 ± 0.02**	0.05 ± 0.01**
Myrtillosa	C	0.47 ± 0.10	0.07 ± 0.02**	0.04 ± 0.01**
	WTH	0.57 ± 0.10	0.09 ± 0.01**	0.04 ± 0.01**
NH_4-N, mg L^{-1}				
Hylocomiosa	SOH	0.06 ± 0.02	0.03 ± 0.01	0.02 ± 0.01**
	WTH	0.02 ± 0.01*	0.01 ± 0.003*/**	0.01 ± 0.004
Myrtillosa	C	0.03 ±0.003	0.01 ± 0.01**	0.01 ± 0.002**
	WTH	0.02 ± 0.01	0.03 ± 0.003	0.01 ± 0.002**
DTN, mg L^{-1}				
Hylocomiosa	SOH	1.67 ± 0.32	0.86 ± 0.52**	0.20 ± 0.07**
	WTH	1.06 ± 0.26	0.19 ± 0.02*/**	0.11 ± 0.01**
Myrtillosa	C	1.09 ± 0.40	0.16 ± 0.03**	0.08 ± 0.01**
	WTH	1.81 ± 0.72	0.19 ± 0.02**	0.13 ± 0.01*/**
DON, mg L^{-1}				
Hylocomiosa	SOH	0.57 ± 0.25	0.63 ± 0.53	0.10 ± 0.05**
	WTH	0.45 ± 0.22	0.06 ± 0.02**	0.03 ± 0.01**
Myrtillosa	C	0.60 ± 0.43	0.08 ± 0.03	0.03 ± 0.01**
	WTH	1.22 ± 0.76	0.08 ± 0.02	0.07 ± 0.01*/**

*Significant differences between treatments within year/ **Significant differences from reference period within treatment.

Part of the N from the soil solution is leached to groundwater and further exported to streams. Kubin (1998) reported elevated N concentration in the groundwater as long as 10 years after clearfelling and slash removal at the middle boreal conifer forest zone. In our study, nitrate, ammonium, dissolved organic nitrogen and dissolved total nitrogen concentration in groundwater actually decreased after felling. It has to be noted, however, that groundwater level was very low at all plots; therefore, it is possible that the concentrations of N-compounds in groundwater were not at all affected by felling.

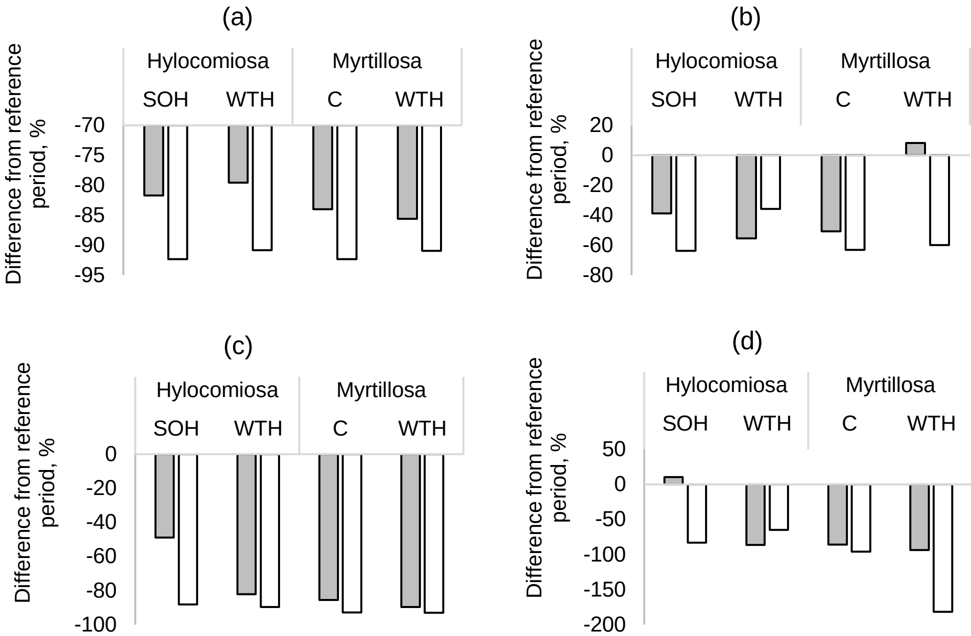

Figure 4. Nitrate (a), ammonium (b), dissolved total nitrogen (c) and dissolved organic nitrogen (d) concentration difference from reference period (2012) in groundwater at the study sites WTH – whole-tree harvesting; SOH – stem-only harvesting; C – control. Grey – 2013, white – 2014.

Changes in pH and nitrogen content in surface water

In 2012, the mean NO_3-N concentration in the streams bordering the *Hylocomiosa* and *Oxalidosa turf. mel.* sites was similar. Concentrations decreased significantly in 2013 (p = 0.013 in *Hylocomiosa* and p = 0.000 in *Myrtillosa*) and increased again in 2014, but did not reach the reference period level (Table 9).

Mean NH_4-N concentration in both streams was the same in 2012, and it decreased in the following years, with the differences from the reference period being significant (in *Hylocomiosa*, p = 0.003 and p = 0.004 in 2013 and 2014; in *Oxalidosa turf.mel.*, p = 0.000 in both 2013 and 2014).

DTN concentration was initially (in 2012) higher in the stream bordering the *Hylocomiosa* site. Also in this case the pattern of change was rather similar: a decrease was observed in 2013, and an increase occurred again in 2014. Differences from the reference period were significant in both streams in both years after harvesting (p = 0.000), and the reference period concentration of total nitrogen after the clearfelling was not reached.

DON concentration followed the same pattern of change – decrease in 2013, slight increase in 2014 but below the level of reference period. Significant differences from the reference period were observed in the stream bordering *Hylocomiosa* both in 2013 (p = 0.001) and 2014 (p = 0.004) and in the stream bordering *Oxalidosa turf.mel.* in 2013 (p = 0.000) (Table 9, Fig. 5).

Table 9. Mean pH, nitrate, ammonium, dissolved total nitrogen and dissolved organic nitrogen concentration in surface water at the study sites

Site	2012	2013	2014
pH			
Hylocomiosa	7.9 ± 0.1	8.1 ± 0.1*	8.0 ± 0.1
Oxalidosa urf.mel.	7.9 ± 0.1	8.1 ± 0.1*	8.1 ± 0.1*
NO_3-N, mg L^{-1}			
Hylocomiosa	0.67 ± 0.12	0.24 ± 0.06*	0.29 ± 0.04*
Oxalidosa urf.mel.	0.69 ± 0.13	0.20 ± 0.06*	0.66 ± 0.22
NH_4-N, mg L^{-1}			
Hylocomiosa	0.03 ± 0.003	0.01 ± 0.003*	0.02 ± 0.004*
Oxalidosa urf.mel.	0.03 ± 0.003	0.01 ± 0.003*	0.01 ± 0.001*
DTN, mg L^{-1}			
Hylocomiosa	2.01 ± 0.27	0.80 ± 0.08*	0.90 ± 0.09*
Oxalidosa urf.mel.	1.38 ± 0.21	0.36 ± 0.08*	1.08 ± 0.35
DON, mg L^{-1}			
Hylocomiosa	1.51 ± 0.29	0.55 ± 0.05*	0.59 ± 0.07*
Oxalidosa urf.mel.	0.69 ± 0.16	0.15 ± 0.03*	0.41 ± 0.14

*Significant differences from reference period within each site.

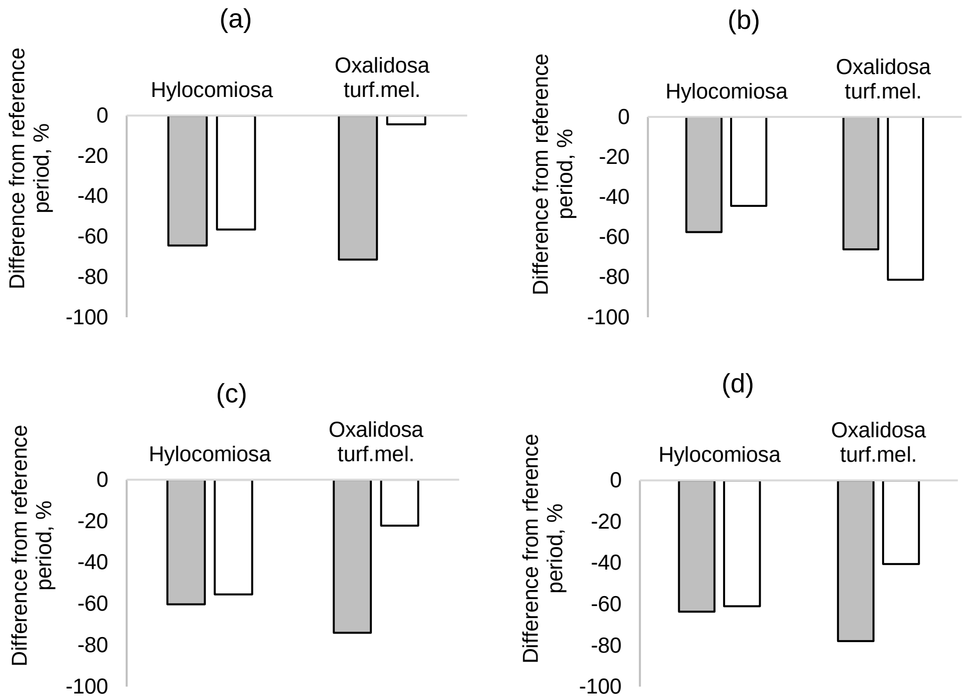

Figure 5. Nitrate (a), ammonium (b), dissolved total nitrogen (c) and dissolved organic nitrogen (d) concentration difference from reference period (2012) in surface water at the study sites. Grey – 2013, white – 2014.

Forest management activities have the potential to adversely affect downstream water quality (Futter et al., 2010). Studies in Sweden have demonstrated that while all forest management activities can impact surface water quality, the effects of final felling and subsequent site preparation are the most dramatic (Löfgren et al., 2014). In the study by Nieminen (2004) on Norway spruce forests growing on drained peatlands in southern Finland, outflow concentrations of NH_4-N and NO_3-N increased at clear-cut areas, but large differences were observed between sites. The average annual increase in NH_4-N concentrations during the first four years after clear-cutting ranged from 0.04 mg L^{-1} to 0.31 mg L^{-1}; increases for NO_3^--N ranged from 0.05 to 0.22 mg L^{-1}. Doubled total N and nitrate concentration in brooks after clearfelling was reported by Ahtiainen and Huttunen (1999). According to study by Nieminen (2003), leaching of dissolved N was most pronounced in the second and third year after treatment, and it was favored by clearcutting with ditching and mounding while clearcutting alone and clearcutting with mounding did not cause significant changes. Results from streams bordering our study objects demonstrated a decrease of nitrate, ammonium, and dissolved organic nitrogen concentration in the first year after clearfelling. Concentrations started to increase in the second year, but the concentration of N-compounds did not reach the level of the reference period. Not all dissolved N is exported to streams, large differences between soil solution and streamwater nitrate concentrations may be observed (Futter et al., 2010). Typically streamwater N concentration is lower than that of the soil solution, as it was also in our case. Riparian buffer zone may attenuate N export to streams by denitrification, immobilization and plat uptake (Gundersen et al., 2010). The processes at the riparian zones are, however, complex and not yet fully clear, and N attenuation may strongly depend on site hydrology and other specific local conditions of the area that should be considered. Design of site-specific buffer zones may provide for reduced leaching of dissolved N to surface waters, as well as for reduction of forest management costs (Ågren et al., 2014; Kuglerová et al., 2014). These topics are presently of large interest in the Nordic-Baltic forest research community and are closely followed also by the authors of current study.

Our results are the first preliminary contribution to the quantification of inorganic nitrogen in soil-, ground-, and surface waters following two types of clearfelling (whole tree harvesting and stem-only harvesting) in Latvia. Sampling in the experimental sites is being continued, with soil preparation carried out in autumn 2014 and planting in spring 2015. As the impact of harvesting on N leaching usually lasts at least 5 years after felling further monitoring of the plots will be carried out to determine middle-term effects of forest management. Longer study period, calculation of N fluxes and inclusion of additional factors in the analysis (e.g., growth of the young stand, ground vegetation dynamics, amount of slash, nitrogen content changes in the buffer zone), will provide us with the results that will further contribute to better understanding of nutrient cycling processes in the forest ecosystems after forest management operations and the nature of possible differences between Nordic and Baltic countries.

CONCLUSIONS

Soil solution nitrate nitrogen concentration at the harvested plots was elevated in 2014 while pH values were lowered, suggesting enhanced nitrification. Generally, increase of the concentration of N-compounds after clearfelling, as compared with the reference period, was observed only in the second year after clearfelling. The differences between WTH and SOH varied depending on the site. Vegetation cover and soil properties are likely the most important influencing factors but quantification of this impact requires additional data and analyses.

Nitrogen concentration in the groundwater decreased after the clearfelling. Forests on dry mineral soils with very low groundwater levels are probably not subject to the risk of groundwater pollution after clearfelling.

No elevated nitrogen concentration in streamwater was observed during the first and second year after harvesting. This is most likely related to N attenuation by the forested buffer between the clearcut and stream, and effect of the bufferzone will be further investigated, as the sampling continues.

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REFERENCES

Ågren, A., Lidberg, W., Strömgren, M., Ogilvie, J. & Arp, P. 2014. Evaluating digital terrain indices for soil wetness mapping – a Swedish case study. *Hydrology and Earth System Sciences* **18**, 3623–3634.

Ahtiainen, M. 1992. The effects of forest clear-cutting and scarification on the water quality of small brooks. *Hydrobiologia* **243/244**, 465–473.

Ahtiainen, M. & Huttunen, P. 1999. Long-term effects of forestry management on water quality and loading in brooks. *Boreal Environment Research* **4**, 101–114.

Åström, M., Dynesius, M., Hylander, K. & Nilsson, C. 2005. Effects of slash harvest on bryophytes and vascular plants in southern boreal forest clear-cuts. *Journal of Applied Ecology* **42**, 1194–1202.

Bengtsson, J., Lundkvist, H., Saetre, P., Sohlenius, B. & Solbreck, B. 1998. Effects of organic matter removal on the soil food web: Forestry practices meets ecological theory. *Applied Soil Ecology* **9**, 137–143.

Bengtsson, J. & Wikström, F. 1993. Effects of whole-tree harvesting on the amount of soil carbon: model results. *New Zealand Journal of Forest Science* **23**, 380–389.

Berdén, M., Nilsson, S.I. & Nyman, P. 1997. Ion leaching before and after clear-cutting in a Norway spruce stand – effects of long-term application of ammonium nitrate and superphosphate. *Water, Air and Soil Pollution* **93**, 1–26.

Bergholm, J., Olsson, B.A., Vegerfors, B. & Persson, T. 2015. Nitrogen fluxes after clear-cutting. Ground vegetation uptake and stump/root immobilisation reduce N leaching after experimental liming, acidification and N fertilisation. *Forest Ecology and Management* **342**, 64–75.

Bishop, K., Allan, C., Bringmark, L., Garcia, E., Hellsten, S., Hogbom, L., Johansson, K., Lomander, A., Meili, M., Munthe, J., Nilsson, M., Porvari, P., Skyllberg, U., Sorensen, R., Zetterberg, T. & Akerblom, S. 2009. The effects of forestry on Hg bioaccumulation in nemoral/boreal waters and recommendations for good silvicultural practice. *Ambio* **38**, 373–380.

Bredemeier, M., Blanck, K., Xu, Y.J., Tietema, A., Boxman, A.V., Emmett, B., Moldan, F., Gundersen, P., Schleppi, P. & Wright, R.F. 1998. Input-output budgets at the NITREX sites. *Forest Ecology and Management* **101**, 57–64.

Carpenter, S.R., Caraco, N.F., Correll, D.L., Howarth, R.W., Sharpley, A.N. & Smith, V.H. 1998. Nonpoint pollution of surface waters with phosphorus and nitrogen. *Ecological Applications* **8**, 559–568.

Cornell, S.E., Jickells, T.D., Cape, J.N., Rowland, A.P. & Duce, R.A. 2003 Organic nitrogen deposition on land and coastal environments: a review of methods and data. *Atmospheric Environment* **37**, 2173–2191.

De Wit, H.A., Granhus, A., Lindholm, M., Kainz, M.J., Lin, Y., Veiteberg Braaten, H.F. & Blaszczak, J. 2014. Forest harvest effects on mercury in streams and biota in Norwegian boreal catchments. *Forest Ecology and Management* **324**, 52–63.

Drápelová, I. 2012. Organic and inorganic nitrogen in precipitation and in forest throughfall at the Bílý Kříž site (Beskydy Mts., Czech Republic) *Journal of Forest Science* 58(2), 88–100.

Dzilna, I. 1970. Resources, composition and dynamics of groundwater in the Baltics. Riga, 185 pp. (in Russian).

EUSTAFOR & Patterson, T. (2011). *Ecosystem Services in European State Forests*. European State Forest Association, Brussels, 40 pp.

FAO 2010. *Global Forest Resources Assessment 2010*. FAO Forestry Research Paper 163, Rome, 387 pp.

Fisher, B., Turner, R.K. & Morling, P. 2009. Defining and classifying ecosystem services for decision making. *Ecological Economics* **68**, 643–653.

Futter, M.N., Ring, E., Högbom, L., Entenmann, S. & Bishop, K.H. 2010. Consequences of nitrate leaching following stem-only harvesting of Swedish forests are dependent on spatial scale. *Environmental Pollution* **158**, 3552–3559.

Gundersen, P., Laurén, A., Finér, L., Ring, E., Koivusalo, H., Saetersdal, M., Weslien, J.O., Sigurdsson, B.D., Högbom, L., Laine, J. & Hansen, K. 2010. Environmental services provided from riparian forests in the nordic countries. *Ambio* **39**, 555–566.

Gundersen, P., Schmidt, I.K. & Raulund-Rasmussen, K. 2006. Leaching of nitrate from temperate forests e effects of air pollution and forest management. *Environmental Reviews* **14**, 1–57.

Gunnarsson, B., Nittérus, K. & Wirdenäs, P. 2004. Effects of logging residue removal on ground-active beetles in temperate forests. *Forest Ecology and Management* **201**, 229–239.

Hedwall, P.O., Grip, H., Linder, S., Lövdahl, L., Nilsson, U. & Bergh, J. 2013. Effects of clear-cutting and slash removal on soil water chemistry and forest-floor vegetation in a nutrient optimised Norway spruce stand. *Silva Fennica* **47**, 2, 16 pp. [online 16 June 2015] URL: http://dx.doi.org/10.14214/sf.933

Huber, C., Weis, W., Baumgarten, M. & Göttlein, A. 2004. Spatial and temporal variation of seepage water chemistry after femel and small scale clear-cutting in a N-saturated Norway spruce stand. *Plant and Soil* **267**, 23–40.

Hyvärinen, A. 1990. Deposition on forest soil – effect of tree canopy on throughfall. In: *Acidification in Finland*, Kauppi et al. (Eds.). Springer-Verlag Berlin, Heidelberg, pp. 199–213.

Indriksons, A. 2010. Cycle of biogenous elements in drained forests. *Resume of the PhD thesis*, Jelgava, 64 pp.

Indriksons, A. & Zālītis, P. 2000. The impact of hydrotechnical drainage on cycle of some biogenous elements in forest. *Baltic Forestry* **6**(1), 18–24.

Kopáček,J., Turek,J., Hejzlar, J. &Šantrůčková, H. 2009. Canopy leaching of nutrients and metals in a mountain spruce forest. *Atmospheric Environment* **43**, 5443–5453.

Kreutzweiser, D.P., Haylett, P.W. & Gunn, J.M. 2008. Logging impacts on the biogeochemistry of boreal forest soils and nutrient export to aquatic systems: a review. *Environmental Reviews* **16**, 157–179.

Krieger, D.J. 2001. *The Economic value of forest ecosystem services: a review*. The Wilderness Society, Washington D.C., 40 pp.
Kristensen, H.L., Gundersen, P., Callesen, I.& Reinds, G.J. 2004. Throughfall nitrogen deposition has different impacts on soil solution nitrate concentration in European coniferous and deciduous forests. *Ecosystems* **7**, 180–192.
Kubin, E. 1998. Leaching of nitrate nitrogen into the groundwater after clear felling and site preparation. *Boreal Environment Research* **3**, 3–8.
Kuglerová, L., Ågren, A., Jansson, R. & Laudon, H. 2014. Towards optimizing riparian buffer zones: Ecological and biogeochemical implications for forest management. *Forest Ecology and Management* **334**, 74–84.
Latvian Ministry of Economics. 2010. Republic of Latvia National Renewable Energy Action Plan for implementing 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 by 2020, *Latvian Ministry of Economics*, Riga, pp. 103. [online 16 June 2015] URL: http://ec.europa.eu/energy/sites/ener/files/documents/dir_2009_0028_action_plan_latvia.zip
Laudon, H., Hedtjärn, J., Schelker, J., Bishop, K., Sørensen, R. & Ågren, A. 2009. Response of Dissolved Organic Carbon following Forest Harvesting in a Boreal Forest. AMBIO: A *Journal of the Human Environment* **38**(7), 381–386.
Laurén, A., Finér, L., Koivusalo, H., Kokkonen, T., Karvonen, T., Kellomäki, S., Mannerkoski, H. & Ahtiainen, M. 2005. Water and nitrogen processes along a typical water flowpath and streamwater exports from a forested catchment and changes after clear-cutting: a modelling study. *Hydrology & Earth System Sciences* **9**(6):657–674.
Löfgren, S., Fröberg, M., Yu, J., Nisell, J. & Ranneby, B. 2014. Water chemistry in 179 randomly selected Swedish headwater streams related to forest production, clear-felling and climate. *Environmental Monitoring and Assessment* **186**(12), 8907–8928.
Löfgren, S., Ring, E., von Brömssen, C., Sørensen, R. & Högbom, L. 2009. Short-term effects of clear-cutting on the water chemistry of two boreal streams in northern Sweden: A paired catchment study. *Ambio* **38**, 347–356.
Maes, J., Teller, A., Erhard, M., Liquete, C., Braat, L., Berry, P., Egoh, B., Puydarrieux, P., Fiorina, C., Santos, F., Paracchini, M.L., Keune, H., Wittmer, H. & Hauck, J. 2013. *Mapping and Assessment of Ecosystems and their Services. An analytical framework for ecosystem assessments under action 5 of the EU biodiversity strategy to 2020*. Publications office of the European Union, Luxembourg. 60 pp.
Merganičová, K., Pietsch, S.A. & Hasenauer, H. 2005. Testing mechanistic modelling to assess impacts of biomass removal. *Forest Ecology and Management* **207**, 37–57.
Michalzik, B., Kalbitz, K., Park, J.H., Solinger, S. & Matzner, E. 2001. Fluxes and concentrations of dissolved organic carbon and nitrogen – a synthesis for temperate forests. *Biogeochemistry* **52**, 173–205.
Miettinen, J., Ollikainen, M., Finér, L., Koivusalo, H., Laurén, A. & Valsta, L. 2012. Diffuse load abatement with biodiversity co-benefits: the optimal rotation age and buffer zone size. *Forest Science* **58**(4), 342–352.
Miura, S., Amacher, M., Hofer, T., San-Miguel-Ayanz, J., Ernawati & Thackway, R. 2015. Protective functions and ecosystem services of global forests in the past quarter-century. *Forest Ecology and Management* **352**, 35–46.
Munthe, J. & Hultberg, H. 2004. Mercury and methylmercury in runoff from a forested catchment – concentrations, fluxes, and their response to manipulations. *Water, Air and Soil Pollution: Focus* **4**, 607–618.
Nasi, R., Wunder, S. & Campos, J.J. 2002. *Forest Ecosystem services: can they pay our way out of deforestation?* A discussion paper for the Forestry Roundtable to be held in conjunction with the UNFF II, Costa Rica on March 11, 2002. 38 pp.

Nieminen, M. 1998. Changes in nitrogen cycling following the clearcutting of drained peatland forests in southern Finland. *Boreal Environment Research* **3**, 9–21.
Nieminen, M. 2003. Effects of clear-cutting and site preparation on water quality from a drained Scots pine mire in southern Finland.*Boreal Environment Research* **8**,5 3–59.
Nieminen, M. 2004. Export of dissolved organic carbon, nitrogen and phosphorus following clear-cutting of three Norway spruce forests growing on drained peatlands in southern Finland. *Silva Fennica* **38**(2), 123–132.
Nikodemus, O., Kārkliņš, A., Kļaviņš, M. & Melecis, V. 2009. *Sustainable use and protection of soil.* Rīga, LU Akadēmiskais Apgāds, 256 pp. (in Latvian).
Olsson, B.A. & Staaf, H. 1995. Influence of harvesting intensity of logging residues on ground vegetation in coniferous forests. *Journal of Applied Ecology* **32**, 640–654.
Palviainen, M., Finér, L., Kurka, A.M., Mannerkoski, H., Piirainen, S. & Starr, M. 2004. Decomposition and nutrient release from logging residues after clear-cutting of mixed boreal forest. *Plant and Soil* **263**(1), 53–67.
Porvari, P., Verta, M., Munthe, J. & Haapanen, M. 2003. Forestry practices increase mercury and methyl mercury output from boreal forest catchments. *Environmental Science & Technology* **37**, 2389–2393.
Powell, I., White, A. & Landell-Mills, N. 2002. *Developing markets for the ecosystem services of forests*. Forest Trends Washington D.C., 12 pp.
Ring, E. 1996. Effects of previous N fertilizations on soil-water pH and N concentrations after clear-felling and soil scarification at a Pinus sylvestris site. *Scandinavian Journal of Forest Research* **11**, 7–16.
Ring, E. 2004. Experimental N fertilization of Scots pine: effects on soil-solution chemistry 8 years after final felling. *Forest Ecology and Management* **188**, 91–99.
Ring, E., Högbom, L. & Nohrstedt, H.Ö. 2001. Effects of brash removal after clear felling on soil and soil solution chemistry and field layer biomass in an experimental nitrogen gradient. *The Scientific World* **1**(S2), 457–466.
Rolff, C. & Ågren, G.I. 1999. Predicting effects of different harvesting intensities with a model of nitrogen limited forest growth. *Ecological Modelling* **118**, 193–211.
Rothe, A. & Mellert, K.H. 2004. Effects of Forest Management on Nitrate Concentrations in Seepage Water of Forests in Southern Bavaria, Germany**.** *Water, Air, and Soil Pollution* **156**(1), 337–355.
Thiffault, E., Hannam, K.D., Pare, D., Titus, B.D., Hazlett, P.W., Maynard, D.G. & Brais, S. 2011. Effects of forest biomass harvesting on soil productivity in boreal and temperate forests – a review. *Environmental Reviews* **19**, 278–309.
Virbulis, A., Bethers, U., Saks, T., Sennikovs, J. & Timuhins, A. 2013. Hydrogeological model of the Baltic artesian basin. *Hydrogeology Journal* **21**(4), 845–862.
Wall, A. 2012. Risk analysis of effects of whole-tree harvesting on site productivity. *Forest Ecology and Management* **282**, 175–184.
Wiklander, G. 1983. Nitrogen leaching from fertile forest land in southern Sweden. Stockholm. *Journal of the Royal Forestry and Agricultural Academy* **1122**, 311–317 (in Swedish).
Wunder, S. & Jellesmark-Thorsen, B. 2014. Quantifying water externalities from forests. In: *The provision of forest ecosystem services*, Thorsen et al. (Eds.). European Forest Institute, Joensuu, Finland, 21–25.
Zālītis, P. 2006. *Preconditions of forest management*. Riga, et cetera, 217 pp. (in Latvian).
Zālītis, P. 2012. *Forest and water*. Salaspils, Silava, 356 pp. (in Latvian).

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Carbon stock changes in drained arable organic soils in Latvia: results of a pilot study

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Abstract. Drained arable organic soils in the most of European countries represent a minor part of the total area of farmlands, but these soils contribute significantly to national greenhouse gas budgets. The aim of the pilot study is to demonstrate methodology for determination of the changes of soil organic carbon stock after drainage of arable land on organic soil by evaluation of subsidence of the land surface from detailed historical pre-drainage topographic maps created during designing of drainage systems and LiDAR. Results of a pilot study show that ground surface level in arable land on organic soil has decreased by 0.8 cm annually after drainage, but soil organic carbon stock has decreased by 4.2 ± 3.3 tonnes C ha^{-1} yr^{-1}. The results of a study show that pre-drainage topographic maps are suitable for estimation of organic layer subsidence after drainage. The estimated mean CO_2 emissions are about 47% less than the default emission factor for drained arable organic soils in boreal and temperate climate zone provided by Intergovernmental Panel on Climate Change Guidelines for National Greenhouse Gas Inventories. The results substantiate the necessity to develop national methodology to estimate emissions from drained organic soils in cropland and grassland.

Key words: carbon stock, drained agricultural land, LiDAR, organic soil, subsidence.

INTRODUCTION

Peatlands are the most effective terrestrial ecosystems at sequestering C over millennial timescales (Leifeld et al., 2011; Loisel et al., 2017). Although they cover only about 3% of the global land area, during the Holocene (the last ca. 11,700 years), high latitude peatlands have accumulated approximately 500 Pg C (Pg = 10^{15} g), which is equivalent to approximately 30% of global soil organic C, and nearly equal to the pre-industrial atmospheric C reservoir (Gorham, 1991; Yu, 2012; Mathijssen et al., 2016). Farmed organic soils in most European countries represent a minor part of the total agricultural area, but these soils contribute significantly to national greenhouse gas (GHG) budgets (Kasimir-Klemedtsson et al., 1997; Fell et al., 2016). Carbon fixed in plant residues through photosynthesis may enter anoxic settings and accumulate as peat, serving as a reservoir in the global C cycling (Joosten & Clarke, 2002). In the warm boreal and temperate zones, many peatlands have been and are still drained to make them usable for agriculture (Luan & Wu, 2015; Bader et al., 2017). When organic soils are drained, the organic soil loses the mechanical support of the water (flotation) and the initial subsidence is rapid, augmented by the pressure from the drained but still water-holding top layer of the peat (consolidation). The dry organic matter is decomposed by microorganisms resulting in tighter compaction, increased bulk density and continuous subsidence (shrinkage) (Fell et al., 2016). Organic soils subside at a rate of 2–20mm yr^{-1} due to oxidation, i.e. microbial respiration emitting CO_2 and continue to subside until the water table reaches the soil surface or until all the peat is oxidised (Berglung, 2011). Cultivation of organic soils (repeated ploughing of the soil, fertilization, liming, increase in pH and mineral soil addition) allows oxygen to enter the soil, which initiates decomposition of the stored organic material, and CO_2 and N_2O emissions increase while CH_4 emissions decrease (Kasimir-Klemedtsson et al., 1997; Maljanen et al., 2007; Grønlund et al., 2008; Musarika et al., 2017). It is known that in organic agricultural soils the decomposition of organic matter is faster than the uptake of CO_2 by plants and therefore there is a net loss of CO_2 from the drained organic agricultural soils (Kasimir-Klemedtsson et al., 1997; Maljanen et al., 2001; Lohila et al., 2004; Maljanen et al., 2004; Musarika et al., 2017). Drainage of organic soils for agricultural purposes increases the emissions of greenhouse gases (CO_2, CH_4, and N_2O) by roughly 1 tonne CO_2 eq. ha^{-1} per year, compared to undrained soils (Kasimir-Klemedtsson et al., 1997). Previous estimates from Denmark, Finland, Sweden, Norway, and the Netherlands indicated that organic soils under agricultural management with cereals, row crops, and grasses are net emitters of CO_2, with fluxes ranging from 0.8 to 31 tonnes C ha^{-1} yr^{-1}(Kasimir-Klemedtsson et al., 1997; Maljanen et al., 2001, 2003a, 2003b; Lohila et al., 2004; Regina et al., 2004; Maljanen et al., 2007; Grønlund et al., 2008; Elsgaard et al., 2012).A recent study by Evans et al. (2016) measured GHGs fluxes from both cultivated peat soils and a near intact peat in East Anglia, finding the cultivated soils to be a source of 25.34–28.45 t CO_2 ha^{-1} yr^{-1} while the near intact fen was a sink measuring −5.13 t CO_2 ha^{-1} yr^{-1} (Musarika et al., 2017). Large uncertainties are associated with considerable variation of CO_2 flux and lack of data, especially in Baltic States.

GHG emissions from agricultural organic soils are included into the National Inventory Report under the United Nations Framework Convention on Climate Change (UNFCCC). In Latvia, the reported share of organic soils in cropland and grassland is $5.18 \pm 0.5\%$ according to summaries of land surveys (L.U. Consulting, 2010). The annual emission of CO_2 from agricultural organic soils in Latvia was estimated by Latvian State Forest Research Institute 'Silava' (LSFRI Silava) using the Tier 1 method of the Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories (IPCC, 2006; IPCC, 2014), i.e., by multiplying national activity data (area of organic soils) and default emission factor. The default CO_2 emission factor for drained organic soils in cropland for boreal and temperate climate zone used for reporting is 7.9 tonnes CO_2-C ha^{-1} yr^{-1}(IPCC, 2014), and it is not validated in Baltic States. Moreover, drained organic soil is one of the key sources of GHG emissions in Latvia. In 2015, the total GHG emissions from agricultural organic soils were estimated to be 3,902.5 kt CO_2 eq. which corresponded to 95% of the total emissions from cropland and grassland (Gancone et al., 2017).

Managed organic soils are a large source of both CO_2 and nitrous oxide (N_2O) emission, due to the degradation (oxidation) of the parent material. The results of degradation is measurable as descending (subsidence) of the ground surface (Kasimir-Klemedtsson et al., 1997; Berglund & Berglund, 2010). One of the historically used field methods to estimate C losses from cultivated peat soil is subsidence rate measurements (Kasimir-Klemedtsson et al., 1997; Grønlund et al., 2008). Peat subsidence after drainage and cultivation results from the combined effects of compaction and soil loss through soil organic matter mineralization. In theory, the exact C loss from peat can be calculated from initial and final peat depths, C concentration profiles and bulk density profiles (Grønlund et al., 2008). Grønlund et al. (2008) estimated C losses from cultivated peatlands in West Norway by three independent methods: (1) long-term monitoring of subsidence rates, (2) changes in ash contents, and (3) soil CO_2 flux measurements. The three methods yielded fairly similar estimates of C losses from Norwegian cultivated peatlands (Grønlund et al., 2008).

The aim of the pilot study is to demonstrate methodology for determination of the changes of soil organic carbon stock after drainage of arable land on organic soil by evaluation of subsidence of the land surface from detailed historical pre-drainage topographic maps created during designing of drainage systems and LiDAR.

MATERIALS AND METHODS

Study site

Study was conducted in 2016 in agricultural land in the central part of Latvia, Jaunmārupe (geographic coordinates: 56.864 N, 23.925 E), the object was drained in 1982 by establishing a pipe drain system. The current thickness of organic topsoil layer in the selected sampling area is 20–40 cm (50–70 cm before). The land is used to cultivate corn for last two years. No historical information is available about long term use of field. Naturally afforested (after 1930–1940) undrained forest stand corresponding to *Dryopterioso-caricosa* site type near the study site was used as a control (Fig. 1). Old topography maps from 1930–1940 shows that both, drained and undrained, sites were open and treeless fields, at least trees did not form tree stand. The mean thickness of the organic layer in sampling area in the undrained forest is about 60–100 cm.

Figure 1. Location of study site.

Determination of subsidence rate

The subsidence of topsoil was calculated as a difference between the ground surface level before drainage and the current surface level. The initial elevation data were obtained from a topographic maps (measurements according to BAS-77 height system) created during the designing of drainage systems. Ground surface elevation is measured with optical level tool with 0.5 cm precision. The current ground surface levelling data are obtained using LiDAR based terrain model (measurements according to LAS-2000, 5 height system, based on European Vertical Reference System).

Soil surface height values from topographic maps were digitalized in QGIS and digital elevation model (DEM) was created in R by krigging interpolation method using krige.conv function built in geoR package (Ribbeiro Jr & Diggle, 2015). The result was transferred to QGIS for further analysis. Raster calculator in QGIS was used to calculate difference between two surface height models, thereby obtaining mean difference. Pixel size was 0.5 m x 0.5 m.

Mean height differences between initial and current mean height of DEM in sampling area is subtracted from differences in auxiliary sample area on mineral soil located within the same drainage system. Subsidence equals to this difference between sampling area on organic soil and auxiliary sample area on mineral soil. It was assumed that organic topsoil layer must be shallower than 10 cm (before drainage, data on topographic maps) to consider the soil in area to be mineral soil.

Difference between initial and current depth of organic soil layer is used for auxiliary validation of calculated subsidence. At stage of drainage system designing the depth of organic layer was measured in 10 cm steps and measurement point density was many times smaller than height measurement points. Therefore, it is used just for auxiliary validation, but not to calculate carbon stock changes.

Determination of soil organic carbon content and stock

In 2016, sample sets, taking undisturbed soil samples at 0–10, 10–20, 20–40 and 40–80 cm depth using soil sample probes (steel cylinder with a 100 cm^3 volume), in three replicates on 8 sample plots (total 24 sample sets) were collected. Sampling design consists of two transects of four sample plots on each transect. Distance between transects is 100 m and between sample plots on transect 50 m. Dry bulk density (the mass of a unit volume of oven dry soil, the volume includes both solids and pores) were determined. Samples were dried until constant mass at 105 °C and weighted after in the Forest Environment Laboratory of LSFRI Silava.

The regression equation describing relationship between organic C content in soils and soil bulk density ($R^2 = 0.96$) was constructed using soil monitoring (BioSoil 2012) data to estimate the current organic carbon content in soil (Fig. 2).

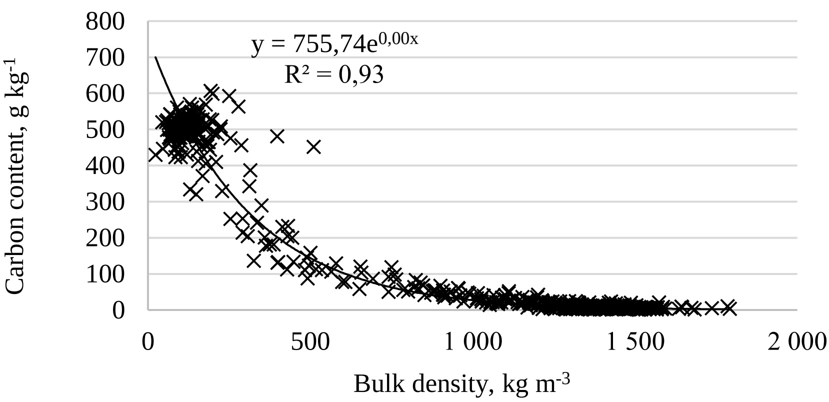

Figure 2. Relationship between soil organic carbon content and soil bulk density according to Biosoil data.

Soil organic C stock was calculated according to equation:

$$SOCS = SOC * SBD * H * (1 - P_{2mm}) * 100^{-1} \quad (1)$$

where: *SOCS* – soil organic carbon stock per unit area, tonnes ha^{-1}; *SOC* – organic carbon content in soil (according to constructed regression equation), g kg^{-1}; *SBD* – soil bulk density, kg m^{-3}; *H* – thickness of the soil layer, m; P_{2mm}– volume fraction of > 2 mm particles in the soil (assumed to be zero as the value is negligible in most soils), %.

Soil organic C stock pre-drainage profile for the drained site was constructed from the profile of undrained site. It was assumed that average depth of organic layer before drainage was 60 cm, as it was not possible to calculate depth more precisely because of poorly distinguishable boundary between organic and mineral layer at drained site.

Organic C profile from control site was proportionally adjusted to pre-drainage profile for drained site, as there is a slight difference of the depth of organic layer between drained and undrained site. Carbon stock in depth of 80 cm in undrained site corresponds to 60 cm depth on pre-drainage profile, 40 cm in undrained corresponds to 30 cm in drained etc. Simple second order polynomial equation was created to characterize pre-drainage carbon stock in organic layer (Fig. 3).

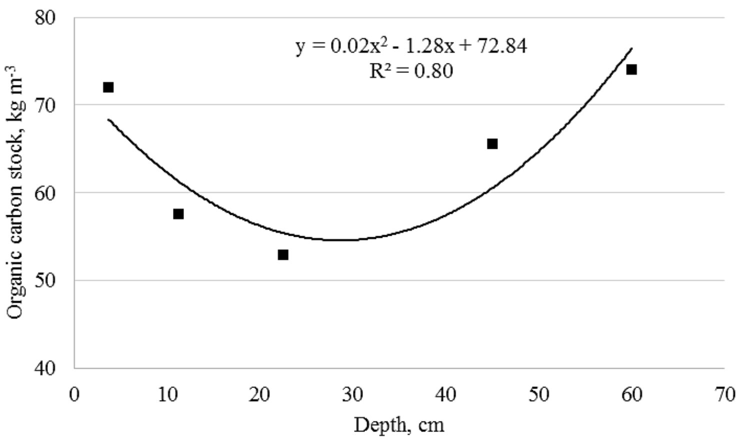

Figure 3. Pre-drainage organic carbon stock profile.

Pre-drainage C stock was calculated as definite integer of created polynomial equation.

$$SOCS^{0-60}_{pre-drainage} = \int_0^{60} (ax^2 + bx + c) \quad (2)$$

where: *x* – depth, cm; *a*, *b*, *c* – coefficients of regression equation.

Carbon stock changes after drainage equals C stock in drained site down to 60 - Δh depth subtracting from pre-drainage carbon stock.

$$\Delta SOCS_{stock} = SOCS^{0-60}_{pre-drainage} - SOCS^{0-(60-\Delta h)}_{drained} \quad (3)$$

where: Δh – subsidence, cm; $SOCS^{0-(60-\Delta h)}_{drained}$ – carbon stock in drained site down to $60 - \Delta h$ depth.

In order to show the uncertainty of carbon stock changes, confidence interval (CI) of carbon stock changes is calculated to show variability of the result. It is assumed to calculate CI as for normally distributed data with significance level of 0.05. CI for carbon stock changes is a sum of:

1) CI of carbon stock in drained site down to 0 – $(60 - \Delta h)$ cm;

2) CI of carbon stock in undrained site down to 60 cm;

3) Uncertainty of subsidence multiplied with average carbon stock in kg m^{-3}. It is assumed that uncertainty of subsidence is ± 0.05 m;

4) Uncertainty due to the use of BioSoil data to estimate carbon content in peat (± 7%, Fig. 2). Uncertainty is multiplied with carbon stock in t ha^{-1} in pre-drainage peat profile.

RESULTS AND DISCUSSION

Subsidence of organic layer

Drainage and cultivation of organic soils increase soil aeration and reverse the carbon flux, resulting in soil subsidence. The initial descending of soil surface after drainage of organic soils is mainly due to physical processes (Bergund, 2011).The primary consolidation is followed by secondary subsidence caused by shrinkage, compaction, wind and water erosion, fire and microbial oxidation of the organic matter (Heathwaite et al.,1993; Berglund & Berglund, 2010). The main factors influencing the oxidation rate on drained organic soils are peat type, climate, cultivation intensity and water table level (Eggelsman, 1976; Berglund & Berglund, 2010).

Results of a pilot study show that ground surface level in arable land on organic soil decreased by 28.6 ± 11.3 cm (mean ± 1 SD) during 34 years or 0.8 cm annually after drainage. In Norway, Grønlund et al. (2008) reported that subsidence of cultivated peat soils averaged about 2.5 cm yr^{-1}. Subsidence rates due to different cultivation intensities under Swedish conditions have been roughly estimated to be 0.5 cm yr^{-1} for pasture (extensive land use and trees),1.0 cm yr^{-1} for managed grassland,1.5 cm yr^{-1} for annual crops except row crops and 2.5 cm yr^{-1} for row crops (Berglund & Berglund, 2010).

Subsidence in this study is determined as a change in ground surface level between initial height (before drainage) and current height. However, absolute height can be highly varying depending on height reference system (Adam et al., 2000; Ihde & Sánchez, 2005), reference point used for height measurements with optical level tool and movement of tectonic plates during longer time span (England & Molnar, 1990; Teixell et al., 2009). The spatial analysis shows that height difference between DEM before drainage and current DEM created from LIDAR data in sampling area is positive (+ 3 cm), thus the elevation of soil surface has increased. This is a sum of measurement and data processing errors and those factors mentioned above which needs to be fixed.

The impact of errors and those factors can be excluded if the relative height differences are analysed throughout relatively small area, where no impact of geological processes or impact of reference point used in measurements can occur. That why, height difference between DEM before and after drainage in sampling area was calibrated, by using auxiliary data on differences between pre-drainage soil surface model and current soil surface model on mineral soil nearby sampled area. The idea is that there should not occur any significant subsidence of mineral soil. Subsidence of the organic layer equals to changes on relative height difference between initial (before drainage) height measurements and current measurements (LiDAR) between organic site and nearby site with mineral soil. It is calculated by mean differences between initial and LiDAR data on organic soil subtracting from mean differences on mineral soil. The result estimated by this method (28.6 cm) is in good accordance to changes in depth of organic layer – 25–35 cm (from 50–70 cm before to 25–35 cm now). Depth of organic layer is also measured during the designing of drainage systems, but the density of depth measurements is too low with an accuracy of 10 cm incremental steps. The density of depth measurements is around 300x300 m and the surface between the organic layers is uneven.

It is crucial to have all the necessary information about conditions, equipment and reference point for height measurements to use old topographic maps from designing of drainage systems if subsidence is calculated as a difference between two DEM. If there is missing all the necessary information, then the approach described in this paper may be applied. It demonstrates good results and can be used to determine subsidence if long term subsidence measurement data are not available, but detailed topographic maps are accessible.

Bulk density and carbon stock changes

Soil bulk density in the drained sites is twice as large on topsoil (0–10) and even bigger in deeper layers in comparison to undrained sites (Fig. 4). Explanation of the difference is not only the natural changes in soil occurring after drainage, but also mechanical impact due to tillage and addition of fertilizers. Organic layer was rather shallow (25–35 cm) during the study and agricultural practices can cause mixing of mineral soil particles with the organic material in topsoil.

In all cases there was a considerable admixture of mineral particles at a depth of 20–40 cm in drained sites (bulk density > 400 kg m^{-3}, mean 520 kg m^{-3}), but the mean bulk density on topsoil (0–20 cm) were less than 400 kg m^{-3}. Due to this reason we didn't collected soil samples from deeper layers at drained sites. Mean bulk density in undrained site varied from 130 to 300 kg m^{-3}.

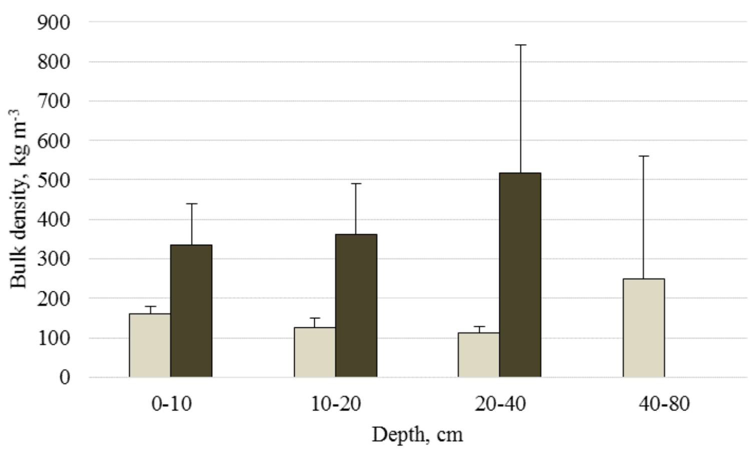

Figure 4. Soil bulk density in drained and undrained sites in different soil layers. Error bars shows 1 SD.

Pre-drainage profile of organic C stock was modelled to calculate the changes in C stock (Fig. 5). Mean C stock in topsoil at drained site through different soil layers have increased by about 50 kg m^{-3}compared to pre-drainage state. The difference of C stock between those two profiles is C loss after drainage. The study results demonstrate that after drainage soil organic C stock has decreased by 137 ± 113 tonnes C ha^{-1} (mean ± CI) during 34 years or 4.2 ± 3.3 tonnes ha^{-1} yr^{-1}.The subsidence of the organic layer caused increase on soil C carbon stock in the upper soil layers due to compaction of organic topsoil (Fig. 3). Approximately 27% of decrease of the ground surface level can be explained by soil compaction. However, the most of the subsidence (73%) observed is due to decomposition of organic matter resulting in CO_2emissions.

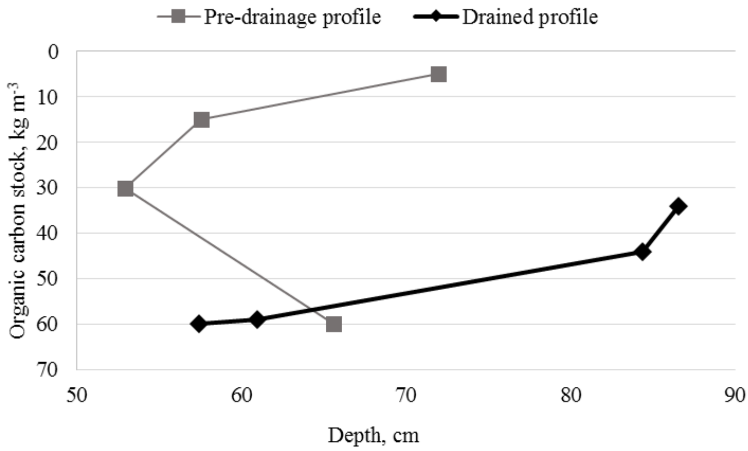

Figure 5. Soil organic carbon stock in different soil depth in drained and control plots.

Emissions estimated during this pilot study are close to those, 4.0–5.5 tonnes CO_2-C ha^{-1} yr^{-1}, estimated earlier for boreal organic agricultural soils (Kasimir-Klemedtsson et al., 1997). Annual CO_2 fluxes from cultivated organic soils in Finland range from 0.8 to 11 tonnes CO_2-C ha^{-1} yr^{-1}(Maljanen et al. 2001, 2003a, 2003b, 2004; Lohila et al. 2004, Regina et al. 2004), but Maljanen et al. (2007) have comparably more recently reported that annual CO_2 fluxes from cultivated organic soils in Finland range from 4.1 to 5.9 tonnes CO_2-C ha^{-1} yr^{-1}. Grønlund et al. (2008) estimated C losses from cultivated peatlands in West Norway by three independent methods. Based on these estimates the corresponding C losses equal 6.0–8.6 tonnesCO_2-C ha^{-1} yr^{-1}.

The estimated CO_2 emissions (4.2 tonnes CO_2-C ha^{-1} yr^{-1}) is by 47% less than the currently applied default emission factor for arable land (7.9 tonnes C ha^{-1} yr^{-1}) provided by IPCC Guidelines for National Greenhouse Gas Inventories. The obtained results substantiate importance of development of the national emission factors for CO_2 to avoid overestimation or underestimation of the GHG emissions from managed organic soils.

Although the method used in this study seems suitable for determination of C stock changes, there are strong limitations to it. Firstly, large uncertainty of carbon stock change should be considered when results are used to drive any conclusions. Uncertainty could be reduced if carbon content would be measured not modelled and sample size (soil samples collected) needs to be several times larger than in this study. Secondly, it is crucial to have detailed and accurate pre-drainage topographic maps. In many cases topographic maps are not available or accuracy of height measurements is too low to use them to calculate subsidence. Thirdly, finding an appropriate control site can be challenging too. Use of historical soil maps could be a useful tool to find an appropriate control sites in agricultural land. Nevertheless, most of the fertile organic soils historically were drained for agriculture. Therefore, availability of reliable control sites is limited.

CONCLUSIONS

After drainage ground surface level in arable land on organic soil has decreased by 0.8 cm annually, but soil organic carbon stock in the study area has decreased by 4.2 ± 3.3 tonnes ha^{-1} yr^{-1}. The estimated CO_2 emissions are by about 47% less than according to the default emission factor for drained arable organic soils in boreal and temperate climate zone provided by IPCC Guidelines for National Greenhouse Gas Inventories. The study results approve credibility of the evaluated methods and substantiate the importance of elaboration of national methodology for accounting of the CO_2 emissions from drained organic soils in cropland and grassland. The subsidence of organic layer due to drainage can be determined if detailed pre-drainage topographic maps are available for the drained site. However, large uncertainty of carbon stock changes points out deficiencies of the study, which needs to be addressed in further studies.

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REFERENCES

Adam, J., Augath, W., Brouwer, F., Engelhardt, G., Gurtner, W., Harsson, B.G., Ihde, J., Ineichen, D., Lang, H., Luthardt, J., Sacher, M., Schlüter, W., Springer, T. & Wösppelmann, G. 2000. Status and development of the European height systems, in: *Schwarz,* P.D.K.-P. (Ed.), Geodesy Beyond 2000, International Association of Geodesy Symposia. Springer Berlin Heidelberg, pp. 55–60.

Bader, C., Müller, M., Schulin, R. & Leifeld, J. 2017. Amount and stability of recent and aged plant residues in degrading peatland soils. *Soil Biology and Biochemistry* **109**, 167–175.

Berglund, Ö. 2011. *Greenhouse gas emissions from cultivated peat soils in Sweden*. Doctoral Thesis, Swedish University of Agricultural Sciences, Uppsala, 73 pp.

Berglund, Ö. & Berglund, K. 2010. Distribution and cultivation intensity of agricultural peat and gyttja soils in Sweden and estimation of greenhouse gas emissions from cultivated peat soils. *Geoderma* **154**(3), 173–180.

Eggelsman, R. 1976. Peat consumption under influence of climate, soil condition and utilization. *Proc. Fifth Int. Peat Congress* **1**, 233–247.

Elsgaard, L., Gorres, C.M., Hoffmann, C.C., Blicher-Mathiesen, G., Schelde, K. & Petersen, S.O. 2012. Net ecosystem exchange of CO_2 and carbon balance for eight temperate organic soils under agricultural management. *Agric. Ecosyst. Environ.*, **162**, 52–67.

England, P. & Molnar, P. 1990. Surface uplift, uplift of rocks, and exhumation of rocks. *Geology* **18**, 1173–1177.

Evans, J., Gauci, V., Grayson, R., Haddaway, N., He, Y., Heppell, K., Holden, J., Hughes, S., Kaduk, J., Jones, D., Matthews, R., Menichino, N., Misselbrook, T., Page, S., Pan, G., Peacoak, M., Rayment, M., Ridley, L., Robinson, I., Rylett, D., Scowen, M., Stanley, K. & Worrall, F. 2016. *Lowland peatland systems in England and Wales - evaluating greenhouse gas fluxes and carbon balances.*Final report to Defra on Project SP1210, Centre for Ecology and Hydrology, Bangor.

Fell, H., Roßkopf, N., Bauriegel, A. & Zeitz, J. 2016. Estimating vulnerability of agriculturally used peatlands in north-east Germany to carbon loss based on multi-temporal subsidence data analysis. *CATENA* **137**, 61–69.

Gancone, A., Sīle, I., Skrebele, A., Puļķe, A., Rubene, L., Ratniece, V., Cakars, I., Siņics, L., Klāvs, G., Gračkova, L., Lazdiņš, A., Butlers, A., Bārdule, A., Lupiķis, A., Bērziņa, L., Degola, L. & Priekulis, J. 2017. *Latvia's National Inventory Report 1990-2015. Submission under UNFCCC and the Kyoto Protocol*. Ministry of Environmental Protection and Regional Development of the Republic of Latvia, 533 pp.

Gorham, E. 1991. Northern Peatlands: Role in the Carbon Cycle and Probable Responses to Climatic Warming. *Ecological Applications* **1**, 182–195.

Grønlund, A., Hauge, A., Hovde, A. & Rasse, D.P. 2008. Carbon loss estimates from cultivated peat soils in Norway: a comparison of three methods. *Nutrient Cycling in Agroecosystems* **81**, 157–167.

Heathwaite, A.L., Eggelsman, R. & Göttlich, K.H. 1993. Ecohydrology, mire drainage and mire conservation. In: *Mires: Processes, Exploitation and Conservation*. Wiley, Chichester, pp. 417–484.

Ihde, J. & Sánchez, L. 2005. A unified global height reference system as a basis for IGGOS. *Journal of Geodynamics, The Global Geodetic Observing System* **40**, 400–413.

IPCC 2006.*2006 IPCC Guidelines for National Greenhouse Gas Inventories*, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston, H.S., Buendia, L., Miwa, K., Ngara, T. & Tanabe, K. (eds). Published: IGES, Japan.

IPCC 2014. 2013 *Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands*, Hiraishi, T., Krug, T., Tanabe, K., Srivastava, N., Baasansuren, J., Fukuda, M. & Troxler, T.G. (eds). Published: IPCC, Switzerland.

Joosten, H. & Clarke, D. 2002. *Wise use of mires and peatlands – Background and principles including a framework for decision-making*. International Mire Conservation Group, International Peat Society, Jyvaskyla, 304 p.

Kasimir-Klemedtsson, Å., Klemedtsson, L., Berglund, K., Martikainen, P., Silvola, J. & Oenema, O. 1997. Greenhouse gas emissions from farmed organic soils: a review. *Soil Use and Management* **13**, 245–250.

Leifeld, J., Müller, M. & Fuhrer, J. 2011. Peatland subsidence and carbon loss from drained temperate fens. *Soil Use and Management* **27**, 170–176.

Lohila, A., Aurela, M., Tuovinen, J.P. & Laurila, T. 2004. Annual CO_2 exchange of a peat field growing spring barley or perennial forage. *J. Geophys. Res*., **109**, D18116.

Loisel, J., van Bellen, S., Pelletier, L., Talbot, J., Hugelius, G., Karran, D., Yu, Z., Nichols, J. & Holmquist, J. 2017. Insights and issues with estimating northern peatland carbon stocks and fluxes since the Last Glacial Maximum. *Earth-Science Reviews* **165**, 59–80.

Luan, J. & Wu, J. 2015. Long-term agricultural drainage stimulates CH_4 emissions from ditches through increased substrate availability in a boreal peatland. *Agric. Ecosyst. Environ.,* **214**, 68–77.

L.U. Consulting (2010). Soils and relief output data preparation and simulation of application of soil and relief criteria for small-favored areas developed by the European Commission. Ministry of Agriculture Republic of Latvia. (in Latvian).

Maljanen, M., Hytönen, J., Mäkiranta, P., Alm, J., Minkkinen, K., Laine, J. & Martikainen, P.J. 2007. Greenhouse gas emissions from cultivated and abandoned organic croplands in Finland. *Boreal Env. Res*. **12**, 133–140.

Maljanen, M., Komulainen, V.M., Hytönen, J., Martikainen, P.J. & Laine, J. 2004.Carbon dioxide, nitrous oxide and methane dynamics in boreal organic agricultural soils with different soil management.*Soil Biol. Biochem*., **36**, 1801–1808.

Maljanen, M., Liikanen, A., Silvola, J. & Martikainen, P.J. 2003a. Methane fluxes on agricultural and forested boreal organic soils. *Soil Use Manage* **19**, 73–79.

Maljanen, M., Liikanen, A., Silvola, J. & Martikainen, P.J. 2003b. Nitrous oxide emissions from boreal organic soil under different land-use. *Soil Biol. Biochem*., **35**, 689–700.

Maljanen, M., Martikainen, P.J., Walden, J. & Silvola, J. 2001. CO_2 exchange in an organic field growing barley or grass in eastern Finland. *Global Change Biol.***7**, 679–692.

Mathijssen, P.J.H., Väliranta, M., Korrensalo, A., Alekseychik, P., Vesala, T., Rinne, J. & Tuittila, E.S. 2016. Reconstruction of Holocene carbon dynamics in a large boreal peatland complex, southern Finland. *Quaternary Science Reviews* **142**, 1–15.

Musarika, S., Atherton, C.E., Gomersall, T., Wells, M.J., Kaduk, J, Cumming, A.M.J, Page, S.E., Oechel, W.C. & Zona, D. 2017. Effect of water table management and elevated CO_2 on radish productivity and on CH_4 and CO_2 fluxes from peatlands converted to agriculture. *Science of the Total Environment* **584–585**, 665–672.

Regina, K., Syväsalo, E., Hannukkala, A. & Esala, M. 2004. Fluxes of N_2O from farmed peat soils in Finland. *Eur. J. Soil Sci*. **55**, 591–599.

Ribeiro Jr, P.J. & Diggle, P.J. 2015.geoR: Analysis of Geostatistical Data.

Teixell, A., Bertotti, G., de Lamotte, D.F. & Charroud, M. 2009. The geology of vertical movements of the lithosphere: An overview. *Tectonophysics, the geology of vertical movements of the lithosphere* **475**, 1–8.

Yu, Z. 2012. Northern peatland carbon stocks and dynamics: a review. *Biogeosciences* **9**(10), 4071–4085.

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The influence of sloping land on soil particle translocation during secondary tillage

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Abstract. Tillage erosion causes the undesirable changes in the soil, mainly decreased of fertility and other functions of soil. The field experiment was aimed at measuring the influence of sloping field on the translocation of soil particles during seedbed preparation by Lemken Kompaktor seedbed combination. Sandy-loam Cambisol is on this field. Depth of soil tillage was 0.10 m, operating speed was 4.5 km h^{-1}. To indicate the soil particles displacement limestone grit with the fraction size of 10–16 mm was used. The measurement results document that differences between movement of seedbed combination on the flat ground and upslope movement (angle of the slope 8.1°) are minimal in terms of displacement of soil particles. But the variant of downslope movement (angle of the slope 9.8°) showed statistically significantly higher values of translocation distances. The dependence of the translocation is in all cases described by an exponential function. The upslope movement of the machine for soil tillage cannot be understood as a full-value corrective measure to the incorrectly chosen direction of downslope movement.

Key words: tillage erosion, sloping lands, seedbed preparation.

INTRODUCTION

Erosion belongs among the main risk factors for soil in conditions of the Czech Republic. While water and wind erosion has been an object of the long-term interest of many scientific studies, tillage erosion is quite a new field of research. As more than 70% of the soil in the CR is arable land, tillage erosion is an underestimated factor. Tillage erosion contributes to undesirable changes in the soil, mainly to the deterioration of fertility and other functions of soil. A significant contribution to research on tillage erosion can be found in Govers et al. (1999), Li et al. (2007) and other authors. Currently, tillage erosion is considered as a phenomenon that should be paid greater attention. Lobb et al. (1995) emphasizes the importance of relationship between tillage translocation and slope gradient, slope curvature, and tillage implements. The authors report that tillage speed can be reduced by as much as 60% during upslope tillage and increased by as much as 30% during downslope tillage. Tillage depth decreased by as much as 20% and increased by as much as 30%, relative to that on level ground. An important role in this has the tillage operator.

Van Muysen et al. (2006) considered tillage erosion as the principal degradation factor influencing arable land in the territory with broken topography. Such erosion results in downslope translocation of soil particles. Blanco–Canqui & Lal (2008) estimated the soil loss more than 15 t ha^{-1} per year due to degradation by soil tillage – this value is applicable to conditions of western Europe. Other authors found lower values – 3.3 t ha^{-1} (Van Oost et al. 2006) and less. Van Oost et al. (2006) present different values of tillage transport coefficient: range in the order of 400–800 kg m^{-1} yr^{-1} and 70–260 kg m^{-1} yr^{-1} for mechanized and non-mechanized agriculture, respectively.

The patterns and consequences of tillage erosion are different from those of water erosion of soil. The washing away of soil on the slope in a direction of the fall line is typical of water erosion. A consequence of soil tillage performed on slopes every year is diminishment of topsoil depth in the upper part of slopes and especially on tops of elevations (Blanco–Canqui & Lal 2008; Papiernik et al. 2009). The convex parts of slopes are the most vulnerable, and on the contrary, the displaced soil is deposited at concave positions on slopes. Lobb et al. (1995) stated that tillage erosion accounts for at least 70% of the total soil loss in the upper part of sloping lands. Tillage erosion can be most pronounced at locations where water erosion is small, while tillage deposition can be most pronounced where water erosion is larges (especially along thalwegs which are filled up by tillage operations after ephemeral gullying).

The study of literature sources shows that currently there is a lack of information on soil particle translocation by particular groups of machines during soil tillage. It applies mainly to secondary tillage and sowing operations. More information is available for primary soil tillage – ploughing with mouldboard ploughs, loosening with chisel ploughs (Li et al., 2007). Large differences between machines and technologies for soil tillage in relation to soil particle translocation were reported by Hůla & Novák (2016). A crucial role is played by the principle of the function of working tools and by the action of particular sections of working tools in combined machines for soil tillage.

MATERIALS AND METHODS

A field experiment was established at the Nesperská Lhota locality in Central Bohemia to measure the translocation of soil particles. The field experiment was aimed at measuring the influence of sloping land on the translocation of soil particles during seedbed preparation. Sandy-loam Cambisol covered this sloping land.

At the beginning of August 2016 winter rape was harvested (yield of 4.8 t ha^{-1}) and the straw was crushed. Subsequently, the field was cultivated by a disk harrow. At the beginning of September (after emergence of shattered seeds) the field was ploughed to a depth of 0.22 m parallelly to the contours. Measurements were done in the second half of September after the soil had subsided. At first, soil tillage was conducted by a field drag and harrow. For the proper measurement of soil particle translocation the Lemken Kompaktor seedbed combination with the working width of 6 m was used. It was attached to a Zetor 12145 tractor. Depth of soil tillage was 0.10 m. Operating speed was 4.5 km h^{-1} at all operations. The field experiment consisted of three variants: movement of the machine on the flat ground, downslope movement and upslope movement.

To indicate the topsoil displacement limestone grit with the fraction size of 10–16 mm was used. Grits were placed into a groove of 1 m in length, 0.10 m in depth (soil tillage depth) and 0.20 m in width. The longer side of the groove was perpendicular to the direction of the Lemken seedbed combination movement. After the groove had been created and filled with limestone grit, the measured place was passed by a Lemken seedbed combination. Individual grits (tracers) were picked by hand in 0.6 m sections from soil depth 0–0.10 m. In a crosswise direction each section was divided into 3 parts. All tracers from the given section were weighed.

Undisturbed soil samples (Kopecky cylinders) with the volume of 100 cm^3 were taken to determine the basic physical properties of soil. Soil moisture was measured with a Theta Probe (Delta T Devices, UK) in a layer of tilled soil. Data were processed using the programmes MS Excel (Microsoft Corp., USA) and Statistica 12 (Statsoft Inc.,USA).

Table 1 shows the basic soil properties. The values of reduced bulk density and porosity are typical of the soil kind in the field. The values of porosity indicate a higher content of macropores, which is a result of recent soil tillage (ploughing).

Table 1. Characteristics of the soil before secondary tillage

Depth (m)	Bulk density ($g\ cm^{-3}$)	Porosity (% vol.)	Cox (%)	Moisture (% vol.)
0.05–0.10	1.33	49.2	1.27	8.6
0.10–0.15	1.36	48.1	1.22	7.4

Content of soil particles smaller than 0.01 mm (% weight) in topsoil was different on sloping field: 19.1% on the top of the field and 23.9% on the lower part of the sloping field.

RESULTS AND DISCUSSION

The translocation of tracers when the Lemken seedbed combination moves on an almost flat ground – very gentle slope of 0.9° (downslope movement) is in Fig. 1. The graph shows that the highest quantity of tracers was translocated to a relatively short distance from their original placement. It was particularly to a distance of 0.6 m. The most remote tracer was at a distance of 7.8 m. The pattern of translocation can be successfully described by an power function plotted in the graph. It is a very strong relationship.

Particle translocation when the seedbed combination goes upslope shows Fig. 2. The slope of this part of the field was 8.1°. The graph illustrates a similar pattern of particle translocation like during movement on the flat ground. The majority of the particles were translocated to a distance shorter than 0.60 m from their original placement. The cultivator tines did not tend to pull over the entire layer of the cultivated soil. During this operation no organic matter adhered to the tines, which would surely have a negative effect on the particle translocation. The most remote particle was found at a distance of about 7 m. The pattern of translocation can also be described by an power function.

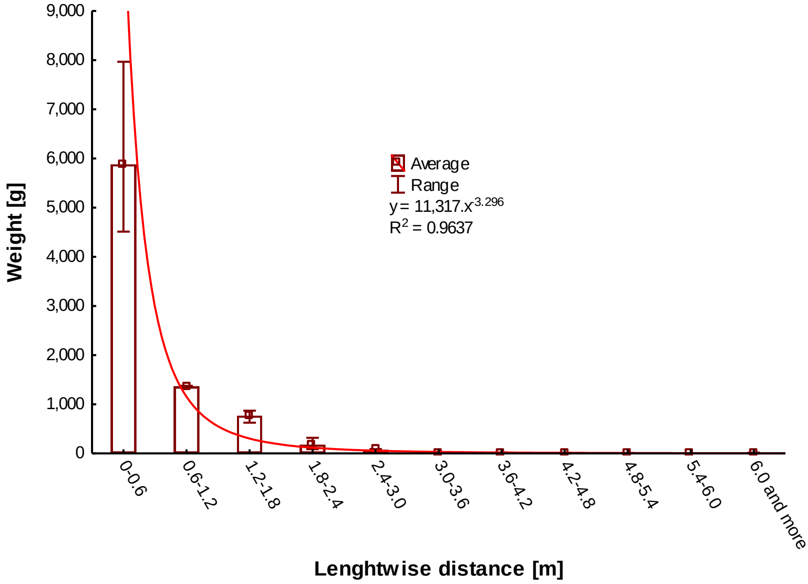

Figure 1. Translocation of tracers when the machine moves on an almost flat ground.

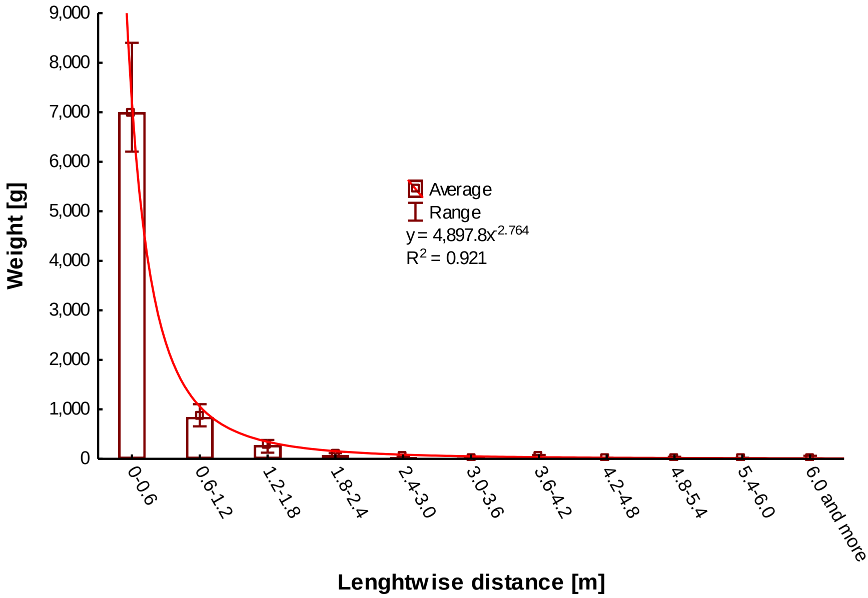

Figure 2. Translocation of tracers when the machine moves goes upslope.

Particle translocation when the seedbed combination goes downslope illustrates Fig. 3. The graph shows a pronounced effect of sloping land on the operation of the machine. The slope was 9.8°. The surface layer of topsoil was carried away by working tools to a relatively long distance. The most distant particle was revealed at a distance of 19.6 m from its original placement. Massive translocation of particles was observed to a distance of approx. 5 m. However, a smaller quantity of particles was translocated to a longer distance. The pattern of the translocation is described by an power function again.

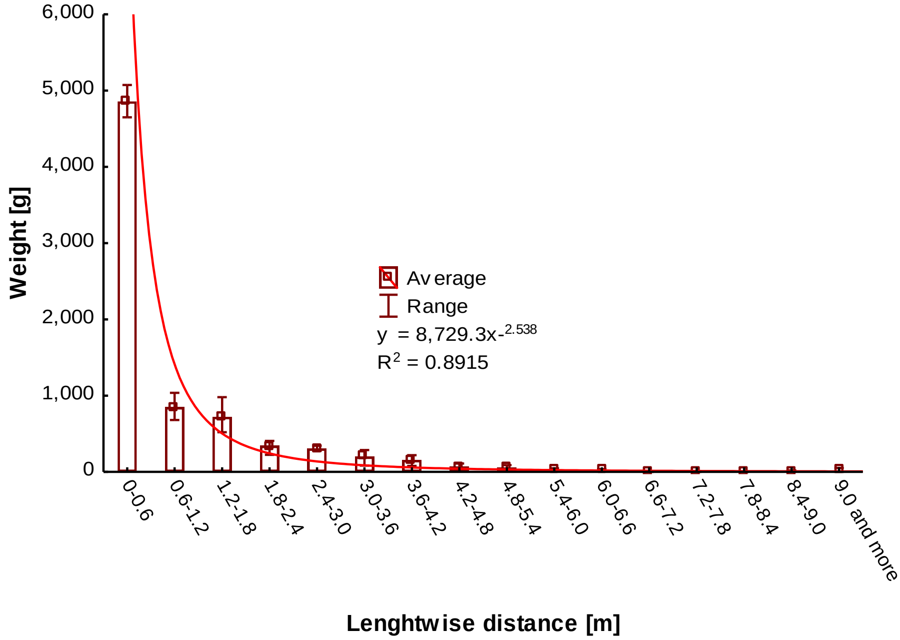

Figure 3. Translocation of tracers when the machine moves goes downslope.

A comparison of particular variants (to a distance of 6 m) is shown in Table 2. Homogeneous groups are designated by letters. For evaluation Tukey's HSD test was used. Indices written at the side of average values designate homogeneous groups. The values document that differences between movement on the flat ground and upslope movement are minimum. But the variant of downslope movement showed statistically significantly higher values of translocation up to medium distances.

Table 2. Average translocation of tracers in three variants of trial and marked out homogeneous groups (*Tukey's HSD test*)

Distance (m)	Movement on the flat ground	Upslope movement	Downslope movement	
0–0.6	5,880[a]	6,997[a]	4,858[b]	Average weight of tracers in section [g]
0.6–1.2	1,362[a]	844[b]	848[b]	
1.2–1.8	769[a]	276[b]	582[a]	
1.8–2.4	177[a]	73[a]	342[b]	
2.4–3.0	73[a]	28[a]	306[b]	
3.0–3.6	17[a]	19[a]	200[b]	
3.6–4.2	19[a]	31[a]	155[b]	
4.2–4.8	7[a]	7[a]	71[b]	
4.8–5.4	7[a]	19[a]	56[b]	
5.4–6.0	5[a]	7[a]	23[b]	

The influence of sloping land during secondary soil tillage was reported also by Van Muysen et al. (2006). In their study they assessed the influence of using power harrows. The results of the present paper are consistent with conclusions of the study of the above-cited authors. Li et al. (2007) considered sloping land as the main parameter influencing tillage erosion in all used technologies of soil tillage. They also demonstrated that the movement during upslope soil tillage could not be considered as a corrective measure to the downslope movement of the machine. Dercon et al. (2006) warned against the risk of soil translocation in the direction of downslope tillage. In their study they demonstrated the negative effect of tillage erosion on qualitative parameters in conditions of light Cambisols. The results reveal the need of changing the movement direction during secondary soil tillage. Such a measure will increase the costs of soil tillage on sloping lands. A potential decrease in labour productivity and an increase in soil tillage costs were reported by Schumacher et al. (1999). However, the higher cost should be compensated by a reduction in soil degradation and gradual increase in yields and quality of field crop production.

CONCLUSIONS

Compared to water erosion tillage erosion is little investigated problem. Neither have all relations been known until now nor have all mechanisms of tillage erosion been described yet. In this paper the influence of sloping land on the translocation of soil particles was studied during secondary soil tillage by a seedbed combination. The results indicate a great influence of this operation on the translocation of soil particles. Secondary soil tillage influences total erosion in this way. The influence of sloping land on the quantity of translocated particles is evident. Conclusively, downslope movement of the machine indicated a higher potential of particle translocation than movement on the flat ground or upslope. A conclusion is drawn that the upslope movement of the machine cannot be understood as a full-value corrective measure to the incorrectly chosen direction of downslope movement. An optimization of the movement direction when the land topography is respected seems to be the most effective measure.

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REFERENCES

Blanco–Canqui, H. & Lal, R. 2008. *Principles of soil conservation and management*. Springer Netherlands, 617 pp.

Dercon, G., Deckers, J., Poesen, J., Govers, G., Sanchez, H., Ramirez, M., Vanegas, R., Tacuri, E. & Loaiza, G. 2006. Spatial variability in crop response under contour hedgerow systems in the Andes region of Ecuador. *Soil & Tillage Research* **86**, 15–26.

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.

Hůla, J. & Novák, P. 2016. Translocation of soil particles during primary soil tillage. *Agronomy Research* **14**(2), 392–399.

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.

Schumacher, T.E., Lindstrom, M.J., Schumacher, J.A. & Lemme, G.D. 1999. Modeling spatial variation in productivity due to tillage and water erosion. *Soil & Tillage Research* **51**, 331–339.

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.

Van Oost, K., Govers, G., de Alba, S. & Quine, T.A. 2006. Tillage erosion: a review of controlling factors and implications for soil quality. *Progress in Physical Geography* **30**(4), 443–466.

Field compaction capacity of agricultural tyres

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Abstract. The rating of soil compaction potential of agricultural tyres, in term Field Compaction Capacity (FCC index), is presented in the paper. Principal task of tyre FCC is used to predict a compaction risk of tyre under arbitrary combinations with inflation pressure and tyre load. FCC improves the originally used Compaction Capacity of tyre (tyre CC-rating) that expresses a compaction potential of single nominal tyre's contact footprint area for every catalogues load limits i.e. speed level under 10 km h^{-1} and relevant inflation pressures exclusively. Primarily, FCC evaluation of tyre includes a calculation of standardized tyre footprint contact area. Adequate combinations of load limits and inflation pressure are used in a range of nominal tyre manufacture's dimensions ('catalogue size') according to ETRTO standards. The contact area size strictly depends on coefficient of tyre stiffness and sidewall deflection; both of them are a function of inflation pressure. Compaction effect of standardized contact area size is converted using compaction function in given contact pressure range. Databank of soil compaction functions for original CC evaluation is unchanged. The soil dry density limit in FCC conception corresponds with tyre CC approach since adequate (individual) mean contact pressure can be converted into compaction function i.e. the application of the same conversion rule for combination: actual versus standardized contact area size; actual versus nominal load, both for corresponding inflation pressure level. Critical soil dry density values for every soil type are set according to pedologic standards. FCC index offers a realistic prediction of the compaction level for any soil type under individual combination of tyre size, load and inflation pressure in depths 20, 30, 40 and 50 cm below a ground surface. It must be considered as the advantageous indicator of ecological tyre operations on cultivated crop-producing land.

Key words: field compaction capacity, agricultural tyres, contact pressure, contact area.

INTRODUCTION

Enormous field traffic produces compaction of soil profile up to the depth 50 cm minimally. Soil deformation reduces soil regimes, biodiversity and plant growth (Gutu et al., 2015). It´s primarily a matter of agricultural traction tyres of vehicles or machinery even if they are loaded and inflated according to regulations because data refer to operation on firm surface. Håkansson in 1990 proposed to use the degree of compactness as a standardized parameter of soil profile damage. The scientific and practical approach of Håkansson & Petelkau (1994) has particularly appreciates for the definition of general limits to axle loads. The sophisticated approach of compaction modelling was reported by Bailey et al. (1996).

Nowadays, advanced research (e.g. in Sweden, Netherlands, Denmark, USA) is aiming at elucidation of links between stress field and compaction of the ground, e.g. Arvidsson & Håkansson (2014), van den Akker & Hoogland (2011), Xia (2011), Keller & Lamandé (2014), Schjønning et al. (2015), however, their conclusions confirm inaccuracies in outputs prediction when crucial parameters are compared with reality (Keller & Lamandé, 2014).

The carried out research in the Czech Republic is to avoid the complicated stress – strain theory and to relate soil compaction directly to the acting tyre load using mean contact pressure in standardized tyre's footprint area. This has been the cornerstone of the CC rating approach which uses laboratory compaction experiments under strictly controlled conditions (Grečenko & Prikner, 2014).

The presented tyre soil compaction potential evaluation, based on the principal study of this subject published in (Grečenko, 1996; Grečenko & Prikner, 2014; Grečenko, 2016), includes the development and application of empirical prediction of individual tyre's contact area size using catalogue's data only. Thus required mean contact pressure in a given contact area is converted into pattern of compaction function conversion. The final product of the presented approach is marked as a FCC index.

MATERIALS AND METHODS

Definitions and calculation of the tyre footprint area

For purposes of tyre Compaction Capacity evaluation described by (Grečenko & Prikner, 2014), the tyre footprint area has been represented by a virtual round pressure plate of the same area to compare the suitability of different tyre sizes for field operation with realistic assessment of ground compaction. Using SGP equation (Surface-Grečenko-Prikner), nominal tyre contact area S_T (cm^2) can be calculated with good precision using the tyre dimensions published in manufacturers' technical catalogues, which mostly comply with official manuals (e.g. ETRTO, 2008). The SGP equation has conventional form:

$$S_T = cb_t\sqrt{d_t^2 - 4r_s^2} = (0.927 + 0.761AR - 1.215AR^2)b_t\sqrt{d_t^2 - 4r_s^2}, \qquad (1)$$

where: c – scaling factor depends on AR (aspect ratio of tyre section), $AR = (d_t - d_r)/2b_t$ (–); b_t – tyre section (cm); d_t – tyre outer diameter (cm); r_s – static loaded radius (cm).

In presented FCC conception, the prediction of individual tyre footprint area S_{Tx} (cm^2) uses tyre catalogue's parameters for any tyre load and inflation pressure combination. Generally, tyre catalogues include the nominal loads W_N (kg) for adequate inflation pressure p_i (kPa or bar) and speeds (km h^{-1}). The nominal tyre's footprint area for any line of nominal catalogue's combination load and inflation pressure W_N/p_i will be denoted S_{TN}.

Basic calculation of actual tyre footprint area includes comparison between tyre nominal sidewall stiffness C_N (kN cm^{-1}) and relevant tyre deflection f (cm). The static radius r_s assessment, tyre manufactures apply the combination of nominal tyre load and inflation pressure 160 kPa for speed limit 30 km h^{-1} (ETRTO, 2008). Corresponding load limit W_N for a given inflation pressure can be specified with the use of the given static radius r_s (speed 30 km h^{-1}); however, nominal tyre load deflection f_N (cm) is an average value over the catalogue range of inflation pressure since the static radius r_s does not remain strictly constant. The tyre nominal sidewall stiffness for required speed level 30 km h^{-1} will be:

$$c_{N(30)} = \frac{W_{N(30)}g}{f_{N(30)}}, \tag{2}$$

where: $c_{N(30)}$ – tyre sidewall stiffness (kN cm^{-1}); g – gravity constant (m s^{-2}); $f_{N(30)}$ – nominal deflection for speed 30 km h^{-1}.

The nominal tyre deflection $f_{N(30)}$ is product of catalogue's values for speed 30 km h^{-1}. There is advantageous to compare nominal deflection $f_{N(30)}$ with maximum tyre deflection $f_{x(10)}$ (refers to speed 10 km h^{-1}):

$$f_{x(10)} = \frac{\Delta W g}{c_{N(30)}}, \tag{3}$$

where: $f_{x(10)}$ – tyre deflection for speed 10 km h^{-1} (cm).
ΔW (kg) presents a difference of load limits under constant inflation pressure:

$$\Delta W = W_{N(10)} - W_{N\,(30)}, \tag{4}$$

where: $W_{N(10)/(30)}$ – nominal load (kg) for speed 10 and 30 km h^{-1}, respectively.
Thus appropriate static radius $r_{sx(10)}$related to the deflection $f_{x(10)}$ will be:

$$r_{sx(10)} = r_s - f_{x(10)}, \tag{5}$$

where: $f_{x(10)}$ – catalogue's tyre static load radius (cm).

Using of the Eq. 5, the coefficient of tyre deformation ε_d (-) as parameter of tyre footprint area change for catalogue's combinations W and p_i reads:

$$\varepsilon_d = 1 - \frac{r_{sx(10)}}{r_s}, \tag{6}$$

where: $r_{sx(10)}$ – tyre static load radius for speed 10 km h^{-1} (cm), (see Eq. 5).

Modification of arithmetic progression model a_n, product a_{Tx} can reliably describe uniformly decreasing (linear trend) of tyre footprint area size:

$$\begin{aligned} a_n &= a_1 + (n-1)d \\ a_{Tx} &= (n-1)\varepsilon_d, \end{aligned} \tag{7}$$

where: $a_1 = 0;\ n \geq 1;\ n \in N$; ($a_1$ – arithmetic progression; n – n^{th} term of the sequence $a_n \Rightarrow a_{Tx}$; $d \Rightarrow \varepsilon_d$ – the common difference of successive members; N – counting number).

The tyre CC/FCC evaluation, catalogue's combinations W_N and p_i for speed level 10 km h^{-1} can describe a static tyre's load compaction effect sufficiently. Thus contact area S_{TN} (cm^2) for nominal catalogue's load and corresponding inflation pressure combination based on modification S_T (cm^2) (see Eq. 1) has a form:

$$S_{TN} = 0.94(1 - a_{Tx})S_T, \tag{8}$$

where: parameter 0.94 (–) represents a standard ratio of real width of tyre thread pattern to catalogue's tyre section b_t, (i.e. 94% reduction of b_t), this proved latest experiments; S_T – nominal tyre contact area adopted from CC-rating, (cm^2).

Grečenko (1996) published the prediction of individual tyre's footprint area A_0 using of correction factor α_A (ratio of actual to nominal contact area):

$$\alpha_A = \alpha_W^n = \left(\frac{W}{W_N}\right)^n, \tag{9}$$

where: α_W^n – ratio of actual to nominal tyre load, (kg); n – correction factor; W – actual load (kg); W_N – nominal load (kg).

The original value of correction factor $n = 2/3$ was recommended by Grečenko (1996). Latest experiments confirmed that the n value corresponds with AR and ε_d, respectively. Thus coefficient n based on tyre type and size reaches the range 0.6–0.78.

Prediction of tyre's contact area S_{Tx} (cm^2) under any load and inflation pressure combinations, the Eq. 8 requires modification using correction factor α_A (Eq. 9):

$$S_{Tx} = \alpha_A S_{TN} = \left(\frac{W}{W_N}\right)^n S_{TN} \tag{10}$$

Definitions and calculation of the tyre FCC

The tyre FCC index is a dimensionless number that compares the state of soil compaction under a loaded tyre with the critical compaction of standardized clay loam soil type (identical conception as CC-rating). It is computed from the same formula pattern as the former Compaction Capacity (CC-rating) (Grečenko & Prikner, 2014):

$$\mathrm{CC} \Rightarrow \mathrm{FCC} = 1{,}000\,[(\rho_{ds} / \rho_{dl}) - 1] = 1{,}000[(\rho_{ds}/1{,}420) - 1] \tag{11}$$

The dry density ρ_{ds} (kg m^{-3}) is the average value of the function $\rho_d = f(z)$ after loading in the depth range $z = 20$ to 50 cm, approximately computed from four dry density readings ρ_{dx} at the depths 20, 30, 40 and 50 cm below the field surface:

$$\rho_{ds} = \tfrac{1}{4}\,(\rho_{d20} + \rho_{d30} + \rho_{d40} + \rho_{d50}), \tag{12}$$

where: ρ_{dl} – critical value of soil dry density (clay loam = 1,420 kg m^{-3}) limiting the growth of field crops on loamy soils (Lhotský, 2000).

The CC rating (Grečenko & Prikner, 2014) proposed the computation of just the nominal tyre contact area S_T (cm^2) for the same load and inflation pressure combination range that might guarantee simple readings of soil density expected within the stated mean contact pressure range.

This access was found out as impractical for the commercial or operating employment because under a given tyre's load state referring to inflation pressure according to present experimental evidence, the corresponding mean contact pressure behaviour in contact area describes precisely soil profile damage after external load.

Experiments

Tyre footprint areas were measured with the improved precision on a laboratory stand including hydraulic actuation attachment and electronic scales up to 65 kN, (Fig. 1). The imprints were made on 1.2 m^2 white chipboard plate placed and fixed on the weight platform 1.5 m^2. The inflation pressure was controlled by the AirBooster with nominal p_{im} = 400 kPa, (PTG Co., Germany). Five pairs of tyre lugs of tyre thread pattern were painted with ink. The real tyre footprints S'_{T0} (cm^2) were exclusively of multiple imprint type when wheel required partial turn corresponded to lug width 5 cm approximately.

Subsequently, they were photographed together with the standard scale of 10 cm. The tyre footprint areas S_{T0} (cm^2) were determined using ImageJ software from the saved pictures (Fig 2). The pictures were transformed by the internal software scale set up on 10 cm as the length of the standard that corresponds with reality. Accuracy of any footprints evaluation guaranteed a reliability of tyre deformation characteristic statement for nominal combinations p_i and W_N, respectively.

Figure 1. Testing of traction tyre Mitas 650/65R38 (RD-03) and laboratory equipment.

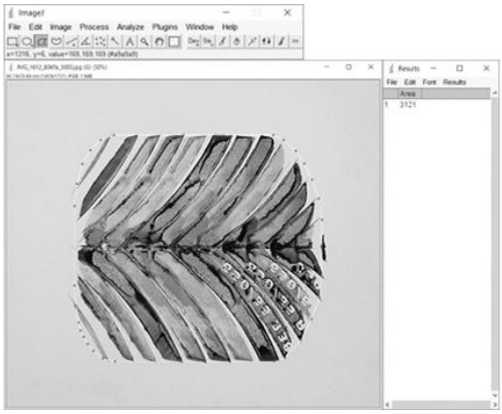

Figure 2. Print screen of ImageJ outputs for tyre multiple footprint area Mitas 650/65R38; (load 3,000 kg, inflation pressure 80 kPa).

Statistical evaluation

Software Statistica Cz 12 (StatSoft, Inc.) was used to evaluate the prediction accuracy of tyre's footprint area. The using Eq. 10, correctness of footprint area estimation was revised with the dimensions of tyre 650/65R38 selected from tyre manufactures. This yields the root mean square error (RMSE) between published and predicted footprint area. The RMSE is given as:

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(|S_{TP} - S_{TM}|)^2}, \tag{13}$$

evaluation includes the fit to the measured data by means of the bias in to form:

$$bias = \frac{1}{n}\sum_{i=1}^{n}(|S_{TP} - S_{TM}|)\ , \tag{14}$$

where: n – number of observations; S_{TP} – predicted contact area (cm^2); S_{TM} – contact area published in tyre's data book (cm^2).

RESULTS AND DISCUSSION

Table 1. presents tyre parameters of tested tyre's size 650/65 R 38. It appears that these formulae can be branded as fully satisfactory but the given values by the tyre manufactures must also be taken into account. The use of Eq. 10, Fig. 3 demonstrates the accuracy in prediction of footprint areas S_{TP} (cm^2) for tyre's size 650/65 R 38 of chosen manufactures. Evaluation confirms the theory of suitability to apply the stiffness tyre sidewall into calculation of tyre footprint area as a main factor affecting progressive change of footprint area size.

Table 1. Catalogue's 650/65 R 38 tyre size from selected manufactures; ETRTO (2008): p_i = 160 kPa, speed 30 km h^{-1}

650/65 R 38	b_t	d_t	r_s	W_k	S_{TM}*
Firestone	640	1,850	828	4,745	3,096
GoodYear	653	1,839	823	4,415	2,905
Michelin	646	1,819	801	4,740	3,000
Mitas	622	1,840	810	4,745	2,400†
Trelleborg	645	1,810	815	4,745	3,050

Note: †unexpected low value in Mitas data book; real footprint area $S'_{T0} \Leftrightarrow S_{TM}$ = 3,100 cm^2; * manufacture's data.

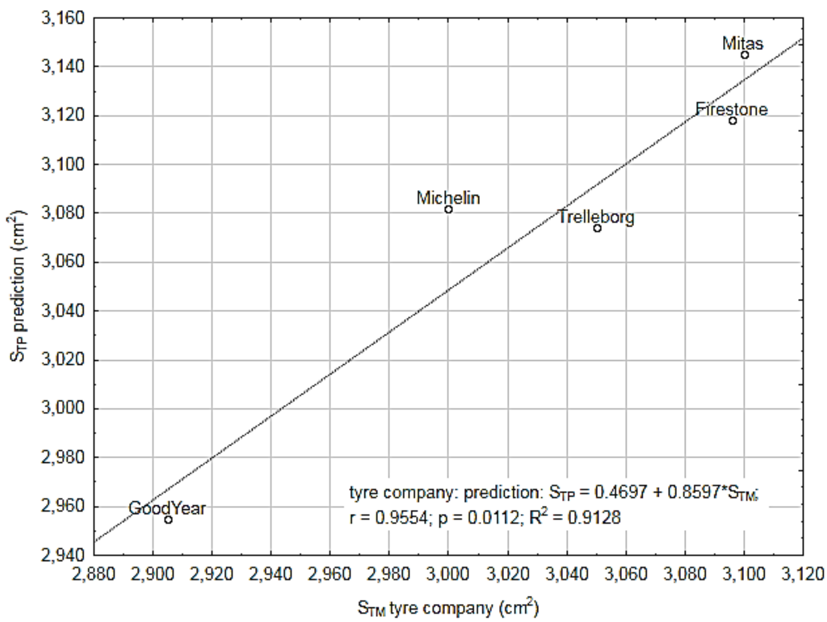

Figure 3. Contact area S_T predicted using the Eq. 10; R^2 – modified coefficient of determination; $RMSE$ = 49.62 cm^2 and $bias$ = 44.60 cm^2; (Statistica Cz 12, original copy).

Theory of Field Compaction Capacity is based on effect of contact pressure in circular contact area. Identical conception as CC rating approach (Grečenko & Prikner, 2014) applies modification of mean contact pressure q_s (kPa) into contact pressure q (kPa) in term:

$$q = (1.06 - 0.06\lambda)q_s, \tag{15}$$

where parameter λ (–) as a ratio of width b (cm) and length l (cm) of contact area gives accuracy to the Eq. 15:

$$\lambda = l/b \tag{16}$$

The advantageous substitution of original footprint shapes by circular area for the radial type of traction tyres is evident. Cross–ply type produces more oval or ellipse area shape; however, identical circular size produces similar outputs in term of mean contact pressure production. Fig. 4, A, B shows comparison of the size for different shapes of multiple tyre footprints.

Generally, the standardized footprint area on a hard ground disposes lower size then published one for a soft soil. In the terrain, tyre contact area can be achieved by an increase up to 80% if the thread pattern is fully pressed (e.g. Schwanghart, 1995; Keller, 2005).

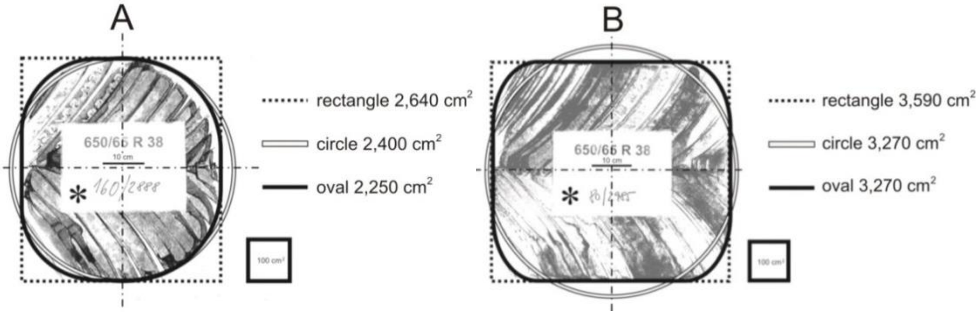

Figure 4. Part (A) multiple tyre footprint (MITAS 650/65 R 38 RD-03) allows to compare contours and differences between regular shapes; Part (B) shows the effect of 50% underinflation (160 → 80 kPa) for similar tyre load; 1,000 cm^2 presents positive 30% contact area increasing (hard surface).

Field compaction capacity (FFC) index expresses a soil compaction risk of tyres for any load capacity listed in catalogue's inflation pressure groups. Similarly, as CC rating, when tyre's mean contact pressure is lower than 70 kPa, both starting S_{Tx} (cm^2) are identical, FCC values are considered as a 'soil friendly'. Fig. 5 shows and proves the difference between FCC and CC indexes. Contact pressure in both conceptions has distinct purpose. In the CC rating as the standardized factor, contact pressure q supports evaluation simplicity with the use of the tyre's contact maximal area S_T (cm^2) across the inflation pressure range. The FCC insists on precise contact area S_{Tx} calculation under a given load which produced contact pressure (Eq. 15). This transformation prefers a cubic polynomial; however the quadratic type is sufficient as well.

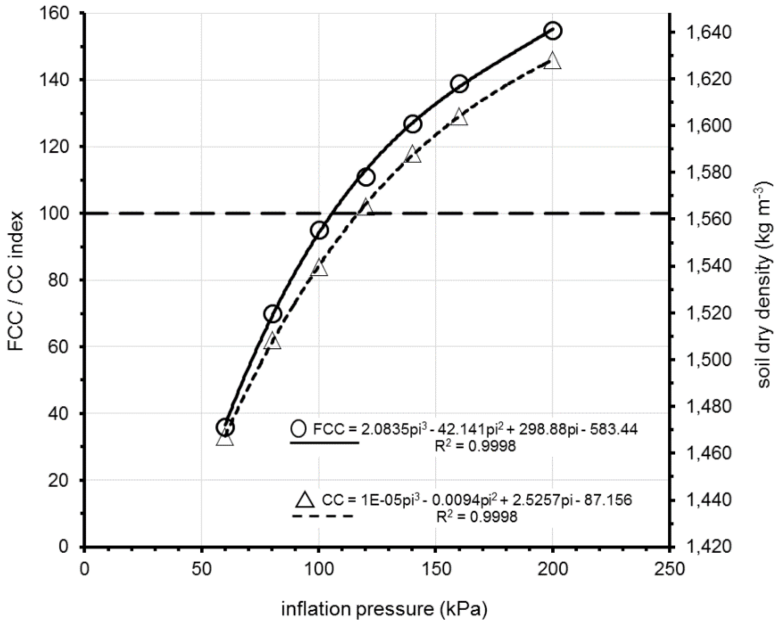

Figure 5. Comparison of FCC and CC quantification for nominal catalogue's load range in dependence on inflation pressure for speed 10 km h^{-1}; (Mitas 650/65 R 38 RD-03); compaction index limit reports to the extreme range of clay-loam soil dry density.

The tyre FCC approach is heading to supplement of the data books of tyre manufacturers for specific agricultural vehicles; alternatively, FCC can be used as a tyre load calculator in soil-friendly traffic propagation. Examples of application of FCC and CC indices are shown in Table 2 (Cross‒ply tractor tyres), Table 3 (Radial front tractor tyres) and Table 4 (Radial rear tractor tyres).

Table 2. FCC rating of selected Cross‒ply tractor tyres in comparison with original CC rating limits (speed 10 km h^{-1}) for standard inflation pressure 140 and reduction 120 kPa; W – load, W_N – nominal load

tyre	16.9–34 (8 PR)			tyre	18.4–34 (8 PR)		
p_i (kPa)	140–120			p_i (kPa)	140–120		
W (kg)	S_T (cm^2)	q (kPa)	FCC	W (kg)	S_T (cm^2)	q (kPa)	FCC
875	1,059–1,185	81–72	6–0	1,200	1,255–1,407	94–84	29–14
1,250	1,153–1,302	106– 94	39–24	1,650	1,363–1,541	119–105	62–45
1,625	1,264–1,440	126–111	60–44	2,100	1,490–1,700	138–121	82–71
2,000	1,400–1,609	140–122	72–55	2,550	1,645–1,891	152–132	93–79
2,375	1,568–1,817	149–128	78–61	3,000	1,834–2,127	160–138	98–83
W_N (kg)	S_T (cm^2)	q (kPa)	CC	W_N (kg)	S_T (cm^2)	q (kPa)	CC
2,750	1,782	153	81	3,450	2,074	165	101
2,470	1,807	135	67	3,100	2,104	146	88

Table 3. FCC rating of selected front radial tractor tyres in comparison with original CC rating limits (speed 10 km h^{-1}) for standard inflation pressure 160 and reduction 120 kPa; W – load, W_N – nominal load

tyre	600/70R30 152 D (155 A8)			tyre	620/75R30 163 B (163 A8)		
p_i (kPa)	160–120			p_i (kPa)	160–120		
W (kg)	S_T (cm^2)	q (kPa)	FCC	W (kg)	S_T (cm^2)	q (kPa)	FCC
1,500	1,949–2,183	76–67	14–0	1,500	1,866–2,085	79–71	43–1
2,000	2,072–2,344	95–84	60–35	2,000	1,973–2,226	100–8	76–45
2,500	2,211–2,526	111–97	90–65	2,500	2,093–2,383	117–103	98–75
3,000	2,371–2,735	124–108	107–84	3,000	2,229–2,561	132–115	113–95
3,500	2,555–2,975	134–115	116–96	3,500	2,383–2,763	144–124	123–106
W_N (kg)	S_T (cm^2)	q (kPa)	CC	W_N (kg)	S_T (cm^2)	q (kPa)	CC
4,970	3,310	149	125	5,355	3,209	165	134
4,580	3,575	127	109	4,780	3,446	137	118

Table 4. FCC rating of selected rear radial tractor tyres in comparison with original CC rating limits (speed 10 km h^{-1}) for standard inflation pressure 160 and reduction 120 kPa; W – load, W_N – nominal load.

tyre	540/65 R 38 147 D (150 A8)			tyre	600/65R38 153 D (156 A8)		
p_i (kPa)	160–120			p_i (kPa)	160–120		
W (kg)	S_T (cm^2)	q_s (kPa)	FCC	W (kg)	S_T (cm^2)	q_s (kPa)	FCC
1,500	1,528–1,720	96–86	48–29	1,500	1,828–2,047	81–72	25–3
2,000	1,646–1.874	120–105	82–62	2,000	1,940–2,192	101–90	69–46
2,500	1,779–2,049	138–120	100–80	2,500	2,065–2,357	119–104	95–74
3,000	1,938–2,256	152– 131	111–91	3,000	2,208–2,544	133–116	110–91
3,500	2,124–2,499	161–137	115–98	3,500	2,373–2,758	145–125	117–102
W_N (kg)	S_T (cm^2)	q_s (kPa)	CC	W_N (kg)	S_T (cm^2)	q_s (kPa)	CC
4,305	2,523	168	119	5,110	3,120	162	130
3,640	2,709	132	95	4,275	3,364	125	103

Grečenko (2016) published the addition to the previous (Grečenko & Prikner, 2014) to specify the eCC index (equivalent Compaction Capacity) for critical parameters of various soil types (Table 5). The eCC index describes the tyre soil compaction capacity for arbitrary soil in the same way as the CC index for standard soil.

Table 5. Critical soil parameters (soil compaction state limit), (Lhotský, 2000)

	C	*Cl*	*L*	*SL*	*LS*	*S*
$\rho_{d\ crit.}$	> 1,350	> 1,400	> 1,450	> 1,550	> 1,600	> 1,700
Porosity (% vol.)	< 48	< 47	< 45	< 42	< 40	< 38
PR	2.8–3.2	3.3–3.7	3.8–4.2	4.5–5.0	5.5	> 6.0

Legend: C – clay; Cl – clay loam; L – loam; SL – sandy loam; LS – loamy sand; S – sand; $\rho_{d\ crit}$ – critical limit of soil dry density (kg m^{-3}); *PR* – penetration resistance (MPa).

Original CC or FCC modification (see Eq. 11), compares ratio of soil compaction state to critical dry bulk density for clay-loam soil type (1,420 kg m^{-3}) exclusively. The eFCC index using previous formula can be defined:

$$\mathrm{eCC} \Rightarrow \mathrm{eFCC} = [(\mathrm{CC} + 1{,}000)\rho_{dl} / \rho_d - 1{,}000] \tag{17}$$

The evaluation of tyre eFCC index is demonstrated using five soil types in Fig. 6. Considering the value of eFCC = 100 as an upper limit, the clay soil admits acceptable eFCC index when tyre load of about 3,530 kg at 60 kPa inflation pressure. The limit for clay loam and loam soil type allows to nominal combinations of load and inflation pressures for 100 and 140 kPa, respectively. The outputs of tyre compaction capacity indexes (CC, FCC, eCC, eFCC) confirm a high soil resistance to critical compaction state in the whole range of inflation pressures for sandy soil demonstrably.

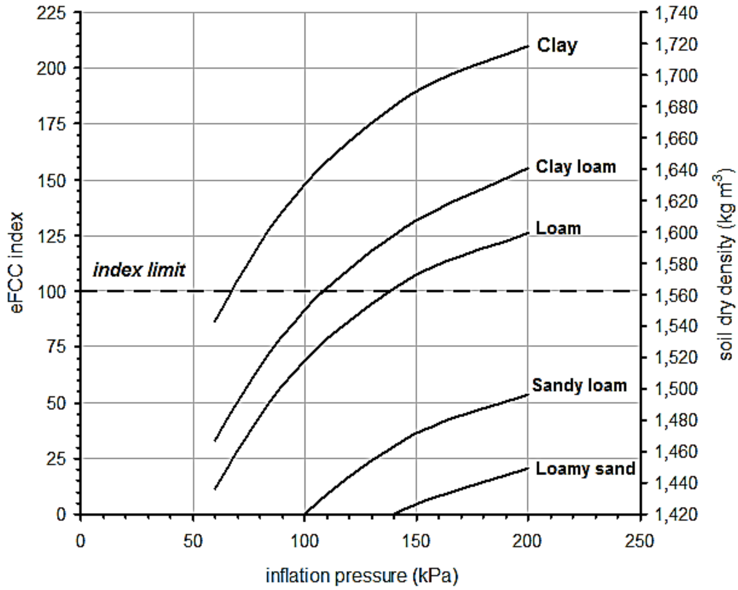

Figure 6. Trends of the eFCC for selected soil types; nominal catalogue's load range in dependence on inflation pressure for speed 10 km h^{-1}; (Mitas 650/65 R 38 RD-03); eFCC index limit reports to the extreme range of soil dry density, referring to clay loam standard.

CONCLUSIONS

The paper describes prediction of the off-road tyre's footprint area on a hard ground (area of the envelope to the contact patch) that can be applied more readily in agricultural engineering. The proposed approach enables to convert the content of tyre catalogue data only. Such a conversion leads to the nominal footprint area which refers to any combination of inflation pressure load listed in the catalogues. New prediction includes the tyre sidewall stiffness in dependence on tyre static radius change, which guarantees to establish size of tyre footprint area in the range of inflation pressure completely. Thus tyre CC index (rating) can be transformed into actual compaction capacity of tyre marked as FCC 'Field compaction capacity' using polynomial function. The FCC index, based on tyre footprint on hard ground, can describe the tyre's compaction effect more precisely. FCC modifications into the eFCC refers to soil compaction risk to characteristic soil types. This is recommended for tyre and machine manufactures to publish optimal tyre inflation pressure levels or suggest advantageous combinations of type or size tyres for field operations on moist soils.

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REFERENCES

Arvidsson, J. & Håkansson, I. 2014. Response of different crops to soil compaction- Short-term effects in Swedish field experiments. *Soil Till. Res.* **138**, 56–63.

Bailey, A.C., Raper, R.I., Way, T.R., Burt. E.C. & Johnson, C.E. 1996. Soil stresses under a tractor tire at various loads and inflation pressures. *J Terramech.* **33**, 1–11.

ETRTO. Engineering design information. Brussels-Belgium: *European tyre and rim technical organization*. 2008.

Grečenko, A. 1996. Tire footprint area on hard ground computed from catalogue values. *J Terramech.* **32**(6), 326–333.

Grečenko, A. & Prikner, P. 2014. Tire rating based on soil compaction capacity. *J Terramech.* **52**, 77–92.

Grečenko, A. 2016. Tire compaction capacity rating on non-standard soil. *J Terramech.* **66**, 59–61.

Gutu, D., Hůla, J., Kovaříček, P. & Novák, P. 2015. The influence of a system with permanent traffic lanes on physical properties of soil, soil tillage quality and surface water runoff. *Agronomy Research* **13**, 63–72.

Håkansson, I. 1990. A method for characterizing the state of compactness of the plough layer. *Soil Till. Res.* **16**, 105–120.

Håkansson, I. & Petelkau, H. 1994. Benefits of limited axle load. In: Soane, B.D. and Van Ouwerkerk, C. (eds.) Soil Compaction in Crop Production. *Developments in Agricultural Eng.* **11**, Elsevier, Amsterdam, The Netherlands, pp. 479–499.

Keller, T. 2005. A model for the prediction of the contact area and the distribution of vertical stress below agricultural tyres from readily available tyre parameters. *Biosyst. Eng.* **92**(1), 85–96.

Keller, T. & Lamandé, D. 2014. Challenges in the development of analytical soil compaction models. *Soil Till. Res.* **111**, 54–64.

Lhotský, J. 2000. Soil compaction and measures against it [in Czech, abstract in English]. In: *Study Inf Plant Product*, **7**. Prague: Institute of Agric. and Food Ind Informations; 62 pp.

Schwanghart, H. 1990. Measurement of contact area, contact pressure and compaction under tyres on soft ground. *J Terramech*. **28**(4), 309–318.

Schjønning, P., Stettler, M., Keller, T., Lassen, P. & Lamandé, M. 2015. Predicted tyre-soil interface area and vertical stress distribution based on loading characteristics. *Soil Till. Res*. **152**, 52–66.

van den Akker, J.J.H. & Hoogland, T. 2011. Compaction of risk assessment methods to determine the subsoil compaction risk of agricultural soils in the Netherlands. *Soil Till. Res.* **114**, 156–154.

Xia, K. 2011. Finite element modelling of tire/terrain interaction: Application to predicting soil compaction and tire mobility. *J Terramech*. **48**(2), 113–123.

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Reliability monitoring of grain harvester

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Abstract. This paper is focused on evaluation of operating reliability of grain harvesters. The aim of research is to improve the efficiency of combine harvesters by calculations which indicate a minimum annual performance and try to move in profit despite the high annual costs. Methods of paper containing all conditions of monitoring and evaluating of responsibility of grain harvesters. Those harvesters worked in real operating conditions. During three years of monitoring all important and other facilities and conditions of watching were recorded. After accumulation of information, their following working was set out according to the given literary sources and according to the own discretion based on experience during monitoring. The last part is focused on evaluating results and personal proposals how to make individual components work more effective. The most important results was recorded in case of turning point calculation where in years 2013, 2014 and 2015 at values 157.93, 156.19 and 166.86 ha year^{-1}, respectively. However, real annual performance was recorded at values 760.5, 604.6 and 905.5 ha year^{-1}. Thus, in all years of observation the grain harvester finished in profits.

Key words: harvester, reliability, performance, cost, turning point.

INTRODUCTION

Agriculture is, certainly, one of the most important industries in the world. It is mainly from two aspects. The first is a fundamental aspect of food security for the population of different countries. The second aspect, which is not less important, is a forage production for livestock production and raw materials for other industries (de Toro et al., 2012; Findura et al., 2013, Nozdrovický et al., 2013).

In Slovakia, crop production has still a large enough presence in the cultivation of cereals. Grain harvest is the most difficult operation in agriculture. The harvest belongs to the activities where you can clearly see the result of all seasonal efforts (Žitňák et al., 2014; Žitňák et al., 2015). Grain harvesters are used during grain harvest. In the past, harvesters were part of all cooperatives, but today the trend shifted to organizations that provide harvest work and relieve the other organizations from the costly operation of grain harvesters. Whereas any one of grain harvest has different conditions (Lee et al., 2016), a great attention must be paid to precise adjust of different parts and components of grain harvester. When errors occur, unwanted harvesting losses certainly displease every farmer (Korenko et al., 2012a; Korenko et al., 2012b; Vladut et al., 2012; Korenko et al., 2015).

Nowadays in modern agricultural machinery, including grain harvesters, it is very important to use them effectively with the highest emphasis on performance and quality of work. The recent grain harvesters are equipped with modern features that provide much higher performance than in the past (Craessaerts et al., 2010; Hanna & Jarboe, 2011; Beloev et al., 2012; Singh et al., 2012; Bujna & Beloev, 2015).

The role of this paper is to monitor John Deere 9660 WTS harvester. The harvester is the property of GoldAgro, Ltd. which is mainly focused on the provision of harvesting services. Grain harvesters provide services throughout Slovakia, Czech Republic and a little of the services performed are in the border areas of Austria and Hungary. We conducted monitoring for the years of 2013, 2014, 2015. Calculating turning points we will ascertain whether the grain harvesters move in loss or profit (Prístavka et al., 2013; Prístavka & Bujna, 2013; Beneš et al., 2014; Prístavka & Bujna, 2014; Mašek et al., 2015).

MATERIALS AND METHODS

The used data were collected during the years of 2013, 2014 and 2015 and they concerned mainly at the cost of the machine, the cost of amortization, capitalization of capital, insurance, bank interest, garaging, repairs and maintenance costs and fuel.

The calculation of the costs harvesters operation

The annual operating cost of the machine can be expressed as:

$$rN_sp = rN_sk + rN_sv \tag{1}$$

where: rN_sp – operating costs of the machine, € year^{-1}; rN_sk – constant costs of the machine, € year^{-1}; rN_sv – variable costs of the machine, € year^{-1}.

Constant costs of the machine can be expressed as:

$$rN_sk = rN_sa + rN_sz + rN_sdmv + rN_szp + rN_su + rN_svp + rN_sg \tag{2}$$

where: rN_sa – annual cost of the machine amortization, € year^{-1}; rN_sz – annual cost of the machine to interest on capital, € year^{-1}; rN_sdmv – annual cost of the machine to the motor vehicle tax, € year^{-1}; rN_szp – annual cost of the machine to insurance statutory, € year^{-1}; rN_su – annual cost of the machine to bank interest, € year^{-1}; rN_svp – annual cost of the machine to optional insurance, € year^{-1}; rN_sg – annual cost of the machine to garaging, € year^{-1}.

Variable annual costs can be expressed as:

$$rN_sv = rN_so + rN_se + rN_szp \tag{3}$$

where: rN_so – the annual cost of the machine to repair and maintenance, € year^{-1}; rN_se – the annual cost of the machine to energy, including fuel and lubricants, € year^{-1}; rN_szp – the annual cost of live work, including contributions, € year^{-1}.

The costs of machine amortization

The annual costs of machine amortization can be expressed as:

$$rN_sa = \frac{CO_s . a_s}{100}; \ (\text{€ year}^{-1}) \tag{4}$$

where: CO_s – cost of machine; €; a_s – depreciation rate for machinery, %.

Unit costs of machine amortization can be expressed as:

$$jN_sa = \frac{rN_sa}{rW_s};\ (€\ ha^{-1}) \tag{5}$$

where: rW_s – annual machine performance, ha year^{-1}.

The costs of interest on capital

The annual costs of interest on capital can be expressed as:

$$rN_sz = \frac{(CO_s + CZ_s)}{2} . \frac{z}{100} . KZ;\ \left(€\ year^{-1}\right) \tag{6}$$

where: CO_s – costs of machine, €; CZ_s – net value of the machine, €; z – interest on own capital, %; KZ – mathematical correction calculating the remuneration.
while:

$$KZ = 0{,}8742 + 0{,}0013 . \left(\frac{VK_s}{CO_s} . 100\right); \tag{7}$$

Unit costs of interest on capital can be expressed as:

$$jN_sz = \frac{rN_sz}{rW_s};\ (€\ ha^{-1}) \tag{8}$$

where: rW_s – annual machine performance, ha year^{-1}.

The cost of vehicle tax

From the 1st of January 2005 the road taxi s replaced by the so-called motor vehicle tax. Motor vehicle tax are imposed (in accordance with the provisions of Law no. 582/2004 on local taxes and local fees for municipal waste and minor construction waste and the provisions of Law no. 583/2004 on budget rules of local governments and amending certain laws) by independently higher territorial units (HTU). This regulation include the amount of tax scales.

Pursuant to EC-Regulation. 582/2004 and generally binding regulations of the Higher Territorial Units (HTU), tax is not applied to the agricultural working machine.

The costs of compulsory liability insurance for damage caused by motor vehicles

The annual cost of liability insurance can be expressed as:

$$rN_szp = rS_szp;\ (€\ year^{-1}) \tag{9}$$

where: rN_szp – annual rate of liability insurance for damage caused by motor vehicles for the machine, € year^{-1}.

Unit cost of liability insurance can be expressed as:

$$jN_szp = \frac{rN_szp}{rW_s};\ (€\ ha^{-1}) \tag{10}$$

where: rWs – annual machine performance, ha year^{-1}.

Costs associated with the use of external sources of capital

Annual cost of bank loan can be expressed as:

$$rN_s u = \frac{SBU_s}{t_s} - \frac{I_s}{t_s};\ (€\ \text{year}^{-1}) \tag{11}$$

where: SBU_s – total payment of a bank loan for the acquisition of machinery, including interest, €; I_s – principal, €; t_s – operation time of machine, years.

Unit costs of a bank loan can be expressed:

$$jN_s u = \frac{rN_s u}{rW_s};\ (€\ \text{ha}^{-1}) \tag{12}$$

where: rWs – annual machine performance, ha year^{-1}.

The costs of optional insurance

The annual cost of machine optional insurance can be expressed as:

$$rN_s vp = \frac{CO_s\ .\ p}{100};\ (€\ \text{year}^{-1}) \tag{13}$$

where: CO_s – cost of machine, €; p – negotiated insurance rates, %.

Unit costs for an optional insurance of the machine can be expressed as:

$$jN_s vp = \frac{rN_s vp}{rW_s};\ (€\ \text{ha}^{-1}) \tag{14}$$

where: rW_s – annual machine performance, ha year^{-1}.

Costs of garaging

The annual cost of garaging can be expressed as:

$$rN_s g = (l_s + 1).(b_s + 1).sgp_s\ ;\ (€\ \text{year}^{-1}) \tag{15}$$

where: l_s – machine length, m; b_s – machine width, m; sgp_s – annual fee for the use of garage area, € m^{-2} year^{-1}.

Unit costs for garaging can be expressed as:

$$jN_s g = \frac{rN_s g}{rW_s};\ (€\ \text{ha}^{-1}) \tag{16}$$

Costs of repairs and maintenance

Mid-unit cost of repairs and maintenance can be expressed as:

$$j_{str} N_s o = \frac{r_{str}\ N_s o}{rWn_s};\ (€\ \text{ha}^{-1}) \tag{17}$$

where: rWn_s – annual normative performance of the machine, ha year^{-1}.

Qualified estimate of the cost for repairs and maintenance

A simple estimate of the annual cost of the machine for repair and maintenance can be expressed as:

$$rN_s o = rN_s a.k_o;\ (€\ \text{year}^{-1}) \tag{18}$$

where: rN_sa – annual cost of amortization with linear way of depreciation, € year^{-1}; k_o – coefficient of repairs.

Standard method for calculating annual costs of the machine for repair and maintenance can be expressed as:

$$rN_so = rN_sa_{10}.k_o.\frac{rWn_s}{rW_{s10}};\ (€\ \mathrm{year}^{-1}) \qquad (19)$$

where: rN_sa_{10} – annual cost of amortization at 10 years of operation in, € year^{-1}; k_o – coefficient of repairs; rW_{s10} – mid-annual machine utilization at 10 years of operation, ha year^{-1}; rWn_s – standard annual machine utilization, ha year^{-1}.

The unit estimate of the cost for repairs and maintenance can be expressed as:

$$jN_so = \frac{rN_so}{rWn_s};\ (€\ \mathrm{ha}^{-1}) \qquad (20)$$

while a coefficient of repairs is given by the ratio and can be expressed as:

$$k_o = \frac{rN_so}{rN_sa}\ ; \qquad (21)$$

where: rN_so – annual cost of repairs at the time of use, € year^{-1}; rWn_s – annual machine performance at the time of use, € year^{-1}; rN_sa – annual cost of the machine for amortization, € year^{-1}.

Costs of machine for energy

The annual costs of the machine for energy without VAT can be expressed as:

$$rN_se = Q.\left(\frac{Ce}{1+\frac{DPH_{UP}}{100}}\right).rW_s.\left(1+\frac{PSM}{100}\right);\ (€\ \mathrm{year}^{-1}) \qquad (22)$$

where: Q – energy consumption (fuel), l ha^{-1}; Ce – cost of energy (fuel) including VAT, € l^{-1}; DPH_{UP} – VAT rate for hydrocarbon fuels, %; rW_s – machine performance, ha year^{-1}; PSM – premise of lubricants consumption, %.

Unit costs of the machine for energy can be expressed as:

$$jN_se = \frac{rN_se}{rW_s};\ (€\ \mathrm{ha}^{-1}) \qquad (23)$$

The cost of living labour

Annual costs of living labour can be expressed as:

$$rN_{zp} = \left(S_{hod} + \frac{S_{hod}.\sum ODV}{100}\right).RP + CN.RP;\ (€\ \mathrm{year}^{-1}) \qquad (24)$$

where: S_{hod} – hourly rate, € h^{-1}; ΣODV– sum of contributions pertaining S_{hod}, %; RP – scope of work, h year^{-1}; CN – travel expenses, € h^{-1}.

Unit costs for living labour can be expressed as:

$$jN_{zp} = \frac{rN_{zp}}{rW_s};\ (€\ ha^{-1}) \tag{25}$$

where: rW_s – annual performance of the machine, ha year^{-1}.

Pricing mechanized work

The price of mechanized work can be expressed as:

$$CMP_s = jN_s p. \left(1 + \frac{MZ}{100}\right);\ (€\ ha^{-1}) \tag{26}$$

where: CMPs – price of mechanized work of the machine, € ha^{-1}; MZ – profit margin, %.

RESULTS AND DISCUSSION

John Deere WTS 9660 harvester with a daily output of 30–40 ha, cutting table with a length of 6.6 meters, adapters for sunflower and maize of Oros brand with 6 rows with a daily output of 15 to 20 hectares, built in 2006, power of 340 PS, 4 x 4, hill master engine capacity 8.13 liters, number of cylinders 6, container volume 9,000 litters, 700 litters fuel tank. John Deere harvester with the year of manufacture 2006 when it was also purchased by the GoldAgro organization cost € 215,760 (Table 1). The full price was paid in 2009 and economically depreciated in the same year. Own funds accounted for the amount of € 75,000 and € 140,760 was a bank loan. Each of costs is shown in Table 1–4.

Table 1. Operation parameters of John Deere WTS 9660

Characteristics of John Deere WTS 9660 operation parameters				
Years		2013	2014	2015
Cost of the machine, €	CO_s	215,760	215,760	215,760
Own funds, €	VK_s	140,760	140,760	140,760
Bank loan, €	BU_s	-	-	-
Plan. net machine price, €	ZC_s	0	0	0
Depreciation, years		-	-	-
Rate of remuneration on current accounts, %	Z	5	5	5
Real annual performance, ha year^{-1}	rW_s	716.50	604.60	905.50
Real hourly performance, ha h^{-1}	hW_s	2.2	2.2	2.6
Normative annual performance, ha year^{-1}	rW_sn	1,000	1,000	1,000
Normative hourly performance, ha h^{-1}	hW_sn	2.5	2.5	2.5
Real fuel consumption, l ha^{-1}	Q_s	17	16	17
Normative fuel consumption, l ha^{-1}	Q_sn	14 – 16	14 – 16	14 – 16
Diesel price incl. VAT, € l^{-1}	Ce	1.314	1.409	1.371
Premise of lubricants consumption, %	PSM	18	33	41
Engine power, kW	P_m	249	249	249
Machine width, mm	b_s	3,250	3,250	3,250
Machine length, mm	l_s	8,900	8,900	8,900

Table 2. Table of fixed costs in annual terms for John Deere 9660 WTS in 2013, 2014, 2015

Item costs	Units	2013	2014	2015
Costs of amortization	€ $year^{-1}$	-	-	-
Costs of interest on capital	€ $year^{-1}$	5,124.30	5,124.30	5,124.30
Costs of vehicle tax	€ $year^{-1}$	-	-	-
Costs of insurance for damage	€ $year^{-1}$	82	82	82
Costs of ban interests	€ $year^{-1}$	-	-	-
Costs of optional insurance	€ $year^{-1}$	2, 157.60	2,157.60	2,157.60
Costs of garaging	€ $year^{-1}$	134.64	134.64	134.64
Total	€ $year^{-1}$	7,498.54	7,498.54	7,498.54

Table 3. Table of variable costs in annual terms for John Deere 9660 WTS in 2013, 2014, 2015

Item costs	Units	2013	2014	2015
Costs of repairs and maintenance	€ $year^{-1}$	3,058.00	3,000.50	4,156.00
Costs of fuel	€ $year^{-1}$	15,738.42	15,106.69	24,797.77
Costs of live labour	€ $year^{-1}$	2,224.47	1,877.69	2,811.25
Total	€ $year^{-1}$	21,020.89	19,984.88	31,765.02

Table 4. Table of total costs in annual terms for John Deere WTS 9660 for the years of 2013, 2014, 2015

Item costs	Units	2013	2014	2015
Total annual costs	€ $years^{-1}$	28,519.43	27,483.42	39,263.56
Total annual revenues	€ $years^{-1}$	54,019.42	49,026.84	60,693.17
Variable units costs	€ ha^{-1}	29.32	33.04	35.06

John Deere WTS 9660 (2013)

John Deere WTS 9660 (in 2013) had a performance of 716.50 ha $year^{-1}$, and we calculated the defined turning point (Fig. 1; Table 6) at a value of 157.93 ha $year^{-1}$ (Fig 2). Thus, in 2013 the grain harvester finished in profits (Table 5).

Table 5. Determination of the minimum annual performance of John Deere 9660 WTS in 2013

John	2013			
Deere	Labour price, € ha^{-1}	rN_sk, € $year^{-1}$	jN_sp, € ha^{-1}	rW_{min}, ha $year^{-1}$
WTS 9660	76.80	7 498.54	29.32	157.93

Table 6. Data table for calculating the turning point of John Deere 9660 WTS in 2013

rW_s, ha $year^{-1}$	rN_sk, € $year^{-1}$	rN_sv, € $year^{-1}$	rN_sp, € $year^{-1}$	rVs, € $year^{-1}$
0	7,498.51	0	7,498.51	0
157.93	7,498.51	4,630.50	12,129.01	12,129.01
400	7,498.51	11,728	19,226.51	30,000
800	7,498.51	23,456	30,954.51	60,000
1,200	7,498.51	35,184	42,682.51	90,000
1,600	7,498.51	46,912	54,410.51	120,000
2,000	7,498.51	58,640	66,138.51	150,000
2,400	7,498.51	70,368	77,866.51	180,000
2,800	7,498.51	82,096	89,594.51	210,000
3,200	7,498.51	93,824	101,322.51	240,000

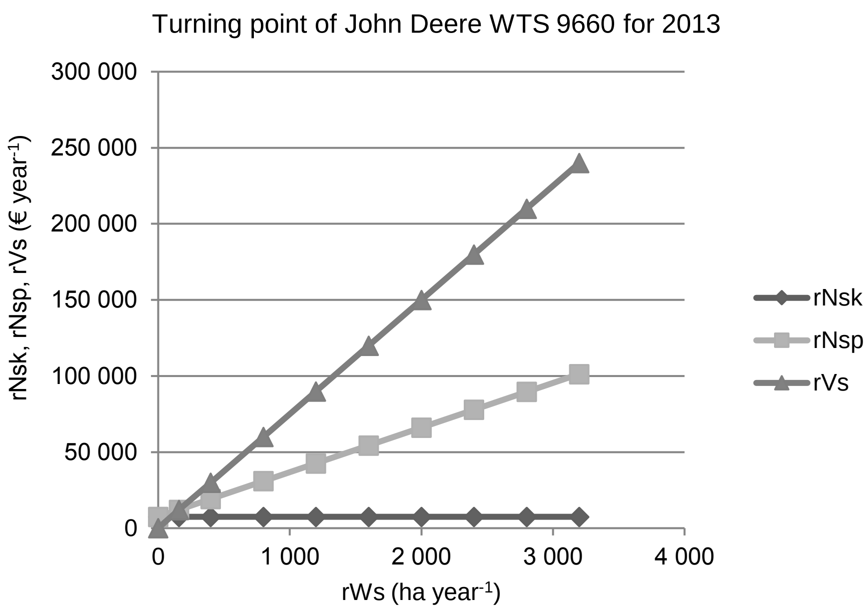

Figure 1. Graph of John Deere WTS 9660 turning point for 2013.

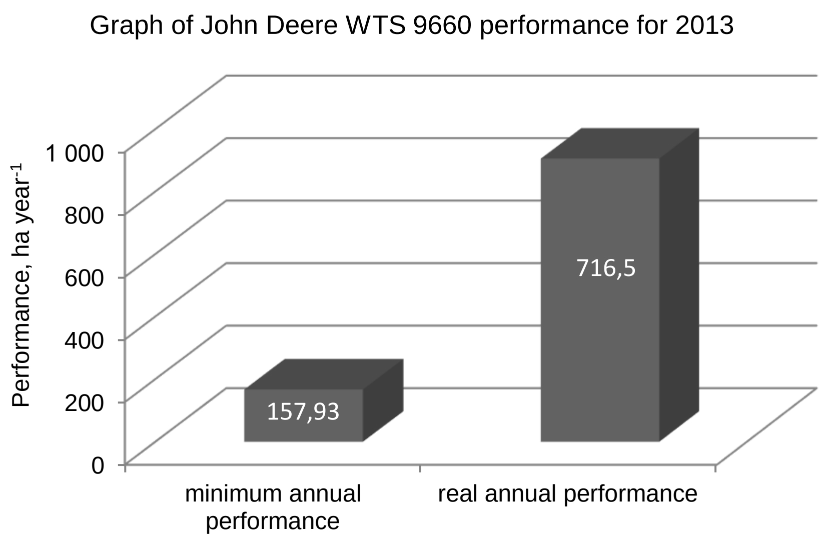

Figure 2. Graph of John Deere WTS 9660 performance for 2013.

John Deere WTS 9660 (2014)

John Deere 9660 WTS 2014 grain harvester had a performance of 604.60 ha $year^{-1}$, and we calculated the defined turning point (Fig. 3; Table 8) at a value of 156.19 ha $year^{-1}$ (Fig. 4). Thus, in 2014 the grain harvester finished in profit (Table 7).

Table 7. Determination of the minimum annual performance of John Deere 9660 WTS 2014

John Deere	2014			
	Labour price, € ha^{-1}	rN_sk, € $year^{-1}$	jN_sp, € ha^{-1}	rW_{min}, ha $year^{-1}$
WTS 9660	81.05	7,498.54	33.04	156.19

Table 8. Data table for calculating the turning point of John Deere 9660 WTS 2014

rW_s, ha $year^{-1}$	rN_sk, € $year^{-1}$	rN_sv, € $year^{-1}$	rN_sp, € $year^{-1}$	rVs, € $year^{-1}$
0	7,498.51	0	7,498.51	0
156.16	7,498.51	5,159.52	12,658.03	12,658.03
400	7,498.51	13,216	20,714.51	30,000
800	7,498.51	26,432	33,930.51	60,000
1,200	7,498.51	39,648	47,146.51	90,000
1,600	7,498.51	52,864	60,362.51	120,000
2,000	7,498.51	66,080	73,578.51	150,000
2,400	7,498.51	79,296	86,794.51	180,000
2,800	7,498.51	92,512	100,010.51	210,000
3,200	7,498.51	105,728	113,226.51	240,000

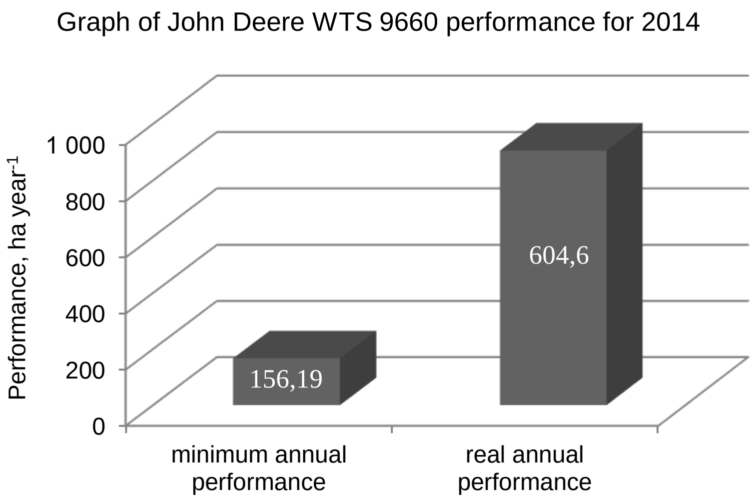

Figure 4. Graph of John Deere WTS 9660 performance for 2014.

John Deere WTS 9660 (2015)

John Deere 9660 WTS (in 2015) had a performance of 905.50 ha year^{-1}, and we calculated the defined turning point (Fig. 5; Table 10) at a value of 166.86 ha year^{-1} (Fig. 6). Thus, in 2015 the grain harvester finished in profits (Table 9).

Table 9. Determination of the minimum annual performance for John Deere 2015

John	2014			
Deere	Labour price, € ha^{-1}	rN_sk, € year^{-1}	jN_sp, € ha^{-1}	rW_{min}, ha year^{-1}
WTS 9660	80.00	7,498.54	35.06	166.86

Table 10. Data table for calculating the turning point of John Deere 9660 WTS in 2015

rW_s, ha year^{-1}	rN_sk, € year^{-1}	rN_sv, € year^{-1}	rN_sp, € year^{-1}	rVs, € year^{-1}
0	7,498.51	0	7,498.51	0
166.86	7,498.51	5,850.11	13,348.62	13,348.62
400	7,498.51	14,024	21,522.51	30,000
800	7,498.51	28,048	35,546.51	60,000
1,200	7,498.51	42,072	49,570.51	90,000
1,600	7,498.51	56,096	63,594.51	120,000
2,000	7,498.51	70,120	77,618.51	150,000
2,400	7,498.51	84,144	91,642.51	180,000
2,800	7,498.51	98,168	105,666,51	210,000
3,200	7,498.51	112,192	119,690.51	240,000

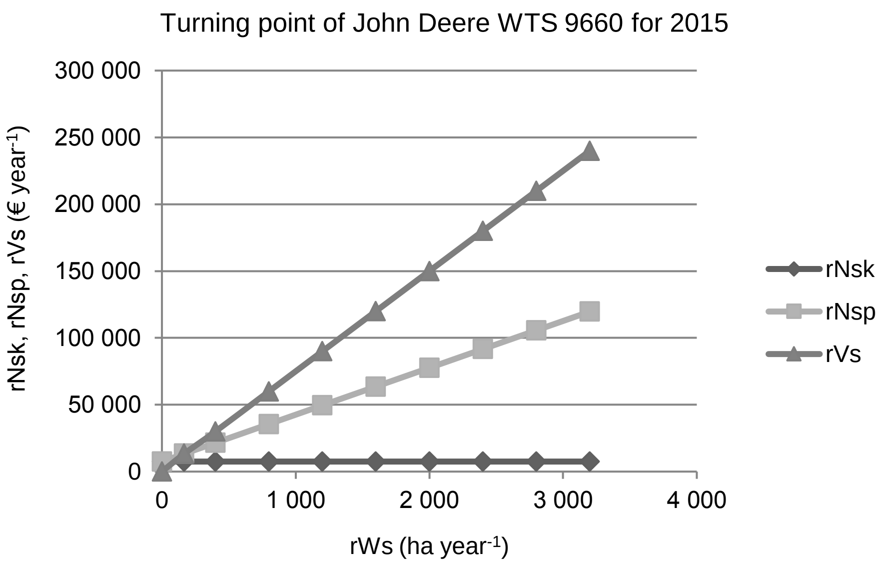

Figure 5. Graph of John Deere WTS 9660 turning point for 2015.

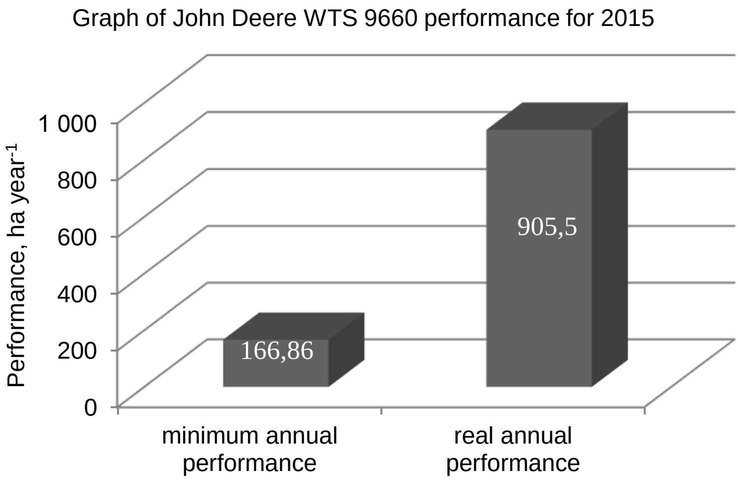

Figure 6. Graph of John Deere WTS 9660 performance for 2015.

After evaluating all the data we came to the conclusion that the organization GoldAgro, Ltd. should increase the performance of individual harvesters. It can be managed by the lowest possible downtime for repairs and maintenance as well as the maximum effort in searching the new customers at the most reasonable means of transport between the different places of operation (Mašek et al. 2015).

CONCLUSIONS

Agriculture in Slovakia has a great potential but organizations that operate in it are just survived from day to day. Without the state subsidies for purchasing agricultural machinery for the renewal of its fleet, it will be very difficult. The competition is intense even within the provision of harvest services. Some organizations offer their work only to cover their costs without any extra profit. The quality of the harvest depends on different types of machines. Nowadays there are various brands of harvesters with different power and size mower clip. GoldAgro, Ltd. organization where we concerned with this issue is the evidence that a high cost of harvesters can bring profit only after quite a few years, if ever. It is important to ensure the efficient use of harvesters and try to raise the actual annual performance. Raising performance should be done by searching of new customers who are interested in harvest services and set price of labour so as to be acceptable to both sides.

The facts that we came to in the research show us that the performance what we achieve depends on technology and service of harvesters. We can see that the older machine that has already been in service for years would lack such performance as a new machine that has advanced technologies built in to achieve the highest possible performance

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about the effect of technological parameters of the surface coating in agricultural and forestry techniques for qualitative parameters, safety and environmental acceptability.

REFERENCES

Beloev, H., Dimitrov, P., Kangalov, P., Stoyanov, K. & Ilieva, D. 2012. Machine operation tests on anti-erosion machine-tractor aggregates for composting and vertical mulching. *Mendeltech international 2012.* International scientific conference, Brno. (in Czech Republic).

Beneš, L., Novák, P., Mašek, J. & Petrášek, S. 2014. John Deere Combine Harvesters Fuel Consumption and Operation Costs. In: 13th International Scientific Conference on Engineering for Rural Development, Jelgava, LATVIA, MAY 20–22, 2015, pp. 13–17.

Bujna, M. & Beloev, C.I. 2015. Tools of risk management in production processes. Ruosse: Angel Kanchev University of Rousse, 105 pp. (in Bulgaria).

Bulgakov, V., Melnik, V., Mohammed, A., Korenko, M. & Kollárová, K. 2016. Methodology of processing the results of field experiment monitoring of the technological procedure of sowing. In *Research in agricultural engineering* **62**, pp. 30–36.

Craessaerts, G., De Baerdemaeker, J. & Saeys, W. 2010. Fault diagnostic systems for agricultural machinery. *Biosystems Engineering* **106**(1), 26–36.

de Toro, A., Gunnarsson, C., Lundin, G. & Jonsson, N. 2012. Cereal harvesting – strategies and costs under variable weather conditions. *Biosystems Engineering* **111**(4), 429–439.

Findura, P., Turan, J., Jobbágy, J., Angelovič, M. & Ponjican, O. 2013. Evaluation of work quality of the green peas harvester Ploeger EPD 490. In *Research in agricultural engineering* **59**, pp.56–60.

Hanna, H.M. & Jarboe, D.H. 2011. Effects of full, abbreviated, and no clean-outs on commingled grain during combine harvest. *Applied Engineering in Agriculture* **27**(5), 687–695.

Korenko, M., Frančák, J., Tkáč, Z., Kročko, V., Kaplík, P. & Daňo, P. 2012. Evaluation of operational reliability of grain harvester. In *Zbirnik naukovych prac Vinničkogo nacionaľnogo agrarnogo universitetu.* Kijev: Ministerstvo agrarnoj politiki Ukraini, pp. 24–32. (in Ukraine).

Korenko, M., Bujna, M., Földešiová, D., Dostál, P. & Kyselica, P. 2015. Risk analysis at work in manufacturing organization. In *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis* **63**, pp. 1493–1497.

Korenko, M., Frančák, J., Kročko, V., Földešiová, D., Dragula, P. & Bulgakov, V. 2012. Analysis methods for measuring system by repeatability and reproducibility. In Konstruovannja, vyrobnictvo ta ekspluatacija silskogospodarskich mašin. pp. 65–70 (in Ukraine).

Lee, D.H., Kim, Y.J., Choi, C.H., Chung, S.O., Nam, Y.S. & So, J.H. 2016. Evaluation of operator visibility in three different cabins type Far-East combine harvesters. *International Journal of Agricultural and Biological Engineering* **9**(4), 33–44.

Mašek, J., Novák, P. & Pavlíček, T. 2015. Evaluation of Combine Harvester Fuel Consumption and Operation Costs. In: *14th International Scientific Conference: Engineering For Rural Development.* Jelgava, LATVIA, MAY 20–22, 2015, pp. 78–83.

Nozdrovický, L., Macák, M., & Šima, T. 2013. Current trends in the development of agricultural machinery and their impact on the knowledge and skills of the human factor. In: *5th International Conference on Trends in Agricultural Engineering.* Czech University of Life Sciences Prague, Dept Systems Eng, Kamycka 129, Prague 6 165 21, Czech Republic, Prague, Czech Republic, Sep 03–06, 2013, pp. 467–474.

Prístavka, M. & Bujna, M. 2013. Use of Satatical Methods in Quality Control. In: *Acta technologica agriculturae*. SUA in Nitra, Nitra pp. 33 –36. (in Slovak Republic).

Prístavka, M. & Bujna, M. 2014. Monitoring the Capability of Production Equipment in Organization. In: *Acta technologica agriculturae.* SUA in Nitra, Nitra pp. 39–43. (in Slovak Republic).

Prístavka, M., Bujna, M. & Korenko, M. 2013. Reliability Monitoring of Grain Harvester in Operating Conditions. *Journal of Central European Agriculture* **14**, 1436–1443.

Singh, M., Verma, A. & Sharma, A. 2012. Precision in Grain Yield Monitoring Technologies: A Review. *AMA-Agricultural Mechanization in Asia Africa and Latin America* **43**(4), 50–59.

Vladut, V., Moise, V., St Biris, S. & Paraschiv, G. 2012. Determining the cost matrix of straw cereals combine harvesters, according to equipment quality nad engine power. In: *40th International Symposium on Agricultural Engineering.* Opatija, CROATIA, FEB 21–24, 2012, pp. 333–343.

Žitňák, M., Kollárová, K., Macák, M., Prístavková, M. & Bošanský, M. 2015. Assessment of risks in the field of safety, quality and environment in post-harvest line. In *Research in agricultural engineering* **61**, pp. 26–36.

Žitňák, M., Macák, M. & Korenko, M. 2014. Assessment of risks in implementing automated satellite navigation systems. In *Research in agricultural engineering* **60**, pp. 16–24.

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Second-generation bioethanol production: A review of strategies for waste valorisation

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Abstract. This paper reviews second–generation biofuel production chain and focuses on its energetic, economic and environmental impacts. The biggest challenge in the production of bioethanol from lignocellulosic material refers to the biomass waste that is left over after the separation of bioethanol in the distillation process. This waste still has high energetic value and could be further utilised to add value to the production chain. Furthermore, the environmental impact of untreated waste from bioethanol production is very high, which also requires attention. Anaerobic digestion of bioethanol production waste has been proposed as a possible solution to utilise the energetic potential of this waste and lower its environmental impact.

Key words: lignocellulosic biomass, biofuel, anaerobic digestion, zero–waste, ERoEI.

ABBREVIATIONS:

AD	Anaerobic digestion
BOD	Biochemical oxygen demand
E_{ret}	Returned/gained energy in the form of the biofuel
E_{req}	Energy input required to produce E_{ret}
ERoEI	Energy return on energy invested
GHG	Greenhouse gas
Mtoe	Million tonnes of oil equivalent
SHF	Separate hydrolysis and fermentation
SSF	Simultaneous saccharification and fermentation
TFC	Total final consumption

INTRODUCTION

In 2014, the energy production of the world was 13,805.44 million tonnes of oil equivalent (Mtoe), more than 100% increase compared to 1973 consumption of 6 213.69 Mtoe. Coal made up 28.8% of it, crude oil 31.2%, natural gas 21.2%, nuclear power 4.8%, hydroenergy 2.4%, biofuels and waste 10.2% and other sources (includes geothermal, solar, wind, heat and electricity trade) 1.3% (OECD/IEA, 2016).

Due to the increase of the energy production (mainly from non–renewable energy sources), petroleum prices, and environmental impacts caused by fossil fuels, there is a need for alternative sources of energy. Among the renewable sources of energy, second–

generation biofuel production, using lignocellulosic biomass as a feedstock, is emerging as an important biofuel for the transportation sector. Biofuels are a replacement for petroleum fuels, a way of limiting the greenhouse gas emissions, improving air quality, and utilising new energetic resources (Jaecker-Voirol et al., 2008; Nigam & Singh, 2011).

Lignocellulosic biomass is a promising feedstock for biofuel production, due to its low cost, vast abundance and sustainability (Agbor et al., 2011). The two most common and viable liquid biofuels in the transportation sector are bioethanol and biodiesel. However, the production of liquid biofuels has obstacles regarding the costs and efficiency of the process. Bioethanol production is still very costly, due to the energy input required (De Paoli et al., 2011), and inefficient use of biomass due to the quantity of waste–products that are left unused at the end of the process (Kaparaju et al., 2009). In order to make bioethanol production feasible, the costs must be optimised and biomass must be used to its fullest potential. Waste–products generated during bioethanol production must be valorised for example, through further anaerobic digestion (AD).

This paper reviews second–generation biofuel production chain with the emphasis on the maximisation of its energetic and commercial value, and minimising its environmental impact.

SECOND-GENERATION BIOETHANOL PRODUCTION

Classification of biofuels

Biofuels can be divided into primary and secondary biofuels based on the processing they undergo prior to their utilisation. Primary biofuels use organic compounds in its unprocessed form such as wood chips, pellets, firewood, and forest residues. These materials are used mainly for heating, cooking and electricity production, especially in developing countries (Voloshin et al., 2016). Secondary biofuels can be solid, liquid or gaseous, and use processed materials. They are further divided into first–generation, second–generation and third–generation biofuels, according to the feedstock and the technology used for its production (Nigam & Singh, 2011).

First–generation biofuels are the most widely used of the three. They are produced from mainly starch, oil and sugar-based feedstock (Demirbas, 2011). However, first–generation biofuels have some limitations due to the competition with food production changes in the land use, and high water requirements (Podkuiko et al., 2014). Thus, great attention has been paid to second–generation biofuels that are produced from lignocellulosic feedstock (Sims et al., 2010; Kikas et al., 2016; Raud et al., 2017).

Second–generation biofuels use lignocellulosic biomass from forest, agriculture, fishery, and municipal wastes. It includes non–food crops, straw, grass, sawdust and wood chips (Sun & Cheng, 2002; Nigam & Singh, 2011). The chemical composition of each one of these organic compounds will influence the potential for bioethanol production.

Composition of lignocellulosic biomass

Lignocellulosic material is composed of three main polymers: cellulose (40–60%), hemicellulose (20–40%) and lignin (10–25%) (McKendry, 2002). These polymers are connected with each other and their relative content in lignocellulosic material varies with the substrate (Table 1).

Table 1. Contents of cellulose, hemicellulose, and lignin for different feedstocks (adapted from (Reddy & Yang, 2005; Saini et al., 2015))

Feedstock	Cellulose	Hemicellulose	Lignin
Cotton, flax	80–95	5–20	–
Grasses	25–40	25–50	10–30
Hardwoods	45 ± 2	30 ± 5	20 ± 4
Hardwood barks	22–40	20–38	30–55
Softwoods	42 ± 2	27 ± 2	28 ± 3
Softwood barks	18–38	15–33	30–60
Corn stalk	39–47	26–31	3–5
Corn stover	38–40	28	7–21
Sorghum stalks	27	25	11
Sorghum straw	32	24	13
Rice straw	28–36	23–28	12–14
Wheat straw	33–38	26–32	17–19
Barley straw	31–45	27–38	14–9
Bagasse	32–48	19–24	23–32

Cellulose and lignin content also depends on the harvesting time of the crops (Tutt et al., 2013). Thus, both culture and the harvesting time should be considered when suitable biomass is selected.

Cellulose, generic formula $(C_6H_{10}O_5)_n$, is the main structural constituent of plant cell walls. It is crystalline, very fibrous, and rigid due to the hydrogen links between cellulose molecules. Cellulose is chemically stable and mechanically robust, making it water insoluble and more resistant to de–polymerization. Usually, it is covered by hemicellulose forming a cellulose-hemicellulose complex that inhibits the access of enzymes, influencing the hydrolysis rates, and therefore, the production of fermentable sugars and the digestibility of lignocellulosic biomass (Harmsen et al., 2010; Zabed et al., 2016). High cellulose content in lignocellulosic material is a promising condition for biofuel production (Raud et al., 2014).

Hemicellulose, generic formula $(C_5H_8O_4)_n$ is the second most abundant polymer of plant cell walls and is mainly composed of xylan and mannan. Comparing to cellulose, hemicellulose has a lower degree of polymerization, it is chemically heterogeneous, and it has a random and amorphous structure (Agbor et al., 2011; Yu et al., 2017). As hemicellulose is wrapped around the cellulose fibrils, it needs to be removed in order to increase the cellulose digestibility. Thus, increase in hemicellulose removal increases the accessibility of the cellulose and its hydrolysis rate (Zabed et al., 2016).

Lignin is a three–dimensional polymer of 4-propenyl phenol, 4-propenyl-2-methoxy phenol and 4-propenyl-2.5-dimethoxyl phenol, and it is the third most abundant constituent of lignocellulosic biomass. Lignin provides structural support to the plants, and contributes to the impermeability and resistance against microbial attack (Hendriks & Zeeman, 2009). This compound ties all the constituents of lignocellulosic biomass making it insoluble in water, and more difficult to degrade. Due to its properties, lignin is the main obstacle to enzymatic hydrolysis (Agbor et al., 2011). In addition, it influences the digestibility of the biomass. High lignin content results in low digestibility of the biomass therefore, increasing the lignin removal increases the biomass digestibility (Chang & Holtzapple, 2000).

Bioethanol production process

Due to the complex composition of the lignocellulosic biomass, its conversion into ethanol requires three sequential steps: (1) pretreatment – to separate hemicellulose and lignin from cellulose, (2) hydrolysis of cellulose – to obtain fermentable sugars, and (3) fermentation – to convert sugars into ethanol – followed by distillation – to separate and purify the ethanol (Demirbas, 2011).

Pretreatment

The pretreatment is essential step prior to the conversion of the lignocellulosic material to ethanol since the three main structural units of lignocellulosic biomass – cellulose, hemicellulose and lignin, are organized into a complex structure, which is recalcitrant to decomposition (Phitsuwan et al., 2013). Therefore, the plant cell walls are very difficult to hydrolyse and pretreatment is a necessary step in order to expose cellulose and hemicellulose for subsequent enzymatic hydrolysis.

Pretreatment methods are divided into: physical, chemical, physio–chemical and biological pretreatments (Mohd Azhar et al., 2017). Physical pretreatments include chipping, grinding, and milling particles. Chemical pretreatments include treatments with dilute acids, concentrated acids, alkali, ozone, ionic liquids, and Organosolv. Physio–chemical pretreatments include uncatalysed steam, acid catalysed steam, liquid hot water/hydrothermal, ammonia fibre explosion, ammonia recycling percolation, soaking aqueous ammonia, wet oxidation, CO_2 explosion. Biological pretreatments include pretreatments with microorganisms (Zabed et al., 2016). It is also possible to combine different pretreatment methods and further improve the efficiency of pretreatment (Mupondwa et al., 2017).

Even though the most common pretreatment methods are dilute acid pretreatment, hydrothermal pretreatment and alkaline pretreatment (Adekunle et al., 2016), other pretreatments have been reported in the literature as efficient for the pretreatment of lignocellulosic biomass. Nitrogen explosion, compressed air and steam explosions have also been shown as effective methods of pretreatment that increase glucose and ethanol yields (Tutt et al., 2014; Raud et al., 2016a; Raud et al., 2016b; Tutt et al., 2016)

From the economic and environmental point of view, some pretreatment methods are more expensive and harmful to the environment than others. As the pretreatment represents 33% of the total costs of the process (Tomás-Pejó et al., 2008), chemical free pretreatments like N_2 explosive decompression and steam explosion are cheaper and environmentally attractive solutions (Raud et al., 2016a).

A range of pretreatment methods have been studied over the years however, none have been singled out as efficient, simple and cost–effective. Pretreatments using moderate conditions are cheaper and simpler, but result in low sugar and ethanol yields. Pretreatments using extreme conditions have higher sugar and ethanol yields, but require expensive chemicals and equipment, making the process unfeasible (Tutt et al., 2012).

Hydrolysis

Pretreatment is followed by hydrolysis, also called saccharification. In this step, cellulose is converted into glucose, using acids or enzymes (Cardona et al., 2010; Raud et al., 2017). Table 2. presents the main characteristics of acid and enzymatic hydrolysis.

Acid hydrolysis is the most common method at the moment, and it utilizes dilute or concentrated acids, such as sulfuric acid (H_2SO_4), hydrochloric acid (HCl), nitric acid (HNO_3), trifluoracetic acid (TFA) or phosphoric acid (H_3PO_4) (Gírio et al., 2010).

In the enzymatic hydrolysis, the fungi *Trichodermareesei* is commonly used (Menind et al., 2012) or commercially available enzyme mixtures. Overall, enzymatic hydrolysis is more promising than hydrolysis using concentrated or dilute acids since the product yields are higher (Cardona et al., 2010), and the utility costs are lower (Sun & Cheng, 2002). Hydrolysis represents 20% of the total costs of cellulosic ethanol production (Mupondwa et al., 2017) and it is affected by several parameters, such as pretreatment conditions, quantity of lignin present in the feedstock, substrates concentration, and cellulase activity (Sun & Cheng, 2002; Raud et al., 2015; Raud et al., 2016c).

Table 2. Main characteristics of the different hydrolysis processes (adapted from (Kamzon et al., 2016))

Hydrolysis processes	Concentrated acid hydrolysis	Dilute acid hydrolysis	Enzymatic hydrolysis
Materials	30–70% H_2SO_4	< 1% H_2SO_4	Cellulases with 5–35 FPU g^{-1} of substrate
Temperature (°C)	40	215	70
Time	2–6 h	3 min	1.5 days
Glucose yield	90%	50–70%	80%–95%
Industrial application	Getting out of date	Industrially adopted Cost-effective	Industrially adopted Process of the future
Environmental impact	Yes	Yes	No

Fermentation

Fermentation is used to convert glucose into ethanol (Raud et al., 2016c). Simultaneous saccharification and fermentation (SSF) and separated hydrolysis and fermentation (SHF) are the two most common processes used in the fermentation of lignocellulosic hydrolysate (Gupta & Verma, 2015).

In SSF, enzymes hydrolyze cellulose into sugars and ferment the hexoses into ethanol, at the same time (Kamzon et al., 2016).This process has several known advantages. It has low capital costs, low enzyme requirements, high hydrolysis efficiency and ethanol yields, reduced process time, low risk of inhibition and contamination, and it does not require reactors with large volumes. However, it has some limitations regarding the compatibility of the temperature of the hydrolysis and fermentation, and inhibition of enzymes (Sun & Cheng, 2002; Chen & Fu, 2016).

In case of SHF on the other hand, hydrolysis and fermentation can proceed at their optimum conditions, but in separate vessels. Although, it has some problems due to the inhibition and the possibility of contamination since it is a long process (Kamzon et al., 2016; Chen & Fu, 2016).

Several microorganisms have been pointed out for fermentation of sugars but, the ideal microorganism (capable of fermenting efficiently both pentoses and hexoses) has not been found (Talebnia et al., 2010). The yeast *Saccharomyces* and the bacteria *Escherichia coli* are the most common microorganisms used to convert the sugars into ethanol (Tong et al., 2012). The yeast *Saccharomyces* can produce ethanol from glucose with almost 90% of theoretical yield (Gupta & Verma, 2015). Nonetheless, it cannot ferment the C5 sugars, so these are converted into furfural, which is toxic to the yeast itself and affects the ethanol yields (Saxena et al., 2009; Farias et al., 2017).

Distillation

The recovery of ethanol from fermentation broth is done by distillation. Different separation methods can be used, and include ordinary distillation, azeotropic distillation, extractive distillation, liquid extraction fermentation hybrid, absorption and membrane separation (Adekunle et al., 2016).

The ordinary distillation can give an ethanol recovery of 95% however, to achieve 99.9% of ethanol recovery (anhydrous ethanol), further dehydration is needed (Zabed et al., 2016). Nevertheless, this purification technique has high-energy requirements, limited capacity for the separation of volatile compounds (since they tend to lodge more in ethanol), and high costs. The costs of the distillation depend on the efficiency of the enzymatic hydrolysis and on the fermentation, and increase with low ethanol concentrations (Onuki et al., 2008; Saini et al., 2015; Farias et al., 2017).

In this step a large quantity of waste–products is generated and left unused. Valorisation through AD has been reported as an efficient handling option for this highly valuable residue (Kaparaju et al., 2009).

ANAEROBIC DIGESTION

AD uses microorganisms in the absence of oxygen to degrade organic material and to convert it into biogas. The four main steps of AD are hydrolysis, acidogenesis, acetogenesis, and methanogenesis (Ariunbaatar et al., 2014).

The hydrolysis uses exoenzymes to convert complex compounds as cellulose, proteins, polysaccharides, and lipids into monomers, such as amino acids, fatty acids, sugars and alcohols (Chandra et al., 2012; Zhen et al., 2017). In this step, the degradation of lignocellulose is a slow process (Deublein & Steinhauser, 2008).

In the acidogenesis, the hydrolysed material is converted into organic acids, alcohols, hydrogen, and carbon dioxide, by anaerobic bacterias as *Peptoccus*, *Clostridium*, *Lactobacillus*, *Geobacter*, *Bacteroides, Eubacterium*, *Phodopseudomonas*, *Desulfovibrio, Desulfobacter*, and *Sarcina* (Zhen et al., 2017).

Acetogenesis uses acetogenic bacteria as *Syntrophobacter*, *Syntrophus*, *Pelotomaculum*, *Syntrophomonas*, *Syntrophothermus*, *Moorella*, and *Desulfovibrio* to reduce the products of the acidogenic phase into acetic acid (Chandra et al., 2012; Zhen et al., 2017).

Lastly, in the methanogenesis, acetate is metabolised to produce methane. In this step, organisms, such as *Methanosarcina*, *Methanosaeta*, *Methanobacterium* and *Methanoculleus*, are commonly used (Zhen et al., 2017).

In the AD, the bacterial activity is influenced mainly by pH, biochemical oxygen demand (BOD), and concentration of volatile fatty acids. Efficiency of the AD depends on the temperature, particles size, substrate C/N ratio, substrate mixing, inoculum, organic loading rate, hydraulic retention time, and solid concentration of the mix (Croce et al., 2016).

AD plays an important role in the final energy production, as an alternative source of energy for the transportation sector (Taherzadeh & Karimi, 2008). The biogas is produced mainly from energy crops and waste, such as manure, wastewater sludge or municipal solid waste (Teghammar et al., 2010). Lignocellulosic wastes such as agricultural wastes, energy crops and forestry wastes can also be used for AD (Loow et al., 2015). This process is particularly attractive due to its low environmental impact, and high potential for energy recovery. Table 3 presents the methane yield for different crops.

Table 3. Methane yields for different crops [adapted from (Murphy et al., 2011)]

Crop	Methane yield (m^3 ton^{-1} VS added)
Flax	212
Grass	298–467
Hemp	355–409
Jerusalem artichoke	300–370
Maize (whole crop)	205–450
Barley	353–658
Straw	242–324
Leaves	417–456
Sorghum	295–372
Sugar beet	236–381
Oats (grain)	250–295
Rye (grain)	283–492
Wheat (grain)	384–426

Anaerobic digestion of biomass

Although it is possible to use untreated material for AD, due to the complex structure of the lignocellulosic material, the methane production of untreated material is inferior to the methane production from treated material (Jimenez et al., 1990; Bauer et al., 2009; Zheng et al., 2009; Teghammar et al., 2010; De Paoli et al., 2011; Song et al., 2013; Taherdanak et al., 2016). Usually, the first step for AD production is the pretreatment, to increase the digestibility and improve methane yields (Xiao & Clarkson, 1997).When pretreated with different methods, biomass has higher methane yields, than raw material (Bauer et al., 2009; Kaparaju et al., 2010; Teghammar et al., 2010; Ziemiński et al., 2012).

In addition, pretreated material reaches the maximum methane production sooner than untreated material, the initial hydrolysis rate and the degradation rate increase in pretreated samples (Rouches et al., 2016). Untreated material has higher digestion time, and lower amounts of dry matter of substrate reduction (total solids and volatile solids) when compared with pretreated material (Zheng et al., 2009).

Anaerobic digestion of waste–products

In the bioethanol production process, a large quantity of biomass waste is generated (Moraes et al., 2015). Several solutions have been proposed as handling options for this biomass waste. These include: discharge, marine outfall, return to agricultural fields, sewage treatment, lagoon treatment, anaerobic digestion, incineration, and drying to an animal feed (Willington & Marten, 1982).

The optimum handling option should take into consideration the characteristics of the waste–products such as the energy return on energy invested, the economic feasibility and their environmental impacts. Table 4 outlines the main characteristics of alcohol stillage handling options.

Table 4. Characteristics of alcohol stillage handling options (adapted from (Willington & Marten, 1982))

	Discharge	Marine Outfall	Agricultural Fields	Sewage treatment	Lagoon treatment	AD	Incinera-tion	Drying
Energy								
Net energy	0	–	–	–	0	+	+[b]	–
Economy								
Capital cost	L	L–M	L–M	H[a]	M	H	H	H
Operating cost	L	L	M–H	H	L	M	M	M
Further treatment	N	N	N	N	Y	Y	N	N
Useful product	N	N	Y	N	N	Y	Y	Y
Environment								
Land use effect	0	0	H	L	M	L	0	0
Water quality	H	M–H	L–M	L	L	0–L	0	0
Air quality impact	0	0	L–M	0	0	L	L	L
Odour potential	M–H	L–M	L–M	L	L–M	L–M	0	L
Flora/Fauna	M–H	L–M	L–M	L	L	L	0	0

0 Zero
– Negative
+ Positive

L Low
M Moderate
H High

N No
Y Yes

[a] Capital cost to the distillery is lower if using municipal sewage facilities;
[b] Depends on the feedstock.

From several handling options for stillage presented in Table 4, AD presents a low land use impact, low water quality impact, low air quality impact, low–moderate odour potential, and a low flora/fauna impact, compared to discharge, marine outfall and return to agricultural fields.

Environment

Waste-products from bioethanol production are a source of environmental pollution due to the large quantity of products generated, and their high pollutant potential. Up to 20 litres of stillage can be generated for each litre of ethanol produced, and the BOD of the liquid phase of stillage can vary between 10 and 100 g $O_2 \cdot L^{-1}$ (Dererie et al., 2011; Kaparaju et al., 2010). Moreover, the environmental risk can be even greater, as the BOD measurements often underestimate the BOD_7 (Raud et al., 2012).

AD of stillage can be presented as an environmental solution for these waste–products, making use of their high BOD for biogas production. AD has high BOD removal efficiency, and it can convert more than 50% of BOD into biogas (Wilkie et al., 2000; Kaparaju et al., 2010). AD of waste-products has several environmental advantages. Firstly, it reduces the organic matter content and therefore, the pollution potential, and secondly, it reduces CO_2 and other greenhouse gas (GHG) emissions by using the waste-products for energy production, reducing the utilisation of fossil fuels.

Costs

From the economic point of view, despite the high–quality fuel produced during bioethanol production, the costs of energy input are still high, making it difficult to compete with petrol and diesel from fossil sources. A solution to offset the costs of bioethanol production and add value to the production chain is the AD of the waste–products.

Several studies reported the value added of AD of waste–products. It can reach up to 30% of the value of the principal product, improving the production costs (Mojović et al., 2012). The use of these high–energy wastes can bring direct and indirect economic revenues. The direct revenues are associated with the energy produced in the form of methane, and the indirect revenues come from the costs avoided with fertilisers, odour reduction and protection of the environment (Pabón Pereira et al., 2013).

Research shows that AD is an economically viable option and a feasible process for the utilisation of biomass wastes (Wilkie et al., 2000), especially when bioethanol waste is used as a raw material. Its AD does not require further pretreatment due to the pretreatment that has already taken place in the bioethanol production, reducing the investment costs (Dererie et al., 2011). It implies that the revenue is enough to cover the upgrade process of waste–products recovery, which includes operational and capital costs and costs of collection and transport (of ethanol waste–products to other facilities for further AD).

Transport and collection include the transport of the feedstock from the field to the biorefineries, and the transport of the waste-products to other facilities for further AD. Long transport distances have several negative disadvantages to the bioethanol production chain. It increases the GHG and CO_2 emissions and influences the viability of the project. If the transportation costs are too high, due to long distances, the project can turn out economically unfeasible. Table 5 illustrates the ethanol transportation costs by water, truck, and rail, in U.S. and Brazil.

Table 5. Ethanol transportation costs by water, truck, and rail, in the U.S. and Brazil (Worldwatch, 2012)

Transportation mode	Cost (€ m^{-3})	
	U.S.	Brazil
Water (including ocean and river barge)	€8–€25	€10
Short distance trucking (less than 300 km)	€8–€17	
Long distance trucking (more than 300 km)	€17–€83	€26
Rail (more than 500 km)	€17–€40	€17

Energy

The full use of biomass resources can be achieved by the utilisation of the waste–products for the production of energy in the form of methane. The energy of these waste–products represents 51–71% of the total energy content of the crops, and it can give higher net energy outputs (Pabón Pereira et al., 2013). In addition, the use of waste–products improve the speed and the rate of the process. As the pretreatment has already taken place, the process starts more rapidly than when using biomass that has not been through bioethanol production (Dererie et al., 2011).

Energy return on energy invested (ERoEI)

ERoEI is the ratio of energy gained from unit of fuel and the energy input required to carry out its production and can be given by Eq. 1. (adapted from (Hammerschlag, 2006; Seghetta et al., 2014)):

$$\mathrm{ERoEI} = \frac{E_{ret}}{E_{req}} \tag{1}$$

where E_{ret} is the returned/gained energy in the form of the fuel and E_{req} is the energy required to produce that amount of fuel. For biofuels, E_{req} includes the energy spent in plantation, production, harvesting, transporting and purification of the feedstock and of the biofuel. Table 6 presents the ERoEI for different types of fossil fuels, and for several alternative sources of energy.

Table 6. ERoEI for different energy sources (adapted from (Hall et al., 2014))

Resource	Year	Country	ERoEI
Fossil fuels (oil and gas)			
Oil and gas production	2006	Global	18
Oil and gas production	2010	Canada	15
Oil and gas production	2008	Norway	40
Oil and gas production	2009	Mexico	45
Oil and gas production	2010	China	10
Fossil fuels (others)			
Natural gas	2005	US	67
Natural gas	2009	Canada	20
Coal (mine–mouth)	2007	US	60
Coal (mine–mouth)	2010	China	27
Other non–renewables			
Nuclear	n/a	US	5 to 15
Nuclear	2010	New Zealand*	9 to 14
Renewables			
Hydropower	n/a	n/a	> 100
Hydropower	2010	New Zealand*	94
Wind turbine	n/a	n/a	18
Wind turbine	2010	New Zealand*	22
Geothermal (electricity)	2010	New Zealand*	9
Wave energy	2010	New Zealand*	18
Tidal energy	2010	New Zealand*	40
Ocean thermal energy conversion	2010	New Zealand*	4
Solar collectors			
Flat plate	n/a	n/a	1.9
Concentrating collector	n/a	n/a	1.6
Photovoltaic	n/a	n/a	6 to 12
Photovoltaic	2010	New Zealand*	9
Passive solar	2010	New Zealand*	6
Biomass			
Solid biomass	2010	New Zealand*	20
Bioethanol	2010	New Zealand*	5
Corn	n/a	US	0.8 to 1.6
Sugarcane	n/a	n/a	0.8 to 10
Biodiesel	n/a	US	1.3
Biodiesel	2010	New Zealand*	2
Electricity	2010	New Zealand*	13

*Source: (Dale, 2010).

From Table 6 it is possible to analyse the different ERoEI for fossil fuels (oil, gas and coal) and for alternative sources of energy. This ratio (ERoEI) is a measure of the efficiency of any kind of production. The lower the ERoEI of a production chain, the higher its energy requirements (making it energetically but also economically and environmentally, disadvantageous), and higher the risk of being considered as an energy sink (Worldwatch, 2012). The fuels most commonly used have higher ERoEI than for example, ethanol produced from cellulosic material (Fig. 1).

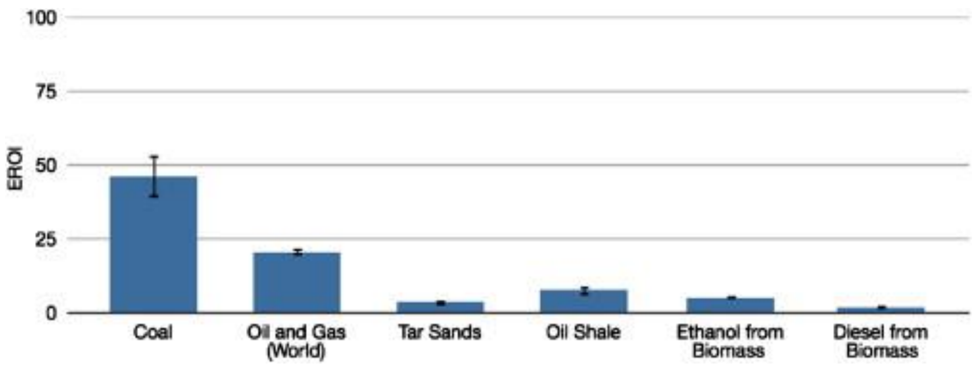

Figure 1. ERoEI for coal, oil and gas (world), tar sands, oil shale, ethanol from biomass and diesel from biomass (Hall, 2017).

AD of bioethanol waste–products can increase the ERoEI of the bioethanol production chain since the waste–products are used to generate energy for the process or/and sell it to the grid. This solution can make the bio-refineries self-sufficient and can offset its energetic needs from external sources of energy to process the waste–products (Worldwatch, 2012).

RESEARCH GAPS AND CHALLENGES

Despite the fact that bioethanol has been used as a biofuel since the 1900s, and the quality of the fuel produced is high, its production still has environmental, economic, and energetic limitations.

Environment

Biofuels production has some environmental constraints regarding, land and soil loss. It can have a high ecological footprint and a high GHG effect. Apart from that, the other environmental restriction is regarding the high pollutant potential of the waste-products generated after the distillation process. The handling options include discharge; marine outfall; agricultural fields; sewage treatment; lagoon treatment; AD; incineration; and drying. However, the best handling option is still not clear, due to the different environmental impacts. Further studies taking into consideration the environmental impacts of bioethanol waste–products, should be carried out.

Costs

From the economic point of view, the main hurdle is associated with the high costs of bioethanol production, and with the high dependence of its economic feasibility on the crude oil prices.

Pretreatment and enzymatic hydrolysis are the two most costly parts of the production process. Pretreatment of raw material represents 1/3 of the total costs of bioethanol production, and it influences the cost of enzymatic hydrolysis and fermentation. Despite the fact that some methods of pretreatment are promising solutions for bioethanol production, it is important to find the optimum pretreatment for each type of lignocellulosic biomass, decrease the overall production costs and the costs of enzymes, and increase the glucose and ethanol yields.

AD of waste–products is a prospective solution to lower the overall production costs, due to its low financial input. Even though its utilisation contributes to the reduction of bioethanol production costs (Yadav et al., 2016), the economic quantification of the benefit of AD of waste-products to the bioethanol production chain still not clear.

The different costs of collection and transport are influenced by the distance between the ethanol production and the distribution grid. This factor shows the importance of adequate planning when building the power plants that should include an economic analysis containing the transport and distribution costs.

Energy

Due to the high-energy content, waste-products can be used for processing energy, through AD to add value to the production chain and improve the energy balance. Although waste-products give a positive energy credit to the ERoEI, some studies do not consider this in their analysis (Giampietro & Mayumi, 2009). Currently, ERoEI is not a consensual subject due to the big range of different results obtained for each feedstock. Different authors consider different energy inputs for the calculations, making the results inconsistent. Some of the energy inputs that are usually taken into consideration include the energy inputs of the seeders / planters, fertilisers, pesticides, and transportation of water to the fields. Other energy inputs are required for harvesting, transporting (from the fields to the facilities), processing (hydrolysis and fermentation), and purifying (distillation). ERoEI is also influenced by the geographical / climatic conditions. Tropical plants have better ERoEI ratios, due the growth conditions (Worldwatch, 2012).

Waste-products

Bioethanol production results in valuable waste-products, after the fermentation process. These waste–products have a high energetic value and large pollution potential. Further utilisation of this biomass waste can improve the overall efficiency of bioethanol production, and the bioethanol economics, by adding value to the production chain. In addition, the maximisation of its utilisation can also be seen as an environmental handling solution, due to its high pollution potential.

The best economic, energetic and environmental handling option for this waste–products still under discussion, but some studies refer to AD as a solution (Willington & Marten, 1982; Dererie et al., 2011; Rabelo et al., 2011).

OUTLOOK AND POSSIBILITIES

As the conversion of lignocellulosic material into ethanol still has economic, technical and environmental obstacles (Sánchez & Cardona, 2008), different feedstocks and methods are being studied to make it more feasible. Bioethanol production method has to be efficient (high energy yields), cost effective (energy return on investment) and environmentally beneficial, in order to be feasible.

From the economic point of view, the costs of bioethanol production are still high, due to large energy inputs. Waste–products of bioethanol production process cannot be used as a transportation fuel, so their AD can help balance the costs of bioethanol production, adding economic value to the production chain, without further energy input.

Technically, these waste–products present high–energy potential. Research has shown that their AD does not need any further pretreatment, due to the initial pretreatment (Dererie et al., 2011), influencing speed and efficiency of the process. The process will start more rapidly than with untreated biomass that has not been through bioethanol production, leading to time and cost efficiency. This process occurs without any additional energy input, increasing the ERoEI and contributing, at the same time, to the economic valorisation of the production chain. Combining ethanol waste–products with biogas production can also help increase the share of renewable energy in the transportation sector.

From the environmental perspective, waste from the bioethanol production is highly polluting (Salomon & Silva Lora, 2009; Kaparaju et al., 2010), so its reutilisation can be seen as an environmental solution to the large quantity of waste–products with high BOD generated during the bioethanol production.

Thus, in Fig. 2, AD of bioethanol waste–products (a) has been proposed as a technical solution for the valorisation of the production chain and for recycling the waste from bioethanol production. Its feasibility should be compared with AD of pretreated biomass (b) and direct AD of untreated biomass (c).

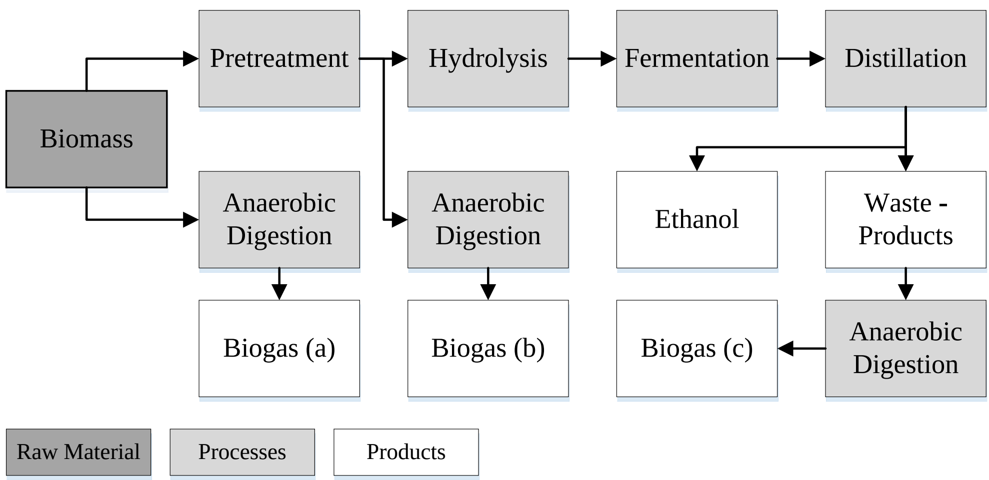

Figure 2. Bioethanol production chain and different possibilities for utilisation of AD process in it (AD of untreated material, pretreated material and waste–products).

A cost–benefit analysis focusing on time vs efficiency of the process should be carried out (and include positive externalities, such as the environmental gains), to assure that the additional energy value from AD of production waste will be enough to give a return on investment into AD technology.

CONCLUSIONS

Bioethanol presents energetic, economic and environmental challenges, in all the steps of its production (pretreatment, hydrolysis, fermentation and distillation). These challenges include lack of cost–efficient technology, low yields, costly pretreatments, cellulose enzymes, and lack of microorganisms capable of ferment both C5 and C6 sugars. Further research needs to be done in all the stages of the process to increase the efficiency of the production, and decrease the costs.

In the distillation process, the biggest challenge refers to the large fraction of biomass waste that is produced and left unused at the end of the process. The best solution for utilisation of these waste–products is still under investigation.

Utilisation of waste–products through further AD has been proposed as a possible path to reduce costs of bioethanol production by adding economic value to the production chain, increasing the efficiency of the process, and as an environmental solution to a large quantity of process residue with high BOD that is generated during bioethanol production.

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REFERENCES

Adekunle, A., Orsat, V. & Raghavan, V. 2016. Lignocellulosic bioethanol: A review and design conceptualization study of production from cassava peels. *Renewable and Sustainable Energy Reviews* **64**, 518–530.

Agbor, V.B., Cicek, N., Sparling, R., Berlin, A. & Levin, D.B. 2011. Biomass pretreatment: Fundamentals toward application. *Biotechnology Advances* **29**(6), 675–685.

Ariunbaatar, J., Panico, A., Esposito, G., Pirozzi, F. & Lens, P.N.L. 2014. Pretreatment methods to enhance anaerobic digestion of organic solid waste. *Applied Energy* **123**, 143–156.

Bauer, A., Bösch, P., Friedl, A. & Amon, T. 2009. Analysis of methane potentials of steam-exploded wheat straw and estimation of energy yields of combined ethanol and methane production. *Journal of Biotechnology* **142**(1), 50–55.

Cardona, C.A., Quintero, J.A. & Paz, I.C. 2010. Production of bioethanol from sugarcane bagasse: Status and perspectives. *Bioresource Technology* **101**(13), 4754–4766.

Chandra, R., Takeuchi, H. & Hasegawa, T. 2012. Methane production from lignocellulosic agricultural crop wastes: A review in context to second generation of biofuel production. *Renewable and Sustainable Energy Reviews* **16**(3), 1462–1476.

Chang, V.S. & Holtzapple, M.T. 2000. Fundamental factors affecting biomass enzymatic reactivity. *Applied Biochemistry and Biotechnology* **84**(1), 5–37.

Chen, H. & Fu, X. 2016. Industrial technologies for bioethanol production from lignocellulosic biomass. *Renewable and Sustainable Energy Reviews* **57**, 468–478.

Croce, S., Wei, Q., D'Imporzano, G., Dong, R. & Adani, F. 2016. Anaerobic digestion of straw and corn stover: The effect of biological process optimization and pre-treatment on total bio-methane yield and energy performance. *Biotechnology Advances* **34**(8), 1289–1304.

Dale, M. 2010. Global Energy Modeling: A Biophysical Approach (GEMBA). in: *University of Canterbury, Christchurch, NewZealand,* pp. 441.

De Paoli, F., Bauer, A., Leonhartsberger, C., Amon, B. & Amon, T. 2011. Utilization of by-products from ethanol production as substrate for biogas production. *Bioresource Technology* **102**(11), 6621–6624.

Demirbas, A. 2011. Competitive liquid biofuels from biomass. *Applied Energy* **88**(1), 17–28.

Dererie, D.Y., Trobro, S., Momeni, M.H., Hansson, H., Blomqvist, J., Passoth, V., Schnürer, A., Sandgren, M. & Ståhlberg, J. 2011. Improved bio-energy yields via sequential ethanol fermentation and biogas digestion of steam exploded oat straw. *Bioresource Technology* **102**(6), 4449–4455.

Deublein, D. & Steinhauser, A. 2008. Biogas from waste and renewable sources: an introduction. *Weinheim: WILEY-VCH Verlag GmbH & Co. KGaA*, pp. 578.

Farias, D., Atala, D.I.P. & Filho, F.M. 2017. Improving bioethanol production by Scheffersomyces stipitis using retentostat extractive fermentation at high xylose concentration. *Biochemical Engineering Journal*, **121**, 171–180

Giampietro, M. & Mayumi, K. 2009. *The biofuel delusion: The fallacy of large scale agro-biofuels production*, London. Sterling, VA, pp. 337.

Gírio, F.M., Fonseca, C., Carvalheiro, F., Duarte, L.C., Marques, S. & Bogel-Łukasik, R. 2010. Hemicelluloses for fuel ethanol: A review. *Bioresource Technology* **101**(13), 4775–4800.

Gupta, A. & Verma, J.P. 2015. Sustainable bio-ethanol production from agro-residues: A review. *Renewable and Sustainable Energy Reviews* **41**, 550–567.

Hall, C.A.S. 2017. *Energy Return on Investment: A Unifying Principle for Biology, Economics, and Sustainability*, Lecture Notes in Energy, Volume 26. Springer, Switzerland, pp. 169.

Hall, C.A.S., Lambert, J.G. & Balogh, S.B. 2014. EROI of different fuels and the implications for society. *Energy Policy* **64**, 141–152.

Hammerschlag, R. 2006. Ethanol's energy return on investment: A survey of the literature 1990 - Present. *Environmental Science and Technology* **40**(6), 1744–1750.

Harmsen, P.F.H., Huijgen, W.J.J., Bermúdez Lópezm, L.M. & Bakker, R.R.C. 2010. Literature Review of Physical and Chemical Pretreatment Processes for Lignocellulosic Biomass *Wageningen UR, Food & Biobased Research,* pp. 49.

Hendriks, A.T.W.M. & Zeeman, G. 2009. Pretreatments to enhance the digestibility of lignocellulosic biomass. *Bioresource Technology* **100**(1), 10–18.

Jaecker-Voirol, A., Durand, I., Hillion, G., Delfort, B. & Montagne, X. 2008. Glycerin for new biodiesel formulation. *Oil and Gas Science and Technology* **63**(4), 395–404.

Jimenez, S., Cartagena, M.C. & Arce, A. 1990. Influence of lignin on the methanization of lignocellulosic wastes. *Biomass* **21**(1), 43–54.

Kamzon, M.A., Abderafi, S. & Bounahmidi, T. 2016. Promising bioethanol processes for developing a biorefinery in the Moroccan sugar industry. *International Journal of Hydrogen Energy* **41**(45), 20880–20896.

Kaparaju, P., Serrano, M. & Angelidaki, I. 2010. Optimization of biogas production from wheat straw stillage in UASB reactor. *Applied Energy* **87**(12), 3779–3783.

Kaparaju, P., Serrano, M., Thomsen, A.B., Kongjan, P. & Angelidaki, I. 2009. Bioethanol, biohydrogen and biogas production from wheat straw in a biorefinery concept. *Bioresource Technology* **100**(9), 2562–2568.

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**(1), 49–54.

Loow, Y.L., Wu, T.Y., Tan, K.A., Lim, Y.S., Siow, L.F., Md. Jahim, J., Mohammad, A.W. & Teoh, W.H. 2015. Recent Advances in the Application of Inorganic Salt Pretreatment for Transforming Lignocellulosic Biomass into Reducing Sugars. *Journal of Agricultural and Food Chemistry* **63**(38), 8349–8363.

McKendry, P. 2002. Energy production from biomass (part 1): overview of biomass. *Bioresource Technology* **83**(1), 37–46.

Menind, A., Oper, L., Hovi, M., Kers, J., Tutt, M. & Kikas, T. 2012. Pretreatment and usage of pulp and paper industry residues for fuels production and their energetic potential. *Agronomy Research* **10**(S1), 149–155.

Mohd Azhar, S.H., Abdulla, R., Jambo, S.A., Marbawi, H., Gansau, J.A., Mohd Faik, A.A. & Rodrigues, K.F. 2017. Yeasts in sustainable bioethanol production: A review. *Biochemistry and Biophysics Reports* **10**, 52–61.

Mojović, L., Pejin, D., Rakin, M., Pejin, J., Nikolić, S. & Djukić-Vuković, A. 2012. How to improve the economy of bioethanol production in Serbia. *Renewable and Sustainable Energy Reviews* **16**(8), 6040–6047.

Moraes, B.S., Triolo, J.M., Lecona, V.P., Zaiat, M. & Sommer, S.G. 2015. Biogas production within the bioethanol production chain: Use of co-substrates for anaerobic digestion of sugar beet vinasse. *Bioresource Technology* **190**, 227–234.

Mupondwa, E., Li, X., Tabil, L., Sokhansanj, S. & Adapa, P. 2017. Status of Canada's lignocellulosic ethanol: Part I: Pretreatment technologies. *Renewable and Sustainable Energy Reviews* **72**, 178–190.

Murphy, J., Braun, R., Weiland, P. & Wellinger, A. 2011. Biogas from Crop Digestion. IEA Bioenergy Task 37 publication.

Nigam, P.S. & Singh, A. 2011. Production of liquid biofuels from renewable resources. *Progress in Energy and Combustion Science* **37**(1), 52–68.

OECD/IEA. 2016. Key world energy statistics, Vol. IEA Publishing. Licence: www.iea.org/t&c, pp. 36–37.

Onuki, S., Koziel, J.A., Van Leeuwen, J., Jenks, W.S., Greweii, D. & Cai, L. 2008. Ethanol production, purification, and analysis techniques: A review. *American Society of Agricultural and Biological Engineers Annual International Meeting 2008, ASABE 2008*, pp. 7210–7221.

Pabón Pereira, C.P., Slingerland, M., Van Lier, J.B. & Rudyrabbinge, R. 2013. 7 – Anaerobic digestion as a key technology for biomass valorization: contribution to the energy balance of biofuel chains A2 – Wellinger, Arthur. in: *The Biogas Handbook*, (Eds.) J. Murphy, D. Baxter, Woodhead Publishing, pp. 166–188.

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.

Podkuiko, L., Ritslaid, K., Olt, J. & Kikas, T. 2014. Review of promising strategies for zero-waste production of the third generation biofuels. *Agronomy Research* **12**(2), 373–390.

Rabelo, S.C., Carrere, H., Maciel Filho, R. & Costa, A.C. 2011. Production of bioethanol, methane and heat from sugarcane bagasse in a biorefinery concept. *Bioresource Technology* **102**(17), 7887–7895.

Raud, M., Tutt, M., Jõgi, E. & Kikas, T. 2012. BOD biosensors for pulp and paper industry wastewater analysis. *Environmental Science and Pollution Research* **19**(7), 3039–3045.

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**(2), 397–406.

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.
Raud, M., Olt, J. & Kikas, T. 2016a. N2 explosive decompression pretreatment of biomass for lignocellulosic ethanol production. *Biomass and Bioenergy* **90**, 1–6.
Raud, M., Rooni, V. & Kikas, T. 2016b. Explosive decompression pretreatment: Nitrogen vs. compressed air. *Agronomy Research* **14**(2), 569–578.
Raud, M., Tutt, M., Olt, J. & Kikas, T. 2016c. Dependence of the hydrolysis efficiency on the lignin content in lignocellulosic material. *International Journal of Hydrogen Energy* **41**(37), 16338–16343.
Raud, M., Mitt, M., Oja, T., Olt, J., Orupõld, K. & Kikas, T. 2017. The utilisation potential of urban greening waste: Tartu case study. *Urban Forestry & Urban Greening* **21**, 96–101.
Reddy, N. & Yang, Y. 2005. Biofibers from agricultural byproducts for industrial applications. *Trends in Biotechnology* **23**(1), 22–27.
Rouches, E., Herpoël-Gimbert, I., Steyer, J.P. & Carrere, H. 2016. Improvement of anaerobic degradation by white-rot fungi pretreatment of lignocellulosic biomass: A review. *Renewable and Sustainable Energy Reviews* **59**, 179–198.
Saini, J.K., Saini, R. & Tewari, L. 2015. Lignocellulosic agriculture wastes as biomass feedstocks for second-generation bioethanol production: concepts and recent developments. *3 Biotech* **5**(4), 337–353.
Salomon, K.R. & Silva Lora, E.E. 2009. Estimate of the electric energy generating potential for different sources of biogas in Brazil. *Biomass and Bioenergy* **33**(9), 1101–1107.
Sánchez, Ó.J. & Cardona, C.A. 2008. Trends in biotechnological production of fuel ethanol from different feedstocks. *Bioresource Technology* **99**(13), 5270–5295.
Sawatdeenarunat, C., Surendra, K.C., Takara, D., Oechsner, H. & Khanal, S.K. 2015. Anaerobic digestion of lignocellulosic biomass: Challenges and opportunities. *Bioresource Technology* **178**, 178–186.
Saxena, R.C., Adhikari, D.K. & Goyal, H.B. 2009. Biomass-based energy fuel through biochemical routes: A review. *Renewable and Sustainable Energy Reviews* **13**(1), 167–178.
Seghetta, M., Østergård, H. & Bastianoni, S. 2014. Energy analysis of using macroalgae from eutrophic waters as a bioethanol feedstock. *Ecological Modelling* **288**, 25–37.
Sims, R.E.H., Mabee, W., Saddler, J.N. & Taylor, M. 2010. An overview of second generation biofuel technologies. *Bioresource Technology* **101**(6), 1570–1580.
Song, Z.-l., Yag, G.-h., Feng, Y.-z., Ren, G.-x. & Han, X.-h. 2013. Pretreatment of Rice Straw by Hydrogen Peroxide for Enhanced Methane Yield. *Journal of Integrative Agriculture* **12**(7), 1258–1266.
Sun, Y. & Cheng, J. 2002. Hydrolysis of lignocellulosic materials for ethanol production: a review. *Bioresource Technology* **83**(1), 1–11.
Zabed, H., Sahu, J.N., Boyce, A.N. & Faruq, G. 2016. Fuel ethanol production from lignocellulosic biomass: An overview on feedstocks and technological approaches. *Renewable and Sustainable Energy Reviews* **66**, 751–774.
Zhen, G., Lu, X., Kato, H., Zhao, Y. & Li, Y.-Y. 2017. Overview of pretreatment strategies for enhancing sewage sludge disintegration and subsequent anaerobic digestion: Current advances, full-scale application and future perspectives. *Renewable and Sustainable Energy Reviews* **69**, 559–577.
Zheng, M., Li, X., Li, L., Yang, X. & He, Y. 2009. Enhancing anaerobic biogasification of corn stover through wet state NaOH pretreatment. *Bioresource Technology* **100**(21), 5140–5145.
Ziemiński, K., Romanowska, I. & Kowalska, M. 2012. Enzymatic pretreatment of lignocellulosic wastes to improve biogas production. *Waste Management* **32**(6), 1131–1137.
Taherdanak, M., Zilouei, H. & Karimi, K. 2016. The influence of dilute sulfuric acid pretreatment on biogas production from wheat plant. *International Journal of Green Energy* **13**(11), 1129–1134.

Taherzadeh, M.J. & Karimi, K. 2008. Pretreatment of Lignocellulosic Wastes to Improve Ethanol and Biogas Production: A Review. *International Journal of Molecular Sciences* **9**(9), 1621–1651.

Talebnia, F., Karakashev, D. & Angelidaki, I. 2010. Production of bioethanol from wheat straw: An overview on pretreatment, hydrolysis and fermentation. *Bioresource Technology* **101**(13), 4744–4753.

Teghammar, A., Yngvesson, J., Lundin, M., Taherzadeh, M.J. & Horváth, I.S. 2010. Pretreatment of paper tube residuals for improved biogas production. *Bioresource Technology* **101**(4), 1206–1212.

Tomás-Pejó, E., Oliva, J.M. & Ballesteros, M. 2008. Realistic approach for full-scale bioethanol production from lignocellulose: A review. *Journal of Scientific and Industrial Research* **67**(11), 874–884.

Tong, Z., Pullammanappallil, P. & Teixeira, A.A. 2012. How Ethanol Is Made from Cellulosic Biomass. Agriculture and Biological Engineering, University of Florida IFAS Extension; 2012. (http://edis.ifas.ufl.edu/AE493).

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.

Tutt, M., Kikas, T. & Olt, J. 2012. Comparison of different pretreatment methods on degradation of rye straw. *Engineering for Rural Development*. pp. 412–416.

Tutt, M., Kikas, T. & Olt, J. 2013. Influence of harvesting time on biochemical composition and glucose yield from hemp. *Agronomy Research* **11**(1), 215–220.

Tutt, M., Raud, M., Kahr, H., Pointner, M., Olt, J. & Kikas, T. 2016. Nitrogen explosion pretreatment of lignocellulosic material for bioethanol production. *Energy Sources, Part A: Recovery, Utilization and Environmental Effects* **38**(12), 1785–1789.

Wilkie, A.C., Riedesel, K.J. & Owens, J.M. 2000. Stillage characterization and anaerobic treatment of ethanol stillage from conventional and cellulosic feedstocks. *Biomass and Bioenergy* **19**(2), 63–102.

Willington, I.P. & Marten, G.G. 1982. Options for handling stillage waste from sugar based fuel ethanol production. *Resources and Conservation* **8**, 111–129.

Voloshin, R.A., Rodionova, M.V., Zharmukhamedov, S.K., Veziroglu, T.N. & Allakhverdiev, S.I. 2016. Review: Biofuel production from plant and algal biomass. *International Journal of Hydrogen Energy http://dx.doi.org/10.1016/j.ijhydene.2016.07.084.*

Worldwatch, I. 2012. *Biofuels for transport: Global potential and implications for energy and agriculture*.

Xiao, W. & Clarkson, W.W. 1997. Acid solubilization of lignin and bioconversion of treated newsprint to methane. *Biodegradation* **8**(1), 61–66.

Yu, J., Paterson, N., Blamey, J. & Millan, M. 2017. Cellulose, xylan and lignin interactions during pyrolysis of lignocellulosic biomass. *Fuel* **191**, 140–149.

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Technical solutions used in different pretreatments of lignocellulosic biomass: a review

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Abstract. Bioethanol production from lignocellulosic biomass has attracted a lot of attention as one of the most promising alternative to liquid fossil fuels. Over the last decades a lot of research has been done to find the optimal methods & devices to produce bioethanol from all kind of lignocellulosic biomass. A traditional three-step production process is used to produce bioethanol from lignocellulosic biomass – pretreatment, enzymatic hydrolysis, & fermentation. Today, the high cost of the pretreatment prevents bioethanol from competing with petrol. In this review article, the positive & negative aspects of different pretreatment methods & patented devices are investigated & analysed. Based on the analysis several options on how to lower lignocellulosic biomass pretreatment costs & how to increase the competitiveness of bioethanol are proposed.

Key words: bioethanol, pretreatment devices, pretreatment methods, biomass.

INTRODUCTION

Presently, most of the primary energy (up to 80%) consumed worldwide is produced from fossil fuels. From this 58% is used by the transportation sector alone (Nigam et al., 2011). Dem& for energy rises year by year but fossil fuels are a limited resource. This limitation has driven scientists to search for new alternatives that could replace fossil fuels as our primary energy source & to ensure some degree of energy independence from them. Biofuels are considered as the most favourable choice at the moment compared to syngas, hydrogen or solar energy due to their renewability, biodegradability & cost-effectiveness (Nigam et al., 2011; Tutt et al., 2012).

Biofuels are classified as primary & secondary biofuels. Primary biofuels are natural & non-refined biomass including firewood, wood chips & pellets used to produce heat or electricity. Secondary biofuels are further divided into three sub-groups: first-, second- & third-generation. Classification is based on the origin of the raw material & technology used for their production (Nigam et al., 2011). First generation biofuels are produced from food crops that are rich in starch or sugar (maize, wheat, sugar-cane etc.) (Agbor et al., 2011). Second-generation biofuels use lignocellulosic biomass (the whole above ground plant biomass) as feedstock (Kikas et al., 2015). Third generation biofuels use algae as feedstock but currently the research in this field is in early stages (Podkuiko et al., 2014).

The most promising natural resource at the moment for the production of liquid biofuels is lignocellulosic biomass. In contrast to the first generation biofuels, it does not compete with food crops. Lignocellulosic biomass is the most economical renewable resource with an annual growth rate of around 200 billion tons (Tojo et al., 2014). Other positive aspects to using lignocellulosic biomass as feedstock include worldwide distribution, the abundance of lignocellulosic wastes (agricultural, municipal & forestry wastes) & low effect on global warming (Galbe & Zacchi, 2012; Raud et al., 2017).

The basic production process of bioethanol from lignocellulosic biomass consists of five main steps: gathering feedstock, pretreatment, hydrolysis, fermentation & distillation. Four of these processes (feedstock gathering, hydrolysis, fermentation & distillation) have been widely studied & optimal methods have been found. Since every lignocellulosic biomass has its own unique chemical composition (Raud et al., 2015a; Raud et al., 2015b), which also depends on the maturity of the plant, makes it harder to find one certain pretreatment method that would suit for all different lignocellulosic biomasses (Tutt et al., 2013). Therefore, low-cost & optimal solution for pretreatment of lignocellulosic biomass is yet to be found.

The aim of this article is to give an overview of different pretreatment methods from the technical point of view & to analyse their advantages & disadvantages. Overview of technical solutions is given for viable methods that already are or have potential to be commercialized.

BIOMASS PRETREATMENT

The aim of the pretreatment process is to facilitate better access of biocatalysts to cellulose that needs to be converted into fermentable sugars by changing physio-chemical characteristics of the biomass (Galbe & Zacchi, 2012; Akhtar et al., 2016). The surface area is increased by unbounding cellulose from lignin & hemicellulose, but this process is very difficult & energy-consuming due to the complex structure of the lignocellulose. The effectiveness of the pretreatment process plays an important role in the efficiency of subsequent processes - high cellulose yield = high sugar yield = high ethanol yield = higher competitiveness with fossil fuels.

Pretreatment method is considered efficient if it meets the following criteria (Galbe & Zacchi, 2012; Silveira et al., 2015):

- Provides high sugar yield,
- Forms minimum amount of inhibitory compounds,
- Consumes minimum amount of energy,
- Requires minimum amount of enzyme for hydrolysis,
- Allows the recovery of other compounds (lignin, hemicellulose, etc.) for conversion into other valuable co-products,
- Prevents sugar & lignin degradation,
- Provides maximum enzyme accessibility to cellulose,
- Costs minimum amount of money.

Several lignocellulosic biomass pretreatment methods (AFEX, steam explosion, alkaline pretreatment, etc.) have been developed & studied with common objective – to find the best possible method that guarantees maximum efficiency. Today the high cost of pretreatment process prevents the availability of second-generation bioethanol as a commercial fuel.

Although numerous review articles concerning different pretreatment methods have been published, the suitability of the proposed technical solutions for industrial scale biofuel production has not been analysed so far.

PRETREATMENT METHODS

Pretreatment methods are classified into four main groups: physical, biological, chemical & physio-chemical methods.

Physical pretreatment

Milling

The main goal of mechanical pretreatment is to reduce the biomass particle size, cellulose crystallinity & to reduce the degree of polymerization, which results in increased specific surface area (S. Sun et al., 2016). Milling also causes shearing of the biomass (Conde-Mejía et al., 2012). Due to the effects mentioned, it is easier for enzymes to react with cellulose, which results in increased glucose yield.

Milling, solely as a pretreatment method, has not reached commercialization due to its high-energy consumption, which is directly related to the particle size. In order to achieve high hydrolysis yields the biomass needs to be grinded into very fine particles, which consumes more energy than we harvest. Currently, only rough milling is used as the first stage for several other pre-treatment methods (nitrogen explosion, acid/alkaline pretreatment etc.).

Irradiation

This method uses microwaves, gamma rays or electric beams to disrupt cellular integrity. The advantages of irradiation methods include increased specific surface area & porosity of the biomass, & decreased cellulose crystallinity. It also softens & partially depolymerizes lignin (Agbor et al., 2011; Balat, 2011).

Today irradiation is not economically feasible for large scale utilization due to expensive equipment & lacking research in this specific field. It is also energy consuming & the use of gamma rays raises environmental & safety concerns (Agbor et al., 2011).

Biological pretreatment

Biological pretreatment uses fungi, selective enzymes &/or microorganisms to degrade the lignin & hemicellulose, which cover the cellulose. Positive aspects of biological pretreatment are low energy consumption, chemical-free processing & mild pretreatment conditions. Although it is an environmentally friendly method, it is not viable for commercial fuel production due to very long pretreatment time, large space requirement & need for constant monitoring of microorganisms growth (Haghighi Mood et al., 2013; Silveira et al., 2015; S. Sun et al., 2016).

Chemical pretreatment

Acid pretreatment

Acid pretreatment is the most studied & commonly used chemical pretreatment method. The method uses concentrated or diluted acids as catalysts in order to dissolve lignin & hemicellulose (Akhtar et al., 2016). Most commonly used acids are sulphuric, hydrochloric, nitric etc. (Behera et al., 2014). The process is carried out at temperatures up to 210 °C depending on the acid concentration. At high temperatures (temperatures over 160 °C) diluted acids are used & at lower temperatures concentrated acids are used (Badiei et al., 2014).

Using concentrated acids results in high yields of fermentable sugars at low temperatures, but has several disadvantages, which limit the competitiveness of bioethanol produced in this way compared to fossil fuels we use today.

Concentrated acids are highly corrosive & therefore, the equipment is expensive. In addition, the acids are very expensive & for economical sustainability, the process requires acid recovery. Acid recovery itself is an energy consuming process, which reduces the efficiency of the overall process. Furthermore, the pretreated biomass requires neutralization prior enzymatic hydrolysis. Acids toxicity also raises environmental & health safety concerns (Rabemanolontsoa et al., 2016). While treating biomass with acids, different inhibitory by-products such as aliphatic carboxylic acids, phenolic compounds, furans, etc. are produced, which may have negative effects on the downstream processes (Chiaramonti et al., 2012; Tutt et al., 2012, Jönsson et al., 2016).

Alkali pretreatment

Alkali pretreatment uses several different reagents such as sodium-, ammonium-, potassium-, calcium hydroxides & sodium carbonate (Kim et al., 2016, Rabemanolontsoa et al., 2016). Pretreatment with alkali uses lower temperatures & pressures than pretreatment with acids (Tutt et al., 2012). It results in reduced energy input & therefore, is more cost-effective.

Main positive effects of this method are: decreased degree of polymerization & crystallinity, broken structural linkages between lignin & carbohydrates, disrupted lignin structure, increased biomass porosity. Effect of this method highly depends on the lignin content in the biomass (Y. Sun et al., 2002; Silveira et al., 2015; Kim et al., 2016).

The disadvantages of this method are: long pretreatment time (measured in hours or even in days) & formation of irrecoverable salts or incorporation into biomass, chemicals used are more expensive than the ones used in acid pretreatment (Mosier et al., 2005; Behera et al., 2014). Similarly to the case of acid pretreatment, the pretreated biomass needs to be neutralized prior to the enzymatic hydrolysis in order to lower the pH, & remove lignin & inhibitory by-products (salts, phenolic acids, furfural & aldehydes) (Menon et al., 2012). Alkali recovery system is needed in order to keep the end product price down.

Ionic liquids

Ionic liquid pretreatment uses salts as solvents. These salts have low melting point (liquid at room temperatures) & are stable up to 300 °C. Due to its non-volatility it is considered an environmentally friendly solvent (Guragain et al., 2011). Ionic liquids are also often called as designer solvents because their physical & chemical properties can be adjusted by choosing different cations, anions & substituents (Xiao et al., 2012).

This pretreatment method has several advantages. Ionic liquids dissolve cellulose, but leave lignin & hemicellulose intact & unaltered which allows their extraction for other chemical uses. Solvents adjustability gives an opportunity to dissolve different biomass types more efficiently.

The main drawbacks of using ionic liquids are solvents high costs & enzyme deactivation (Akhtar et al., 2016).

Organosolv

Method uses an organic or aqueous organic solvent mixture with inorganic acid catalysts depending on the temperature at which the process is conducted (Y. Sun et al., 2002; Behera et al., 2014). Preferred solvents have low boiling point, such as methanol or ethanol due to their low cost & ease of recovery (Zhang et al., 2016). Also, solvents with high boiling point are used, such as ethylene glycol, glycerol, etc. or other organic compounds, such as ethers, ketones or phenols (Y. Sun et al., 2002; Zhang et al., 2016). Organosolv pretreatment increases enzymatic hydrolysis efficiency by delignification & hemicellulose removal. Cellulose-rich residue is easily hydrolysed with enzymes to almost theoretical glucose yields (Binod et al., 2010).

On the positive side, this method can be used on both soft- & hardwood & relatively pure lignin can be recovered as a valuable co-product. Unfortunately, it also has several disadvantages, such as high capital investment, formation of toxic inhibitors & need for solvent recycling (Akhtar et al., 2016).

Physio-chemical pretreatment

Ammonia fibre explosion (AFEX) pretreatment

In this method lignocellulosic biomass is exposed to liquid ammonia at relatively high temperatures & pressures for a period of time. Contact with ammonia at high temperatures & pressures causes swelling & partial decrystallization of cellulose. Explosive decompression disrupts cellular integrity & therefore, enhances biomass digestibility (Tutt et al., 2014; Rawel Singh et al., 2016).

AFEX pretreatment has several advantages as it does not form toxic compounds, increases accessible surface area, & is very effective for herbaceous & low lignin content biomass (Behera et al., 2014; S. Sun et al., 2016).

Disadvantages of this method are that AFEX pretreatment does not perform very well on biomass with high lignin content, it does not remove lignin instead it alters its structure & it does not solubilize hemicellulose. One of the biggest drawbacks is that ammonia & its recycling is very expensive (Akhtar et al., 2016; Rawel Singh et al., 2016).

Steam explosion pretreatment

In steam explosion pretreatment high pressure (1–3.5 MPa) saturated steam is used to treat the lignocellulosic biomass. The biomass is heated rapidly to the desired temperature, incubated for a period of time (5–10 minutes) & followed by a rapid decompression (Renu Singh et al., 2014; Silveira et al., 2015).

Rapid decompression causes superheated water in plant cells to flash into steam & the steam volume exp&s explosively resulting in cell structure disruption. The cellulose bundles are defibrillated therefore, enhancing enzymatic hydrolysis efficiency. In order to remove hemicellulose high pretreatment temperatures are needed (150–250 °C) (Tutt et al., 2014).

Steam explosion is currently the most widely used pretreatment method for bioethanol production from lignocellulosic biomass, but it has several disadvantages such as formation of inhibitory compounds, incomplete disruption of lignin-carbohydrate matrix, is not effective enough at lower temperatures (Chiaramonti et al., 2012; Tutt et al., 2014).

Nitrogen explosion pretreatment

A novel pretreatment method developed in the Estonian University of Life Sciences Institute of Technology. This method uses pressurized N_2 (pressure up to 6 MPa) & high temperature (up to 175 °C) combined with explosive decompression to open the biomass structure for more efficient enzymatic hydrolysis(Raud et al., 2014; Raud, Olt, et al., 2016; Raud, Rooni, et al., 2016; Tutt et al., 2016).

Due to high pressure, lignocellulosic biomass cells are filled with nitrogen saturated water. Rapid pressure change to normal pressure elicits a sudden change in volume of the nitrogen causing cell walls to rupture & resulting in better cellulose fibre exposure to enzymes (Raud, Olt, et al., 2016).

ANALYSIS OF PATENTED PRETREATMENT TECHNOLOGIES

There are several various patented technical solutions available for the pretreatment of lignocellulosic biomass. Large proportion of patented technical solutions is based on AFEX or steam explosion methods. Although there are lot of different technical solutions for pretreatment, they all have both, advantages & disadvantages. Most common disadvantages are the use of toxic chemicals (alkali, acids, ammonia, etc.) or need for extreme conditions (high pressure & temperature).

Steam explosion pretreatment devices

All the devices described in patents US 8,603,295 B2 (Dottori et al., 2013), US 2012/0111515 A1 (Nilsen et al., 2012), US 5,328,562 (Scott et al., 1994) use the conventional approach to pressurize the biomass in pretreatment reactors by adding sufficient amount of steam. One exception is the device described in US patent 2008/0277082 (Pschorn et al., 2008), where the final desired pressure is achieved by a high-pressure discharge compressor. The reason for using this compressor is to reduce the amount of hot steam needed for the pressurisation of the biomass. The energy needed to drive the compressor is considered lower than the energy needed to produce steam to raise pressure 0.5–1 bar.

Most of the devices use regular blow-valves to achieve the explosive decompression. Device described in US patent 2012/0111515 A1 uses 2-stage decompression in order to prevent erosion of the pressure relief tank. It is questionable if this multi-step decompression prevents erosion since the first pressure drop is preferably 2–13 bar & the second one only 0.2–1.6 bar (Nilsen et al., 2012). This two-staged decompression eliminates erosion in the final pressure relief tank, but it probably takes place in the first pressure relief tank. In addition, it is questionable if such two-stage pressure relief guarantees maximum disruption in the biomass cellular structure.

One negative aspect is that most of the devices described in the patents do not use the excess heat energy released during the rapid decompression of the steam. By using the excess heat, energy for preheating the biomass prior to entering the pretreatment reactor could significantly reduce the energy input of the process.

Disadvantage of most of the analysed devices, is that they tend to use acids or alkali in order to gain better access to cellulose fibres. Using acids or alkali significantly increases the cost of the final product. Not only are the added alkali & acids expensive, by using chemicals the pretreated biomass needs further neutralization before the enzymatic hydrolysis can take place. In a laboratory-scale, small amounts are used, but for industrial-scale, large quantities of acids or alkali are needed. Therefore, expensive specialised tanks are needed to store the chemicals. Furthermore, extra certified & trained personnel are needed to h&le it. While using chemicals in the process, there is always an environmental risk involved.

One way to reduce pretreatment costs in steam explosion devices is to use the pressure generated by steam to transfer biomass from one vessel to another instead of using screw devices (US patent 8,603,295 B2 (Dottori et al., 2013)) or high pressure compressors (pressure is generated by pistons, US patent 2008/0277082 (Pschorn et al., 2008)). Steam with elevated temperatures should be able to generate enough overpressure to move biomass through pipes & tanks, & to guarantee explosive decompression at the blow-valve.

Using different augers or compressors makes the device more complex & thus, more expensive. Using many different units increases the cost of the device as well as the frequency of the device maintenance.

AFEX pretreatment devices

All investigated AFEX pretreatment devices have one common disadvantage; the method uses highly volatile & toxic ammonia. The use of ammonia, whether in gaseous or liquid form, raises both environmental & health concerns. In addition, none of the devices described in the patents are continuous pretreatment devices, instead, they are batch systems.

Positive aspect of devices described in patents US 2013/0244284 A1 (Machida et al., 2013), is that they all recover & reuse most of the ammonia. Ammonia recovery & reuse can be considered as an advantage, but also as a disadvantage. Reusing ammonia helps to lower the price of the final product. On the other h&, it makes the device technologically even more complex.

N_2-explosion pretreatment device

Unlike the pretreatment methods described previously, nitrogen explosion pretreatment uses pressurised nitrogen gas to disrupt cellular integrity of the biomass thus, exposing cellulose to the enzymes (Raud, Olt, et al., 2016, Tutt et al., 2016).

The method uses lower pressures & temperatures compared to steam explosion devices, where effective temperatures are around 200+ °C & pressures up to 22 bars (Dottori et al., 2010). Pretreatment temperatures & pressures with nitrogen explosion range from 100 °C to 175 °C (with optimum at 150 °C) & from 10 to 60 bar (optimum at 30 bar), respectively (Raud, Rooni, et al., 2016; Tutt et al., 2016). A positive aspect of the device is also that no chemicals are used during the pretreatment process. It helps to lower pretreatment costs, since no additional treatment of the pretreated biomass is required.

The biggest flaw of the device described in patent EE05784 B1 at the moment is that it is not continuous pretreatment device & therefore, the productivity is very low. In addition, the excess heat, released during the explosion, is not utilised, which could lower the final cost of bioethanol production (Kikas et al., 2016).

Acid & alkali pretreatment device

The device described in patent EE05748B1 (Kikas et al., 2013) is a device that is usable for bioethanol production via chemical pathway.

Positive aspects of the device described in this patent are that it is an integrated system & the system allows continuous ethanol production. Also, the pretreatment system does not need any additional energy input, because it is interconnected to distillation unit, where temperature is held constantly at 130 to 150 °C.

The main problem is that the usage of chemicals makes the process very costly. When we use acids or alkali, we also need additional chemicals to adjust the pH to levels acceptable for enzymes. In addition, since the device uses an upright container for fermentation without any mixing unit probably the solids & liquid are separated & the fermentation is not efficient. The same applies to hydrolysis process. If the flow rate is very slow the solids & liquid may separate from each other & high efficiencies are not reached.

DISCUSSION

There are many methods & patented pretreatment devices for the pretreatment of the lignocellulosic biomass, yet only few of them (AFEX, steam explosion) are commercially used for bioethanol production. There are several reasons why any particular method or device is not used, but they all lead to one disadvantage, high product cost compared to fossil fuels. The cost of the final product is the main reason why only few of these methods & devices are used in commercial scale.

Most of the drawbacks are common to all of the patented devices reviewed in this article, whether it is AFEX or steam explosion device. Some of them are due to the nature of the material that is processed but also due to the chemicals that are used in the pretreatment process. Since chemicals & biomass are both corrosive, the devices must be made of stainless steel, which is expensive. In addition, since most of the devices use high pressures & temperatures the reactor vessels need to be made of hardened & tempered stainless steel that could withst& such extreme conditions.

Although the usage of chemicals (alkali, acids, etc.) improves the ethanol yields, it raises the question whether it is justified. The usage of chemicals requires:

1. Competent personnel to h&le the chemicals/toxic gases;
2. Additional equipment for storage of chemicals/toxic gases;
3. Additional process prior hydrolysis (neutralization);
4. Additional equipment to recycle/neutralize chemicals/toxic gases;
5. Additional waste treatment system(s)/device(s).

All these requirements add to the production costs & therefore, raise the price of the final product & make it uncompetitive with the traditional petrol.

In order to increase lignocellulosic bioethanol competitiveness with fossil fuels the main goal is to lower the production costs. Since the pretreatment is the most expensive step in the bioethanol production, the pretreatment devices need to be improved & optimized.

There are several options to reduce the energy input. All of the methods that are used commercially today use high temperatures, & a lot of excess heat is released during the explosion, whether it is steam or ammonia fibre explosion. If the excess heat would be used to preheat the biomass prior the pretreatment, it would be possible to considerably reduce the amount of energy needed to reach the necessary process temperatures.

A novel N_2-pretreatment device has been developed & investigated in the Estonian University of Life Sciences Institute of Technology that uses no catalysts or chemicals, which makes this pretreatment method attractive. In addition, the process uses quite modest temperatures compared to steam explosion or AFEX pretreatment. Even though the production costs can be reduced on the expense of using no chemicals & lower temperatures, it still has several drawbacks, such as lack of recycling of excess heat released during the explosive decompression & the fact that it is a batch system.

CONCLUSIONS

From the analysis of the literature & patents available, we can conclude that even though there has been a lot of research & technological development in the field of second-generation biofuel production from lignocellulosic biomass, an economical, cost-effective & feasible apparatus for the pretreatment of lignocellulosic biomass is still to be developed. Therefore, in the near future the second-generation bioethanol will still not be able to compete with the fuels derived from the fossil resources.

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REFERENCES

Agbor, V.B., Cicek, N., Sparling, R., Berlin, A. & Levin, D.B. 2011. Biomass Pretreatment: Fundamentals toward Application. *Biotechnology Advances* **29**(6). Elsevier Inc., 675–685.

Akhtar, N., Kanika, G., Goyal, D. & Goyal, A. 2016. Recent Advances in Pretreatment Technologies for Efficient Hydrolysis of Lignocellulosic Biomass. *Environmental Progress & Sustainable Energy* **35**(2), 489–511.

Badiei, M., Asim, N., Jahim, J.M. & Sopian, K. 2014. Comparison of Chemical Pretreatment Methods for Cellulosic Biomass. *APCBEE Procedia* **9**(Icbee 2013). Elsevier B.V., 170–174.

Balat, M. 2011. Production of Bioethanol from Lignocellulosic Materials via the Biochemical Pathway: A Review. *Energy Conversion & Management* **52**(2). Elsevier Ltd, 858–875.

Behera, S., Arora, R., Nandhagopal, N. & Kumar, S. 2014. Importance of Chemical Pretreatment for Bioconversion of Lignocellulosic Biomass. *Renewable & Sustainable Energy Reviews* **36**. Elsevier, 91–106.

Binod, P., Sindhu, R., Singhania, R.R., Vikram, S., Devi, L., Nagalakshmi, S., Kurien, N., Sukumaran, R.K. & P&ey, A. 2010. Bioethanol Production from Rice Straw: An Overview. *Bioresource Technology* **101**(13). Elsevier Ltd, 4767–4774.

Chiaramonti, D., Prussi, M., Ferrero, S., Oriani, L., Ottonello, P., Torre, P. & Cherchi, F. 2012. Review of Pretreatment Processes for Lignocellulosic Ethanol Production, & Development of an Innovative Method. *Biomass & Bioenergy* **46**. Elsevier Ltd, 25–35.

Conde-Mejía, C., Jiménez-Gutiérrez, A. & El-Halwagi, M. 2012. A Comparison of Pretreatment Methods for Bioethanol Production from Lignocellulosic Materials. *Process Safety & Environmental Protection* **90**(3). Institution of Chemical Engineers, 189–202.

Dottori, F.A., Benson, R.A.C. & Benecht, R.-O. 2010. Fractionation of Biomass for Cellulosic Ethanol & Chemical Production, Patent US 2010/0313882 A1. USA.

Dottori, F.A., Benson, R.A.C. & Benecht, R.-O. 2013. Separation of Reactive Cellulose from Lignocellulosic Biomass with High Lignin Content, Patent US 8,603,295 B2. USA.

Galbe, M. & Zacchi, G. 2012. Pretreatment: The Key to Efficient Utilization of Lignocellulosic Materials. *Biomass & Bioenergy* **46**. Elsevier Ltd, 70–78.

Guragain, Y.N., De Coninck, J., Husson, F., Durand, A. & Rakshit, S.K. 2011. Comparison of Some New Pretreatment Methods for Second Generation Bioethanol Production from Wheat Straw & Water Hyacinth. *Bioresource Technology* **102**(6). Elsevier Ltd, 4416–4424.

Haghighi Mood, S., Hossein Golfeshan, A., Tabatabaei, M., Salehi Jouzani, G., Najafi, G.H., Gholami, M. & Ardjm&, M. 2013. Lignocellulosic Biomass to Bioethanol, a Comprehensive Review with a Focus on Pretreatment. *Renewable & Sustainable Energy Reviews* **27**, 77–93.

Jönsson, L.J. & Martín, C. 2016. Pretreatment of Lignocellulose: Formation of Inhibitory by-Products & Strategies for Minimizing Their Effects. *Bioresource Technology* **199**, 103–112.

Kikas, T. & Olt, J. 2013. Lignotselluloossest Biomassist Etanooli Tootmise Integreeritud Läbivooluline Seade, Patent EE05748B1 (in Estonian), 16.

Kikas, T., Tutt, M., Raud, M., Alaru, M., Lauk, R. & Olt, J. 2015. Basis of Energy Crop Selection for Biofuel Production: Cellulose vs. Lignin. *International Journal of Green Energy*, no. (in press), 37–41.

Kikas, T., Tutt, M., Raud, M. & Olt, J. 2016. Lämmastiklõhkamismeetod Biomassi Rakustruktuuri Lõhkumiseks, Patent EE05784 B1 (in Estonian). Estonia.

Kim, J.S., Lee, Y.Y. & Kim, T.H. 2016. A Review on Alkaline Pretreatment Technology for Bioconversion of Lignocellulosic Biomass. *Bioresource Technology* **199**. Elsevier Ltd, 42–48.

Machida, M., Fukunuga, T., Morimitsu, K., Sakashita, S., Torikata, Y., Kosugi, A., Mori, Y., Murata, Y. & Arai, T. 2013. Method for Subjecting Solid Biomass to Saccharification Pretreatment, Apparatus Therefor, & Method for Saccharification of Solid Biomass, Patent US 2013/0244284 A1. USA.

Menon, V. & Rao, M. 2012. Trends in Bioconversion of Lignocellulose: Biofuels, Platform Chemicals & Biorefinery Concept. *Progress in Energy & Combustion Science* **38**(4). Elsevier Ltd, 522–550.

Mosier, N., Wyman, C., Dale, B., Elander, R., Lee, Y.Y., Holtzapple, M. & Ladisch, M. 2005. Features of Promising Technologies for Pretreatment of Lignocellulosic Biomass. *Bioresource Technology* **96**(6), 673–686.

Nigam, P.S. & Singh, A. 2011. Production of Liquid Biofuels from Renewable Resources. *Progress in Energy & Combustion Science* **37**(1). Elsevier Ltd, 52–68.

Nilsen, P.J., Solheim, O.E. & Walley, P. 2012. Method & Device for Thermal Hydrolysis & Steam Explosion of Biomass, Patent US 2012/0111515 A1. USA.

Podkuiko, L., Ritslaid, K., Olt, J. & Kikas, T. 2014. Review of Promising Strategies for Zero-Waste Production of the Third Generation Biofuels. *Agronomy Research* **12**(2), 373–390.

Pschorn, T., Sabourin, M. & Mraz, P. 2008. High Pressure Compressor & Steam Explosion Pulping Method, Patent US 2008/0277082 A1. USA.

Rabemanolontsoa, H. & Saka, S. 2016. Various Pretreatments of Lignocellulosics. *Bioresource Technology* **199**. Elsevier Ltd, 83–91.

Raud, M., Kesperi, R., Oja, T., Olt, J. & Kikas, T. 2014. Utilization of Urban Waste in Bioethanol Production: Potential & Technical Solutions. *Agronomy Research* **12**(2), 397–406.

Raud, M., Mitt, M., Oja, T., Olt, J., Orupõld, K. & Kikas, T. 2017. The Utilisation Potential of Urban Greening Waste: Tartu Case Study. *Urban Forestry & Urban Greening* **21**. Elsevier GmbH., 96–101.

Raud, M., Olt, J. & Kikas, T. 2016. N2 Explosive Decompression Pretreatment of Biomass for Lignocellulosic Ethanol Production. *Biomass & Bioenergy* **90**. Elsevier Ltd, 1–6.

Raud, M., Rooni, V. & Kikas, T. 2016. Explosive Decompression Pretreatment: Nitrogen vs. Compressed Air. *Agronomy Research* **14**(2), 569–578.

Raud, M., Tutt, M., Olt, J. & Kikas, T. 2015a. Dependence of the Hydrolysis Efficiency on the Lignin Content in Lignocellulosic Material. *International Journal of Hydrogen Energy* **41**(37). Elsevier Ltd, 16338–16343.

Raud, M., Tutt, M., Olt, J. & Kikas, T. 2015b. Effect of Lignin Content of Lignocellulosic Material on Enzymatic Hydrolysis. *Agronomy Research* **13**(2), 405–412.

Scott, K.E. & Rafferty, A.J. 1994. Process for Preparing a Hydrolysed Lingnocellulosic Material, Patent US 5,328,562. New Zel&.

Silveira, M.H.L., Morais, A.R.C., Da Costa Lopes, A.M., Olekszyszen, D.N., Bogel-Łukasik, R., Andreaus, J. & Pereira Ramos, L. 2015. Current Pretreatment Technologies for the Development of Cellulosic Ethanol & Biorefineries. *ChemSusChem* **8**(20), 3366–3390.

Singh, R., Krishna, B.B., Kumar, J. & Bhaskar, T. 2016. Opportunities for Utilization of Non-Conventional Energy Sources for Biomass Pretreatment. *Bioresource Technology* **199**. Elsevier Ltd, 398–407.

Singh, R., Shukla, A., Tiwari, S. & Srivastava, M. 2014. A Review on Delignification of Lignocellulosic Biomass for Enhancement of Ethanol Production Potential. *Renewable & Sustainable Energy Reviews* **32**. Elsevier, 713–728.

Sun, S., Sun, S., Cao, X. & Sun, R. 2016. The Role of Pretreatment in Improving the Enzymatic Hydrolysis of Lignocellulosic Materials. *Bioresource Technology* **199**. Elsevier Ltd, 49–58.

Sun, Y. & Cheng, J. 2002. Hydrolysis of Lignocellulosic Materials for Ethanol Production , A Review. *Bioresource Technology* **83**(1), 1–11.

Tojo, S. & Hirasawa, T. 2014. *Research Approaches to Sustainable Biomass Systems*. 1 Ed. Oxford: Academic Press.

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.

Tutt, M., Kikas, T. & Olt, J. 2012. Influence of Different Pretreatment Methods on Bioethanol Production from Wheat Straw. *Agronomy Research, Biosystems Engineering Special Issue* **1**, 269–276.

Tutt, M., Kikas, T. & Olt, J. 2013. Influence of Harvesting Time on Biochemical Composition & Glucose Yield from Hemp. *Agronomy Research* **11**(1), 215–220.

Tutt, M., Raud, M., Kahr, H., Pointner, M., Olt, J. & Kikas, T. 2016. Nitrogen Explosion Pretreatment of Lignocellulosic Material for Bioethanol Production. *Energy Sources, Part A: Recovery, Utilization, & Environmental Effects* **38**(12), 1785–1789.

Xiao, W., Yin, W., Xia, S. & Ma, P. 2012. The Study of Factors Affecting the Enzymatic Hydrolysis of Cellulose after Ionic Liquid Pretreatment. *Carbohydrate Polymers* **87**(3). Elsevier Ltd., 2019–2023.

Zhang, K., Pei, Z. & Wang, D. 2016. Organic Solvent Pretreatment of Lignocellulosic Biomass for Biofuels & Biochemicals: A Review. *Bioresource Technology* **199**. Elsevier Ltd, 21–33.

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Theoretical analysis of the technological process of hop drying

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Abstract. This article is aimed at the current questions concerning hop drying, a process which represents a significant part of energy consumption for hop producers. The water content drops during hop cone drying from the original approx. 80% of moisture to 8 or 10%. The drying medium is heated air, and the maximum drying temperatures range between 55 °C and 60 °C, remaining practically stable for the entire duration of drying. Hops are exposed to these temperatures for 6 to 8 hours. The current old and ageing belt dryers record large losses. Their modernisation and particularly new drying technologies need to derive from perfect knowledge of thermal characteristics of materials and drying devices. The drying process and the actual implementation necessarily depend on the knowledge of the entire process calculation that is why the paper introduction outlines simplified issues concerning a 'theoretical dryer' following the h-x chart. An experimental measurement was carried out in an operating belt dryer. It included measurements of the drying medium thermal and moisture parameters and of the drying hop qualitative parameters. These drying parameters were monitored by means of continuously recording data loggers and of a laboratory analysis of the samples (hop moisture content, alpha bitter acids, Hop Storage Index). The drying process revealed that hops are practically dry (10 ± 2.0% of moisture content) already at the end of the second belt or possibly at the beginning of the third belt. It was also proven that hops are excessively dried (moisture content of 4 to 8%), adjusted to their final moisture of 8–10% through conditioning. Excessive drying results in considerate hop-cone shatter which makes the hop manipulation difficult during further processing, leading to larger losses of lupulin.

Key words: hop, hop drying, belt dryer.

INTRODUCTION

The current state in the field of hop drying and hop conditioning technology is not ideal, as regards the operating costs as well as qualitative properties of the final product. The belt dryers prevailing so far, following stationary picking lines, derive their drying process from continuous progress of the harvest. In a belt dryer hop cones are dried at a temperature of the drying air ranging between 55–60 °C for 6–8 hours from the initial 80% moisture content to 8 or up to 10%. Drying hop cones below 10% of moisture content and following controlled conditioning require approximately 1/3 of the overall energy requirements necessary for hop growing (Doe & Menary, 1979).

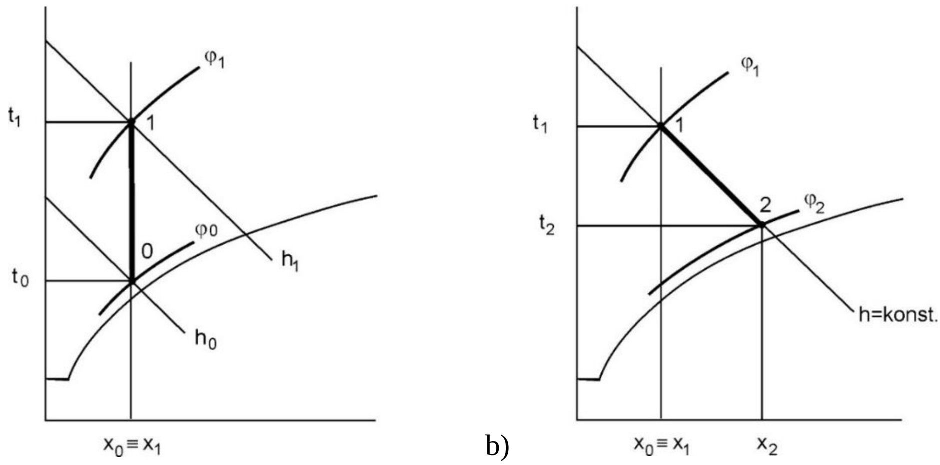
The following outlined simplified process referring to 'theoretical dryer' based on the h-x chart only introduces the matter but does not cover the problem linked to hop drying as a whole. For the real dryer psychrometric mechanisms need to be considered, as well as thermal energy savings, recirculation and recovery (Srivastava et al., 2006).

The process between the initial and final state of the hops and air is illustrated in the Molliere h-x diagram by isobaric air heating (0–1) and its isenthalpic humidification (1–2) through the moisture released from the hops. This process is called 'theoretical dryer' (Fig. 1).

The weight of dried-off moisture content is determined from weights of the input and output hops M_1 and M_2, with a proportion of hop moisture content w_1 and w_2 and specific hop moisture u_1 and u_2 (Henderson & Miller, 1972; Aboltins & Palabinskis, 2016):

$$M_w = M_1 - M_2 = M_1 \frac{w_1 - w_2}{100 - w_2} = M_2 \frac{w_1 - w_2}{100 - w_1} = M_{dm}(u_1 - u_2) \qquad (1)$$

where: M_w – weight of the dried-off moisture, kg d.o.m.; M_1, M_2 – weight of the input and output hops, kg; w_1, w_2 – hop moisture content wet basis,% w.b.; M_{dm} – dry matter weight determined in accordance with the standard (ISO), kg; u_1, u_2 – hop specific moisture, kg kg^{-1}.



a) b)

Figure 1. Theoretical dryer: a) air heating; b) air moistening; t_0, t_1, t_2 – air temperature, °C; x_0, x_1, x_2 – hop moisture content dry basis, kg kg^{-1} d.b.; φ_0, φ_1, φ_2 – relative humidity; h, h_0, h_1 – enthalpic, kJ kg^{-1}.

The initial moisture content of the hopes is $M_1 - M_{dm}$ and the humidity of the air is $M_{da} \cdot x_0$ when entering the dryer, becoming and $M_2 - M_{dm}$ and $M_{da} \cdot x_2$ respectively, while leaving the dryer, where: M_{da} – the weight of dry air, kg d.a.

The remainder is the evaporated moisture carried away by the outlet air:

$$M_w = M_1 - M_2 = M_{da} = M_{da}(x_2 - x_0) \qquad (2)$$

Specific air requirements – λ:

$$\lambda = \frac{M_{da}}{M_w} = \frac{1}{x_2 - x_0}, \frac{kg\ d.a.}{kg\ d.o.m.} \qquad (3)$$

The outlet hop moisture content dry basis x_2 is determined by state 2 which is the intersection of enthalpic humidification (1–2) with the relative humidity curve φ_2 and with the air isotherm t_2 which is usually determined from the admissible temperature of hop warming, i.e. the temperature which when exceeded causes a damage to the physico-chemical hop properties and which in practice is 60 °C. The dependency of the hop specific moisture on time is the drying curve. Its derivation is the drying rate speed curve. Both curves illustrate in a concise manner the drying process in time. Shortening the drying time by up to a half the usual time will lead to substantial energy savings (Chyský, 1977; Jokiniemi et al., 2015).

Currently used belt dryers are ageing, as they were implemented in the 70s and 80s of the last century (Rybáček et al., 1980). The overall drying capacity now amounts to 9,500 tons of dry hops which exceeds by 38% the total production being approx. 6,000 tons of dry hops. Consequently, there is no need to build new hop dryers, but only to focus on modernization and automation of drying process as a whole within the current drying technologies. The objective of this paper is, following the theory, the analysis of the current state of drying, conditioning and stabilization of hops, which in terms of content precedes the innovation in the entire process of hop drying.

MATERIALS AND METHODS

The measurements were carried out in PSCH 325 belt dryer being parts of the plants of the Research Farm in Stekník, Hop Research Institute Co. Ltd. Žatec.

The measured parameters were the temperature and moisture parameters of the drying medium, and the qualitative parameters of the hops being dried – temperature, moisture content, drying time (Hanousek et al., 2008). Given the large extent of the measured values, only selected results are presented in this paper. Further results are available from the authors.

The monitored parameters were determined in two ways (Ma Xu et al., 2015):

- through measuring by means of inserted data-loggers Voltcraft DL-121-TH,
- through a laboratory analysis of the samples.

The data-logger was integrated together with the sensor in a plastic case and powered with a battery. The plastic case was fitted with a USB connector at one of its ends, via which the stored data were imported into the computer (Fig. 2).

The advantage of data-loggers compared to fixed sensors in a dryer is that they pass together with hops through the dryer (Fig. 3), continuously recording the entire drying process. The following graphs are based on the average values received from the employed data-loggers.

Figure 2. Inserting a data-logger into a protective sieve.

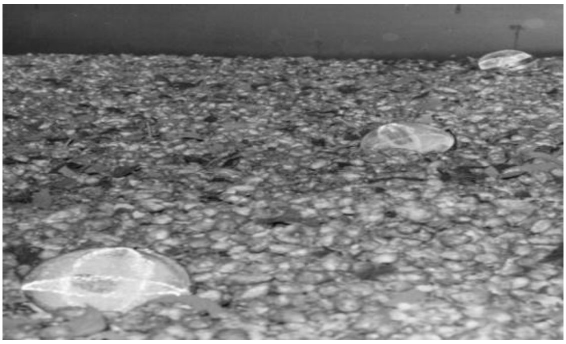


Figure 3. Deployment of data-loggers to dryer width.

Hop samples were being taken throughout the process of drying, following a pre-determined schedule, and then were submitted to a laboratory analysis. The analysis allowed for identification of the Hop Storage Index (HSI), the content of alpha bitter acids, and the hop sample moisture content was also determined (Krofta, 2008). The HSI is used to estimate losses of alpha bitter acids during storage and handling. It could be used as an indicator of 'hop freshness' for brewing.

The first sample was always fresh green hops taken immediately after picking. Other samples were taken at check window points (Fig. 4) by individual belts, three samples from each belt (Jech et al., 2011). Last samples were taken prior to and after the conditioning, and one more sample prior to baling.

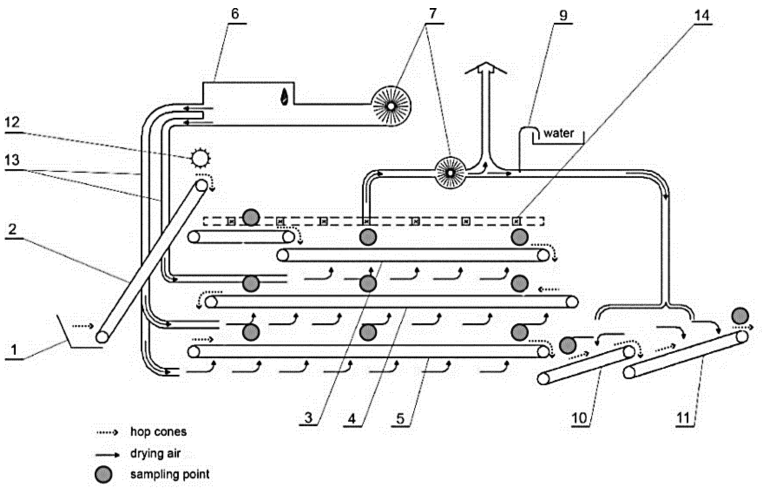


Figure 4. Scheme of the belt dryer with indicated sampling points:1 – hopper; 2 – inclined wire mesh belt; 3(4,5) – upper (middle, lower) drying wire mesh belt; 6 – hot-air aggregate; 7,8 – fan; 9 – humidifier; 10(11) – first (second) wire mesh belt of the conditioning chamber; 12 – straightening roll; 13 – distribution air pipes; 14 – suction openings.

In Stekník the monitored hops were mainly of the Saaz hop variety. The hop moisture content was determined in the laboratory dryer of the Hop Research Institute Co. Ltd. Žatec with forced air circulation according to the EBC 7.2 method. The HSI was determined using the EBC 7.13 conventional spectrophotometric method from a toluene hop extract. The content of alpha bitter acids was measured by liquid chromatography according to the HPLC EBC 7.7 method. Tables and graphs were created reflecting the results of the hop sample laboratory analyses.

RESULTS AND DISCUSSION

The graph in Fig. 5 clearly shows the whole drying process is recorded when measured continuously. Around the 90th minute the temperature dropped and the relative humidity increased due to the dryer failure and following forced interruption of operation.

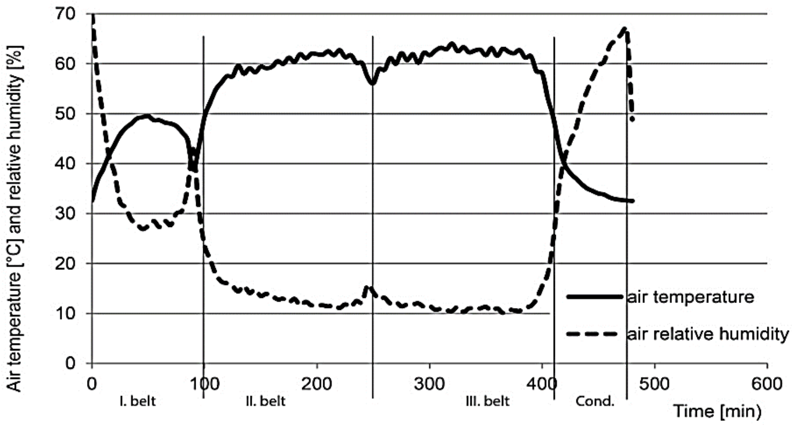


Figure 5. Air temperature and air relative humidity of the Saaz hop variety measured by means of data-loggers: I. belt – upper b.; II. belt – middle b.; III. belt – lower b.; Cond. – conditioning chamber.

Fig. 6 presents an example of one measurement carried out with samples from a laboratory dryer. Besides hop moisture content, the graph also depicts the HSI progresses. The graph confirms the previously mentioned changes in the hop moisture content dependending on hop passage through the dryer. A conclusion can be drawn that hops are dried to approx. 10% of moisture content already at the end of the second belt. The laboratory analyses also indicate that only minimum changes occur both in alpha bitter acids and the HSI after the hops have passed through the belt dryer (Henderson, 1973).

The reports from travels to important hop-growing areas in the USA, Germany and China provided by hop experts showed that in these countries hops have been dried and processed in a similar way, therefore we may assume similar outputs from the measurement. Foreign research centres do not deal with these particular issues, which is the reason why there are no comparable results available for possible discussion.

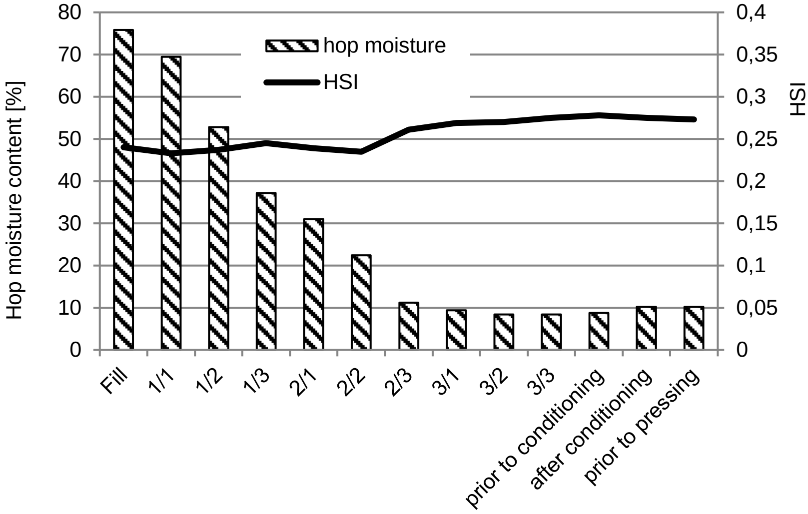


Figure 6. Changes in the hop moisture content and HSI with samples of the Saaz hop variety: Fill – hopper; 1/1 – 1st (upper) belt and 1st window… 3/3 – 3rd (lower) belt and 3rd window.

CONCLUSION

The progress of drying in the operating belt dryer showed that hops are practically dry (10 ± 2.0% of moisture content) already at the end of the second belt, or possibly at the beginning of the third belt. Hop drying in the belt dryer proved that hops are considerably over-dried (4 to 8% of moisture content) and are subsequently adjusted to the final moisture content of 8–10%. According to the company staff this state is intentional, working as prevention against the occurrence of nests of moist hops, which occur on irregular basis when drying hops with high initial moisture content. Over-drying results in extensive hop cone shattering, rendering the manipulation with hops for further processing more difficult and leading to larger losses in the lupulin content.

Further research activity will focus on data visualization as well as on automation of the entire drying process control including curing in belt dryers. The experiments will be aimed both at increasing the quality of the final hop product and also at saving the heating medium and electricity.

As indicated in the above, there is great room for improvement in the whole drying process, both in terms of energy and the quality of the final hop product. A complex innovation in the hop drying process in the current belt dryers is very much needed and logically we may assume savings of heat medium and electric energy, resulting from shortening the drying time, increasing the capacity of the facility, and shortening the harvest time.

ACKNOWLEDGEMENTS. This paper was created with the contribution of the Czech Ministry of Agriculture as a part of NAZV n°QJ1510004 research project. In the project solution, besides CULS Prague, are involved: Hop Research Institute Co., Ltd., Žatec, Chmelařství, cooperative Žatec, Rakochmel, Ltd., Kolešovice and Agrospol Velká Bystřice Ltd.

REFERENCES

Aboltins, A. & Palabinskis, J. 2016. Fruit Drying Process Investigation in Infrared Film Dryer. *Agronomy Research* **14**(1), 5–13.

Chyský, J. 1977. *Moist air.* SNTL, Prague, 160 pp. (in Czech).

Doe, P.E. & Menary, R.C. 1979. Optimization of the Hop Drying Process with Respect to Alpha Acid Content. *J. Agric. Engng Res*. **24**, 233–248.

Hanousek, B., Rybka, A. & Bernášek, K. 2008. Evaluation of hop picker line PT 30/15 and hop drying in belt and kiln dryers in 2007. In P. Svoboda (eds): *Economic-technological seminar about hop production problems.* Hop Research Institute Co. Ltd., Žatec, pp. 43–61. (in Czech).

Henderson, S.M. 1973. Equilibrium Moisture Content of Hops. *J. Agric. Engng Res*. **1**, 55–58.

Henderson, S.M. & Miller, G.E. 1972. Hop Drying-Unique Problems and Some Solutions. *J. Agric. Engng Res.* **17**, 281–287.

Jech, J., Artim, J., Angelovičová, M., Angelovič, M., Bernášek, K., Honzík, I., Kvíz, Z., Mareček, J., Krčálová, 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-harvesting and treatment of plant material.* Profi Press s.r.o., Prague, 368 pp. (in Czech and Slovak).

Jokiniemi, T., Oksanen, T. & Ahokas, J. 2015. Continuous airflow rate control in a recirculating batch grain dryer. *Agronomy Research* **13**(1), 89–94.

Krofta, K. 2008. *Evaluation of hop quality.* Hop Research Institute Co. Ltd., Žatec, 50 pp. (in Czech).

Ma, Xu., Driscoll, R. H. & Srzednicki, G. 2015. Development of in-store dryer model for corn for varying inlet conditions. *Agronomy Research* **13**(1), 202–211.

Rybáček, V., Fric, V., Havel, J., Libich, V., Kříž, J., Makovec, K., Petrlík, Z., Sachl, J., Srp, A., Šnobl, J. & Vančura, M. 1980. *Hop production*. SZN Prague, 426 pp. (in Czech).

Srivastava, A.K., Goering, C.E., Rohrbach, R.P. & Buckmaster, D.R. 2006. *Engineering Principles of Agricultural Machines.* ASABE, 2nd Edition, Michigan, 569 pp.

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Method for selection of pig manure processing technologies

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Abstract. The criteria, which take into account both economic and environmental indicators, were suggested for assessment of technologies and selection of the most reasonable solution. The method of Pareto optimization was applied. Technologies suited for the North-West Russia were considered to design a mathematical model and to obtain the required indicators for the criteria calculation. The technology of multi-stage processing of pig manure with cyclic sedimentation tanks was studied in more detail based on a separate, specially designed three-level mathematical model. The objective function was the eco-economic index of nitrogen, which is the ratio between the economic benefit from the marketed yield increment and the costs of nutrients retention in the organic fertilizers applied to soil under the harvested crop yield. The resulting simulation data were substantiated by experimental studies. A mathematical model and an algorithm for selecting the best-suited technology were designed. As the calculation process involved a large bulk of data, the WEB programming was used. Simulation results demonstrated 90% accurate choice of technology. The designed model was tested for the conditions of a pig complex in Leningrad Region with the manure output of 150 t per day and no own farmland for organic fertilizer application. Calculations proved the economic and ecological effectiveness of the multi-stage processing of pig manure: operating costs per one ton of produced organic fertilizer were reduced 1.8 times, fuel costs – 1.4 times and labour costs – 3.3 times. The chosen technology also featured higher ecological safety coefficient. Estimated ecological and economic effect of introduction of this technology amounted to 5936 thousand roubles per year.

Key words: manure management, processing method, algorithm, mathematical model, pig farm.

INTRODUCTION

Currently manure utilisation is one of the issues, which influences the effective operation of pig farms, and at times even hampers their development.

The detailed study of the current situation in pig farming in the North-Western Federal District of Russia shows that many pig farms do not have enough their own cultivated land to apply the produced organic fertilizers; often the distance between the fields and the pig farms exceeds 15 km (Shalavina, 2015). At the same time large-scale pig farms produce significant amount of liquid manure, e.g. a pig farm with 100,000 pigs produces above 365 thousand tons of liquid manure per year.

Leningrad Region is ranked among the pork production leaders in the North-Western Federal District (Figs 1 & 2) (http://www.gks.ru/).

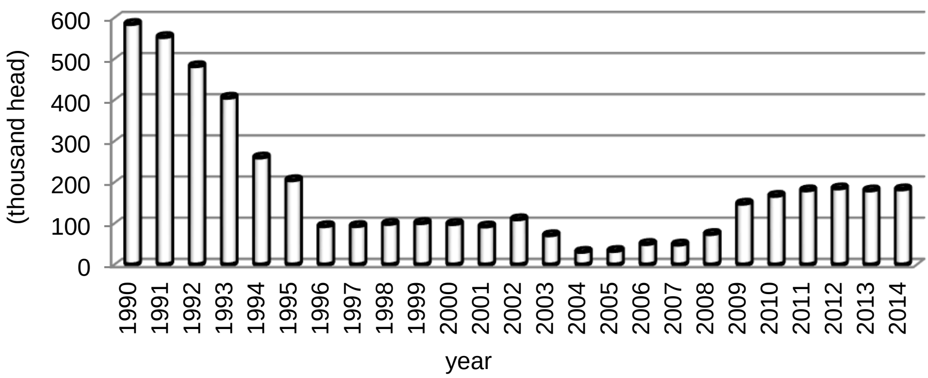

Figure 1. Dynamic pattern of average annual number of pigs in Leningrad Region.

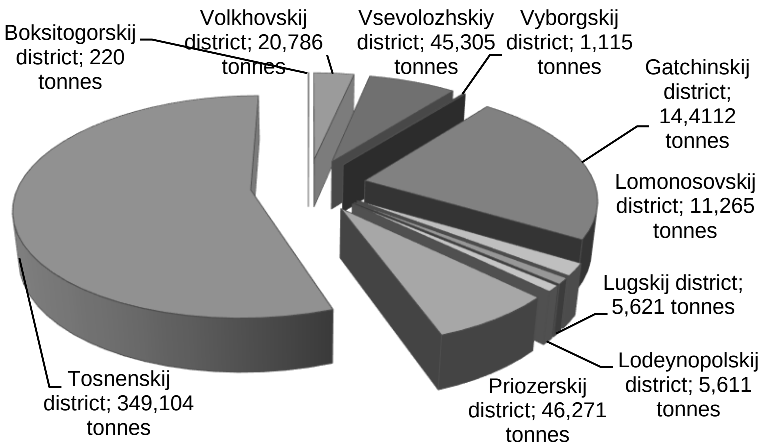

Figure 2. Annual manure output in the districts of Leningrad Region.

The problem of effective processing of pig manure was initially raised in 1980s, when large-scale pig breeding complexes were put into operation, such as 'Novyi Svet', 'Novgorodskiy', 'Vostochnyi' and others. At that time Russian researchers N.G. Kovalev, N.M. Marchenko, V.N. Afanasiev, V.V. Kaljuga and others did a lot to improve the technologies for manure utilization (Afanasiev et al., 1977; Kovalev et al., 1998; Kaljuga et al., 2011; Rabinovich et al., 2015). The relevant European experience was also considered (Singh et al., 2006; Salomon et al., 2012; Selimbasic et al., 2012).

In order to generalize and systematize information the available pig manure processing technologies were analysed (Fig. 3).

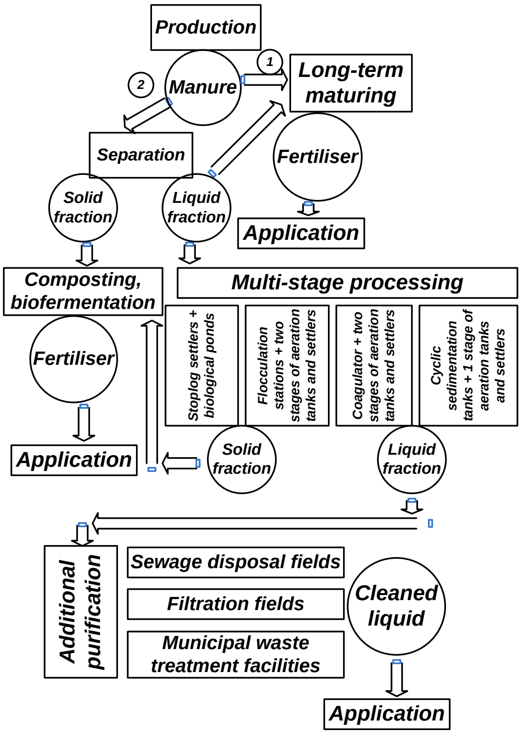

Figure 3. Technologies for pig manure processing.

According to Figure 3 there are two basic approaches to pig manure processing: long term maturing and separation into fractions with subsequent individual processing of solid and liquid fractions. These approaches have their own advantages and disadvantages depending on conditions of use. For example, some technologies might require significant land areas for application of organic fertilizers; some feature excessive power consumption, or require specific chemicals. All of that imposes certain constraints on the usage of these technologies under conditions of particular livestock complexes.

MATERIALS AND METHODS

To select pig manure processing technology, which is best suited for specific farm conditions, an algorithm was developed (Fig. 4).

‘Farm Data’ block includes information about production factors, resources, technical and technological characteristics. ‘Database’ block contains normative and informative references and the data on machines and equipment. ‘Restrictions’ block contains the criteria for selecting the optimal technology with due account for the farm potential.

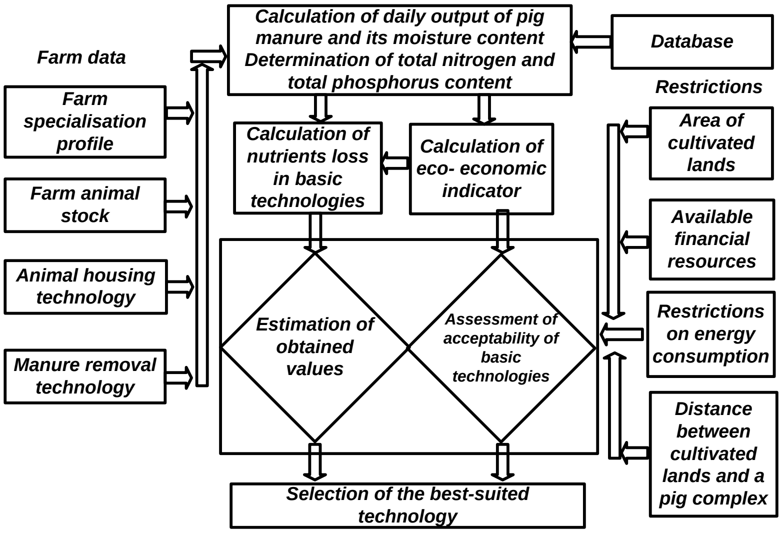

Figure 4. Pattern for selecting a technology of pig manure processing.

Based on literature review, the following criteria were accepted to select a technology:

1. Economic criterion:

$$Z = SCC + SOC, \quad (1)$$

SCC – specific capital costs, thousand roubles per ton; SOC – specific operating costs, thousand roubles per ton.

2. Ecological criterion – mass of retained nutrients in produced organic fertilizer:

$$M_{NP} = M_N + M_P = M_{N1} - L_N + M_{P1} - L_P, \quad (2)$$

M_N – mass of retained total nitrogen in organic fertilizer, t; M_P – mass of retained total phosphorus in organic fertilizer, t; M_{N1} – mass of total nitrogen in pig manure, t; L_N – loss of total nitrogen at all stages of the technology, t; M_{P1} – mass of total phosphorus in pig manure, t; L_P – loss of total phosphorus at all stages of the technology, t.

Pareto analysis was applied to compare the pig manure processing technologies by the above criteria.

Technologies suited for the North-West Russia were considered to design a mathematical model and to obtain the required indicators for the criteria calculation. The technology of multi-stage processing of pig manure with cyclic sedimentation tanks was studied in more detail (Fig. 5), based on a separate, specially designed three-level mathematical model (Shalavina & Briukhanov, 2015).

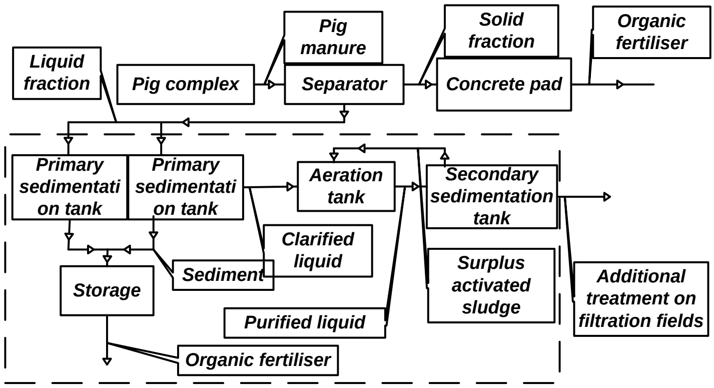

Figure 5. Technology for multi-stage processing of pig manure using batch sedimentation tanks (useful model patent of the Russian Federation No. 139469).

The objective function was the eco-economic index of nitrogen, which is the ratio between the economic benefit from the marketed yield increment and the costs of nutrients retention in the organic fertilizers applied to soil under the harvested crop yield:

$$K_{ЭЭ_N} = f(X1_i, X2_i, X3_i) = \frac{N_P}{K_{spvj} + E_{spvj}}, \tag{3}$$

$X1_i$ – redistribution of mass during *i-th* technological operation, t; $X2_i$ – redistribution of nitrogen during *i-th* technological operation, t; $X3_i$ – redistribution of phosphorus during *i-th* technological operation, t; N_P – net profit, thousand roubles; K_{spvj} – capital costs of nutrients retention under *j-th* technology, thousand roubles; E_{spvj} – operating costs of nutrients retention under *j-th* technology, thousand roubles.

$$N_P = C_n - C_{\text{в}} = f(X1_i) \tag{4}$$

C_n – cost of yield increment from the entire area, where organic fertilizers were applied, thousand roubles; $C_{\text{в}}$ – self-cost of yield increment owing to fertilizer application, thousand roubles.

$$K_{spvj} = \frac{\sum_{i-1}^{Kop}(Z_{si} + Z_{oi})}{M_{NP} - L_j} = f(X2_i, X3_i) \tag{5}$$

Kop – number of technological operations in the technology; i – index number of a technological operation; Z_{si} – total capital costs of facilities for *i-th* technological operation, thousand roubles; Z_{oi} – total capital costs of equipment and machines for *i-th* technological operation, thousand roubles; L_j – mass of nutrient loss per year under *j-th* technology, t.

$$E_{spvj} = \frac{E_{spvgj}}{M_{NP} - L_j} = f(X2_i, X3_i) \tag{6}$$

E_{spvgj} – operating costs of nutrients retention, thousand roubles.

$$X1_i = f(t_i, Q), Q\epsilon[50{,}300] \tag{7}$$

$$X2_i = f(t_i, N, Q), Q\epsilon[50{,}300], N\epsilon[2000{,}6000] \tag{8}$$

$$X3_i = f(t_i, P, Q), Q\epsilon[50,300], P\epsilon[500,1500] \quad (9)$$

t_i – time length of the *i-th* technological operation under: i = 1 – technological operation of primary sedimentation; i = 2 – technological operation of aeration with secondary sedimentation; i = 3 – technological operation of long term manure maturing.

Q – mass of daily output of the liquid fraction of pig manure, t; N – total nitrogen content in the liquid fraction of pig manure, mg kg^{-1}; P – total phosphorus content in the liquid fraction of pig manure, mg kg^{-1}.

RESULTS AND DISCUSSION

To obtain the indexes required for the criteria calculation the laboratory studies were conducted. The following technological operations were considered: primary sedimentation, aeration with secondary sedimentation, and long-term manure maturing. The obtained data were processed by the mathematical statistics method in the *STATGRAPHICS® CenturionXV* program. The study results of primary sedimentation and aeration are shown in Figs 6–11.

The primary sedimentation process was studied for 10 day period. It was found that the maximal volume of clarified liquid was formed during the seven days of primary sedimentation (Fig. 6), with the total nitrogen content in the sediment reaching 78% (Fig. 7) and total phosphorus content reaching 85% (Fig. 8).

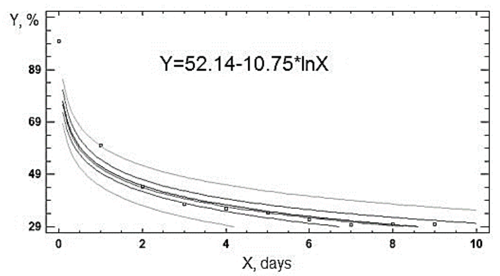

Figure 6. Ratio of sediment mass Y to liquid fraction mass depending on time X, %.

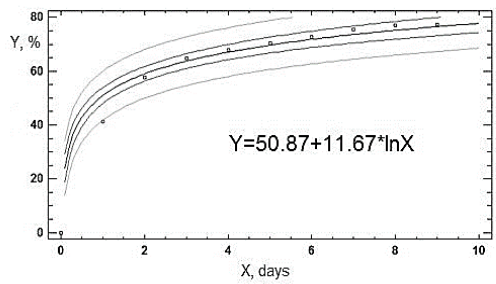

Figure 7. Total nitrogen in the sediment mass Y depending on time X, %.

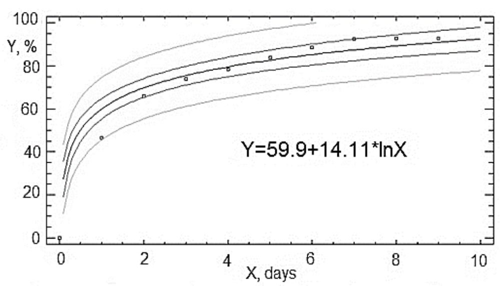

Figure 8. Total phosphorus in the sediment mass Y depending on time X, %.

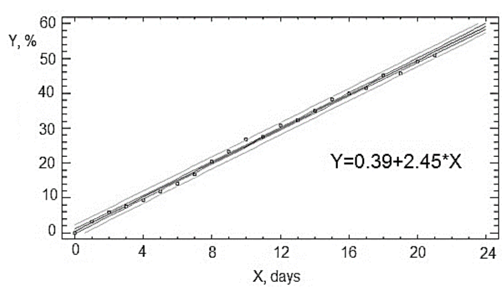

Figure 9. Ratio of loss of clarified liquid to activated sludge Y depending on time X, %.

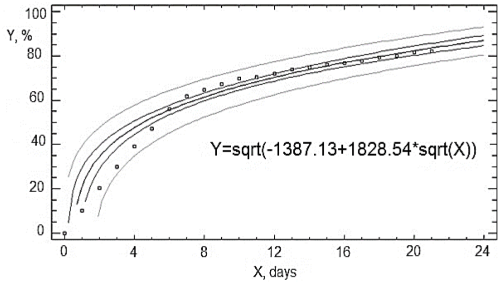

Figure 10. Share of total nitrogen in the liquid that is being purified (clarified liquid and activated sludge) Y depending on time X, %.

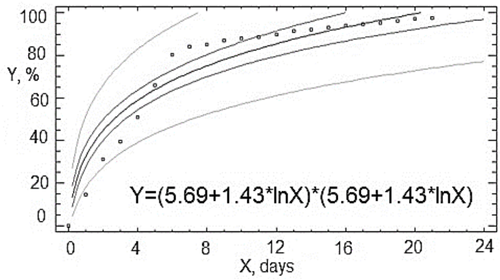

Figure 11. Share of total phosphorus in the liquid that is being purified (clarified liquid and activated sludge) Y depending on time X, %.

The aeration process was studied during 24 days period. 5 kg of activated sludge were placed in an aeration tank; the air supply was set at 30 l min^{-1} as measured by a rotameter. The air was supplied to the aeration tank according to performed calculations via the aeration system. It was found that 21 days were enough to achieve the minimal total nitrogen and total phosphorus content in the purified liquid.

Based on obtained theoretical and experimental data the coefficients were calculated, which were further used to create a mathematical model and an algorithm for selecting the proper technology of pig manure processing (Fig. 12).

The following six technologies were compared: 1) long term manure maturing in special facilities; 2) separation of manure into fractions with subsequent individual processing of solid and liquid fractions; 3) processing of pig manure in sedimentation tanks with stop logs and biological ponds; 4) processing of pig manure using flocculation and biological treatment facilities; 5) processing of pig manure using coagulators and biological treatment; 6) processing of pig manure using cyclic sedimentation tanks and biological treatment.

'Estimation of indicators with due account for farm conditions' block is used to assess the applicability of the technology in particular climatic zone, sufficient amount of arable land, etc.

'Calculation of indicators' block is used to calculate the criteria of technologies based on coefficients obtained from theoretical and experimental studies.

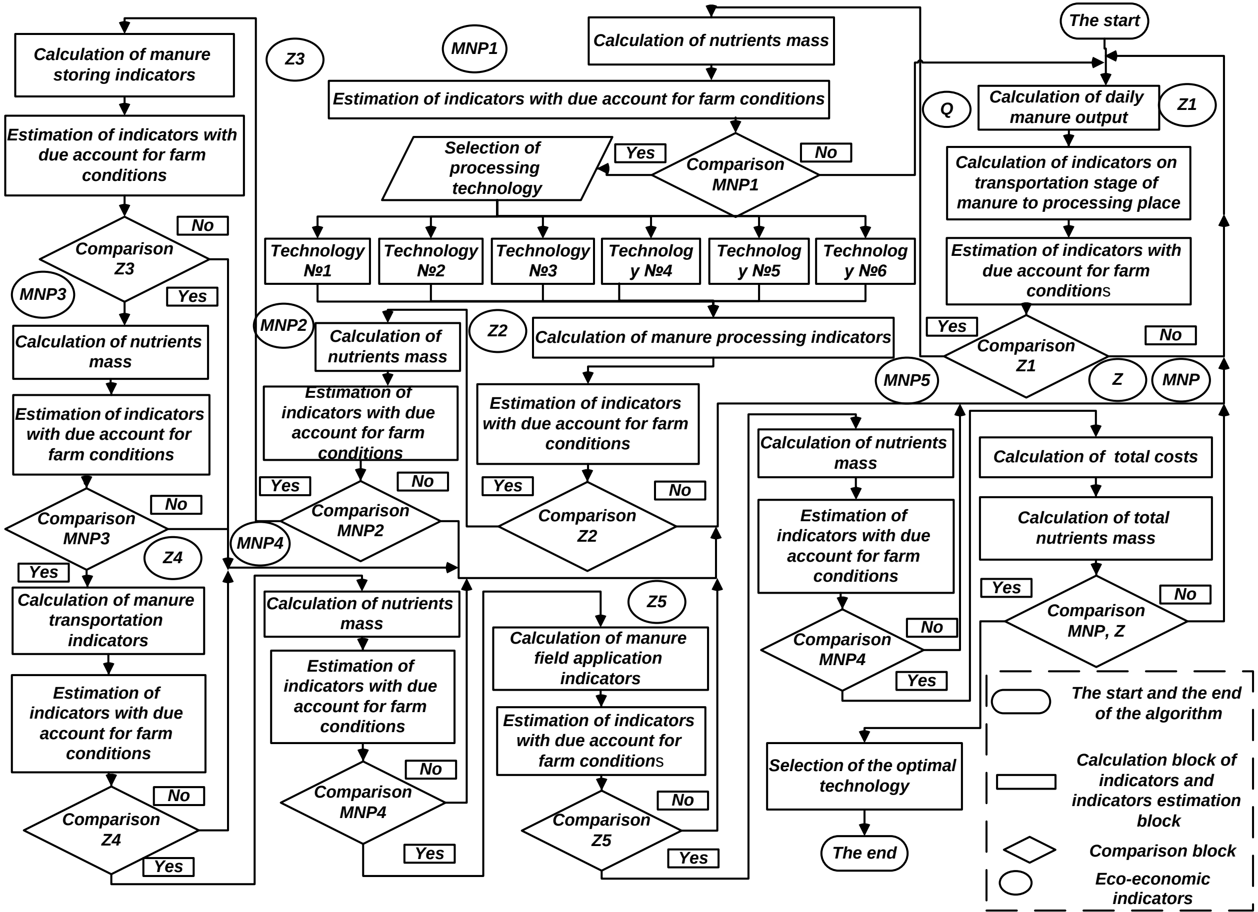

Figure 12. An algorithm to select the proper pig manure processing technology.

For automated selection of pig manure processing technology a web based computer program was created using PHP and MySQL (State Registration Certificate of Computer Program No. 2016611106; http://eco.sznii.ru/test/pigs1.html).

The designed algorithm was tested using the initial data from a pig complex in Leningrad Region with manure output of 150 t per day (with 93.4% moisture content) and no own farmland for organic fertilizer application. The compared technologies (No. 1–No. 6) were assessed for the conditions of this complex (Table 1, Table 2). The program selected the technology of pig manure processing using cyclic sedimentation tanks and biological treatment (No. 6). Currently the technology of long-term manure maturing in special facilities (No. 1) and subsequent application of liquid organic fertilizers on the fields rented from other farms is in place, with the transportation distance being up to 50 km.

Table 1. Comparison of pig manure processing technologies

Title/Number of technology	Units	Extremum direction	1	2	3	4	5	6
Economic criterion Z	thousand roubles t^{-1}	min	4.12	4.44	4.96	4.42	4.54	4.11
Ecological criterion M_{NP}	t	max	278.9	270.6	178.4	256.9	232	336.4

Table 2. Annual economic and ecological indicators

Indicator	Technology in place (No. 1)	Selected technology (No. 6)
Capital costs, thousand roubles	198,195	210,240
Specific capital costs, thousand roubles t^{-1}	3.63	3.84
Labour inputs, man – hour t^{-1}	6	1,8
Energy inputs, roubles per ton	10	96
Fuel inputs, thousand roubles per ton	0.11	0.08
Operating costs, thousand roubles	26,828	14,783
Specific operating costs, thousand roubles per ton	0.49	0.27
Ecological effect from improved soil fertility, roubles per ton	970	1,030
Reduced costs, thousand roubles per ton	4.12	4.11
Ecological indicator, t	278.9	336.4

The above values prove the eco-economic effectiveness of the technology of multi-stage processing of pig manure. It features lower operating costs, fuel and labour inputs as well as higher ecological effect owing to improved soil fertility.

The designed method for selection of pig manure processing technology was applied when rendering consulting services to above 10 pig rearing complexes in Kaliningrad, Leningrad, Kursk and Tver Regions. Recommended technologies were included in the on-farm document ‘Technological Regulations. Proprietary Standard for Manure Processing and Application’.

The obtained results are in line with the previous investigations (Arkhipchenko et al., 1987).

CONCLUSIONS

The result of presented study is the algorithm for selecting the best-suited technology of pig manure processing. The algorithm demonstrates that:

– in case the farm does not have its own land for application of produced organic fertiliser, the multi-stage processing is a feasible option of pig manure utilisation. Such technologies produce solid concentrated organic fertilizers (40–50% from the initial mass of manure) and clarified liquid (40–50% from the initial mass of manure), which can be discharged on filtration fields;
– in case the farm has sufficient amount of cultivated land, the long- term manure maturing is used.

The developed algorithm is formalized in a mathematical model, based on two criteria: economic and ecological (mass of retained nutrients in produced organic fertilizer). The model is implemented in a web based computer programme (using PHP and MySQL). Simulation results demonstrated 90% accurate choice of technology.

The designed model was tested for the conditions of a pig complex in Leningrad Region with the manure output of 150 t per day and no own farmland. The programme selected a pig manure processing technology using cyclic sedimentation tanks and biological treatment. As compared with the practice in place this technology demonstrated 1.8 times lower operating costs per one ton of produced organic fertilizer, 1.4 times lower fuel inputs and 3.3 times lower labour inputs. It also featured higher ecological safety coefficient. Estimated ecological and economic effect of introduction of this technology amounted to 5936 thousand roubles per year.

REFERENCES

State Statistics website: *http://www.gks.ru/* Accessed 17.11.2016

Afanassiev, V.N., Iskra, N.S. & Yablochkov, V.I. 1977. Economic assessment of manure processing and utilisation techniques. *Technologies, machines and equipment for mechanised production of plant and livestock products* **23**, 132–134 (in Russian).

Arkhipchenko, I.A., Belimov, A.A. & Vasiliev, V.B. 1987. Balance of nitrogen, phosphorus and potassium in aerobic processing of pig fattening waste. *Bulletin of the Russian Academy of Sciences of the USSR. Division of Biological Sceince*. **6**. 894–901 (in Russian).

Kaljuga, V., Kara, I., Nikolaev, S. & Bazykin, V. 2011. Stress free technology for low and medium capacity pig farms of peasant and farm husbandries. *Efficient and safe production processes in sustainable agriculture and forestry. XXXIV CIOSTA CIGR V Conference. University of Natural Resources and Applied Life Sciences.* 337–338.

Kovalev, S., Marchenko, N., Swendeman, S., Laquaglia, M. & Moll, U.M. 1998. Expression level, allelic origin, and mutation analysis of the p73 gene in neuroblastoma tumors and cell lines. *Cell Growth and Differentiation* **11**, 897–903.

Rabinovich, G.Yu., Fomicheva, N.V. & Kovalev, N.G. 2015. Selection of an effective stabilizer for the new liquid-phase biological product. *Journal of Agricultural Science* **7**(1), 72–77.

Salomon, E., Rodhe, L., Malgeryd, J., Lindgren, K. & Lindahl, C. 2012. Ammonia Losses from Outdoor Pig Fattening at Two Swedish Organic Farms. *The Open Agriculture Journal* **6**, 27–35.

Singh, P., Gamal, M., Bromley, D. & Ikehata, K. 2006. Alum settling and filtration treatment of liquid swine manure. *American Society of Agricultural and Biological Engineers* **49**(5), 1487−1494.

Selimbasic, V., Marić, S., Petric, I. & Djozic, A. 2012. Anaerobic batch fermentation of cattle manure. Effect of ammonia. *Journal of environmental protection and ecology* **13**(1), 211–218 pp.

Shalavina, E. 2015. Improvement of manure processing efficiency through optimisation of technological processes and by designing of farm-tailored technologies. *Dissertation in support of candidature for the scientific degree of Candidate of Sciences (Engineering).* SPBGAU, 152 pp. (in Russian)

Shalavina, E.V. & Briukhanov, A.Y. 2015. Mathematical model of multi-stage processing of the liquid fraction of pig manure. *Technologies, machines and equipment for mechanised production of plant and livestock products*. IEEP Publishers **86**, 103–112. (in Russian)

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The effect of different pre-crops on *Rhizoctonia solani* complex in potato

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Abstract. Rhizoctonia disease in potato is widely distributed in Estonia. Field experiments with cv. 'Red Fantasy' were undertaken with seven pre-crop treatments at the Estonian Research Institute of Agriculture in 2009 and 2010. Monocropped potato, spring barley, spring barley underseeded with red clover, spring wheat, grain pea, spring oil seed rape and oil seed radish were involved in the study as pre-crops. Growing conditions on both years were rather optimal for potato growth but year 2010 was drier at early bulking stage. The effect of different pre-crops on *Rhizoctonia solani* complex was studied (*i.e.* incidence and severity of stem and stolon canker and black scurf) at 15, 30, 45, 60, 90 and 120 days after planting. Results indicated that pathogen-free seed tubers are of primary importance in the disease control and no pre-crop was suppressive to disease if seed tubers had sufficient amount of inoculum. However, to achieve consistent reduction in disease development, inoculum-free seed tubers and crop rotation with non-host crops should be considered.

Key words: potato, stem canker, stolon canker, black scurf, chemical control, pre-crops.

INTRODUCTION

The disease complex incited by *Rhizoctonia solani* Kühn causes remarkable losses in potato due to reductions in both total and marketable yield across the world (Tsror, 2010). The causal organism was first described by German scientist Julius Kühn in 1858 and the fungus has remained one of the most important and widely distributed fungal pathogens in the crop production as well as it has proved to be a popular fungal test organism in the scientific studies during the last century (Ogoshi, 1996; Menzies, 1970). For long time, no clear distinction between *R. solani* Kühn isolates was used until advent of numbered anastomosis groups (AGs) in the 1960s (Parmeter et al., 1969). Nowadays, at least 13 AGs have been identified, among which AG1 through AG5 affect potato crop as pathogens (Carling et al., 2002). In temperate and cool climates main damage in potato is caused by AG 3 (Carling et al., 1986; Campion et al., 2003; Woodhall et al., 2007, Lehtonen et al., 2008).

In potato, *Rhizoctonia solani* Kühn causes stem and stolon canker and black scurf that have also been recognised as main symptoms and signs of the disease. Later, several other symptoms have been found, *e.g.* skin blemishes (necrosis, cracks), tuber malformations, shifts in tubers size distribution (Ahvenniemi et al., 2006b; Lehtonen, 2009; Buskila et al., 2011 and Muzhinji et al., 2014). A disease cycle for AG 3 of *R. solani* consists infection of sprouts and stolons by hyphae growing from sclerotia or mycelium on seed tubers or in soil (*i.e.* tuber- and soilborne infections, respectively), damage in young, juvenile tubers and production of sclerotia on progeny tubers (*i. e.* typical 'black scurf' sign). The causal organism has also sexual stage *Thanatephorus cucumeris* (Frank) Donk that can be seen as whitish mat at the base of above-ground stems near soil surface (*i.e.* 'white collar') (Cubeta & Vilgalys, 1997; Woodhall et al., 2008). The plants showing this sign have usually severe stem canker below ground (Carling et al., 1989). The host range of AG 3 is confined to *Solanaceae,* among which potato is exceptional due to being clonally propagated (Lehtonen, 2009). Seed tubers provide an excellent route for the fungus to disseminate from field to field, continentwide as well as between continents (Tsror, 2010).

Comparing the effect of tuber- *vs*. soilborne inoculum, both are etiologically important in the disease cycle (Frank & Leach, 1980; Tsror (Lahkim) & Peretz-Alon, 2005). Tuberborne inoculum is close to emerging sprouts and stolons, however, it can be destroyed by dressing seed tubers with effective fungicides or biocontrol agents (Hide & Cayley, 1982; Weinhold et al., 1982; Carling et al., 1989; Wicks et al., 1995; Bains et al., 2002). In contrast, soil-borne inoculum is unevenly distributed in the field soil and control strategies are more limited (Gilligan et al., 1996).

Classical methods for reduction soilborne inoculum and infections include crop rotations with non-hosts and/or disease-suppressive effects (Larkin & Honeycutt, 2006), fumigation, solarisation, sterilisation by steam *etc* (Agrios, 2005). Proper cropping sequences and rotation crops often provide the best and most cost-effective strategy in the disease management as other methods may be costly to use and applicable only on a small scale (*e.g*. greenhouses, seed beds, orchard sites). Intercropping has proved to be a valuable tool in order to control soilborne pathogens. The crucifers (*Brassicaceae*) are among the most effective plants since these crops contain glycosinolates which hydrolyse to release fungistatic or fungicidal isothiocyanates after incorporation into soil (*i.e.'biofumigation'*) (Kirkegaard, 2009). Anyhow, AG 3 of *R. solani* has poor survival without its potato host and population declines rapidly after decomposing host tissues and sclerotia (Lehtonen, 2009; Ritchie et al., 2013). The biological fitness of AG 3 is to produce as many sclerotia as possible on progeny tubers and disseminate by seed tubers (Woodhall et al., 2008; Lehtonen et al., 2009).

Several biocontrol agents (BCA) have been tested for control of *R. solani* (Brewer, Larkin, 2005). In Finland, *Trichoderma harzianum* clearly reduced incidence of black scurf on progeny tubers, but the best control effect was achieved by combining BCA and seed dressing with fungicide (Wilson et al., 2008). Yet, integration of all methods available for disease management provides better and more consistent control for the Rhizoctonia disease complex than using each control measure separately.

The objectives of the study was to examine the effect of different pre-crops on the incidence and severity of stem and stolon canker and black scurf in potato.

MATERIAL AND METHODS

Field experiments with potato cultivar 'Red Fantasy' were undertaken at the Estonian Research Institute of Agriculture in 2009 and 2010. 1-year potato crop was grown prior to planting seven pre-crops, *i.e.* potato, spring barley, spring barley underseeded with red clover, spring wheat, grain pea, spring oilseed rape and oil seed radish in 2008 and 2009. Seed tubers were chitted in a natural light at 15–20 °C for 3–4 weeks. A day before planting, seed tubers of grade 35–55 mm were treated with fludioxonil (commercial formulations Maxim 025 FS and 100 FS, Syngenta Crop Protection AG, Switzerland) by immersion at rate 185 and 500 ppm for 3 minutes to kill mycelium and sclerotia on tuber surface. Higher concentration (500 ppm) was used in 2010 since 185 ppm was too dilute to destroy larger sclerotia. Tubers were allowed to dry and planted by machine in 70-cm rows at 33-cm apart. Compound fertiliser Kemira Gropcare 8-11-23 (Kemira GrowHow, Finland) at rate $N_{75}P_{47}K_{178}$ was in-furrow applied by machine at planting. Weed control performed by ridging and harrowing in 2009 and Titus herbicide supplemented cultural practises in 2010. Plants were sprayed with fungicides up to seven times during growing seasons to protect them from foliar late blight including fungicides such as Ridomil Gold, Ranman and Shirlan. Haulms were flailed 10–12 days before the final sampling (120 days after planting (DAP)) in order to encourage skin set and production of sclerotia on progeny tubers.

Soil has been described in the previous study (Simson et al., 2016). In short, soil type was *Endogleyic Cambisol (eutric)* (Deckers et al., 2002) and texture was a loamy sand. Soil contained 2.5–3.0% organic matter and pH was 5.5.

Experimental years were relatively optimal for potato growth and the mean temperatures were similar. July 2010 was warmer and drier than July 2009 that mainly affected tuber size but both years were favourable for development of *R. solani* (Tabel 1).

Table 1. Meteorological data in the experimental years

Month	Temperatures, °C		Precipitation, mm	
	2009	2010	2009	2010
May	10.8	11.4	20	52
June	13.5	13.5	93	42
July	16.5	21.0	149	78
August	15.5	17.1	89	48
September	12.9	10.9	39	63

The trials had three replicates for all treatments and sampling times. The sampling unit included 2x2 plants in square from two middle adjacent rows. The plants were sampled for stem canker at 15, 30, 45, 60, 90, 120 DAP in 2009 and at 15, 30, 45, 60, 90 DAP in 2010. Stolon canker incidence and severity were assessed at 60, 90, 120 DAP in 2009 and at 60, 90 DAP in 2010. Black scurf infestation on progeny tubers was examined at 120 DAP in both years. For stem and stolon canker, Rhizoctonia stem and stolon lesion index (RSI) were calculated. To find out the RSI, each stem and stolon was assessed separately and placed in one of the following classes: 0, 1–5, 6–25, 26–37, 38–50, 51–75 and 76–100% of belowground stem surface area covered by lesions. The number of stems in each class was multiplied by the midpoint of the class and the sum of all values was divided by the total number of stems to give the RSI for each sampled plant

(Weinhold et al., 1982). The maximum RSI is 88 that is the midpoint of the class 76–100. At the final sampling, progeny tubers of sampled plants were recovered and washed with a brush to remove adhering soil and debris. Tubers were then allowed to dry before the further evaluation. In order to estimate black scurf infestation on progeny tubers, the assessment key for the amount of sclerotia of *R. solani* was used consisting of five classes: free, very lightly, lightly, moderately and heavily covered by sclerotia. By counting tubers in each severity class, black scurf index (BI) was calculated using the formula (Dijst, 1985). The maximum value is 100.

The Statistica version 11.0 (Statsoft Inc.) software package was used for all statistical analyses. Factorial analysis of variance (ANOVA) and one-way ANOVA were applied to test the results. The means are presented with their standard error. The level of statistical significance was set at $P < 0.05$, unless indicated otherwise.

RESULTS AND DISCUSSION

During the growing season, as a mean of all treatments, RSI_{stem} increased from 5.1 at 15 days after planting (DAP) to 23.8 at 90 DAP in 2009. The RSI_{stem} varied from 0.3 at 15 DAP to 11.3 at 90 DAP in 2010 (Fig. 1). Stolon lesions were first assessed at 60 DAP when the RSI_{stolon} was 13.4 in 2009 and 1.1 in 2010 (Fig. 2). At 90 DAP stolon damage was 8.4 in 2009 and 0.9 in 2010. At the final sampling (120 DAP), RSI_{stolon} reached 9.4 in 2009. In 2010, the last evaluation was omitted due to earlier senescense of stems that made it impossible to score disease severity properly.

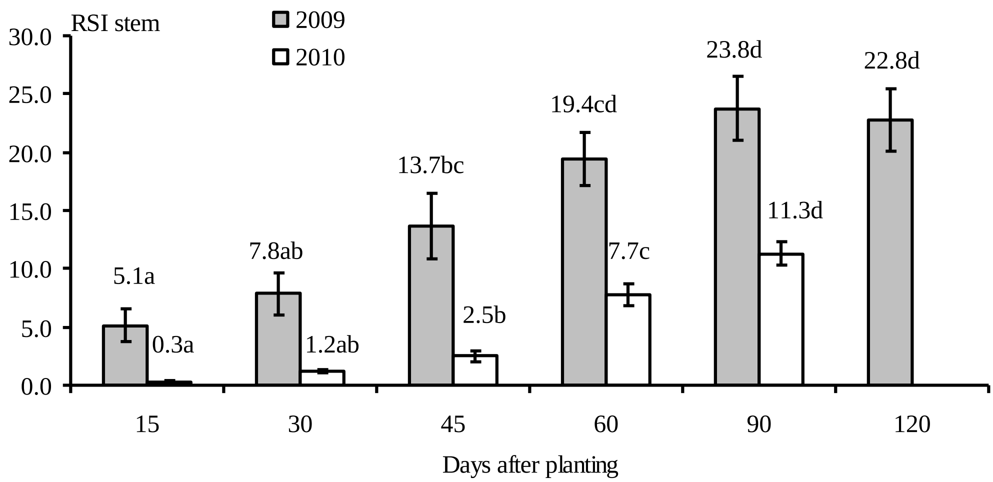

Figure 1. Disease development in belowground portions of the stems measured as RSI_{stem} as mean of the pre-crops. Vertical bars denote 0.95 standard error. Different letters indicate significant differences ($P < 0.05$) between days after planting.

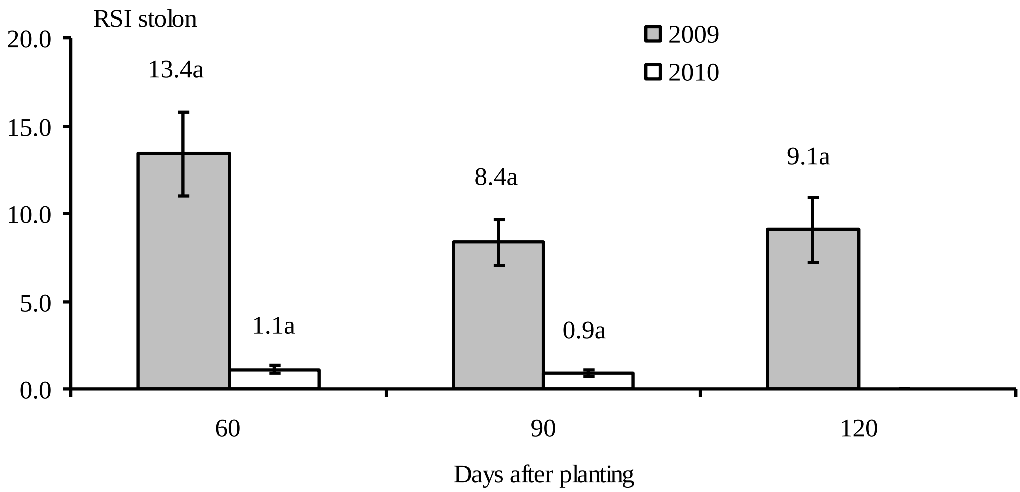

Figure 2. Disease development in stolons measured as RSI_{stolon} as mean of the treatments. Vertical bars denote 0.95 standard error. Different letters indicate significant differences ($P < 0.05$) between days after planting.

The effect of different pre-crops was as follows. In 2009, the lowest RSI_{stem} was recorded in the potato plot after spring wheat pre-crop (12.9) and the highest one in barley with underseeded red clover treatment (18.7). There were no statistically significant differences among treatments. In 2010, RSI scores were lower. Mean RSI stem was 2.6 after spring wheat and 6.1 after barley with underseeded red clover. Stolon damage based RSI_{stolon} was rated 7.3 for pea plot and 15.2 on barley plot in 2009. In 2010, lowest severity was encountered in potato pre-crop plot (0.1) and the highest one in pea plot (2.0).

Table 2. The effect of different pre-crops on stem canker (RSI_{stem}) and stolon canker (RSI_{stolon})

Pre-crop	RSI_{stem}		RSI_{stolon}	
	2009	2010	2009	2010
Potato	15.1 ± 2.3a*	3.0 ± 0.6a	8.0 ± 2.2a	0.1 ± 0.0a
Barley	15.8 ± 2.8a	3.9 ± 0.8ab	15.2 ± 4.1a	0.2 ± 0.1a
Barley us red clover	18.7 ± 3.0a	6.1 ± 1.2b	12.6 ± 3.2a	2.0 ± 0.6b
Spring wheat	12.9 ± 2.4a	2.6 ± 0.6a	11.3 ± 2.7a	0.5 ± 0.3a
Spring rape	14.0 ± 2.6a	3.5 ± 0.8a	9.8 ± 2.9a	0.3 ± 0.1a
Pea	16.5 ± 3.1a	3.7 ± 0.8a	7.3 ± 2.7a	0.8 ± 0.3a
Oil seed radish	15.0 ± 2.3a	4.2 ± 0.9ab	7.6 ± 2.1a	0.7 ± 0.2a

Note. Within the same column, values with different letters are significantly different (ANOVA, Fisher LSD test); * – ± denote the standard error.

Black scurf index (BI) was 0.8 in potato plot and 15.5 in barley plot (Fig. 3). In other treatments, BI varied from 5.4 to 12.9 in 2009. The progeny tubers infested with sclerotia were found on 4–9 of 12 sampled plants in 2009 (data not shown). In 2010, BI reached 3.7 in potato plot. In addition, 7 out of 12 plants had the progeny tubers with sclerotia in this treatment (data not shown). In other plots, BI was 1.3 in barley with underseeded red clover pre-crop and 2.2 for pea pre-crop plot. No black scurf infestation was found on tubers from the plots after spring barley, spring wheat, spring oilseed rape and oil seed radish in 2010.

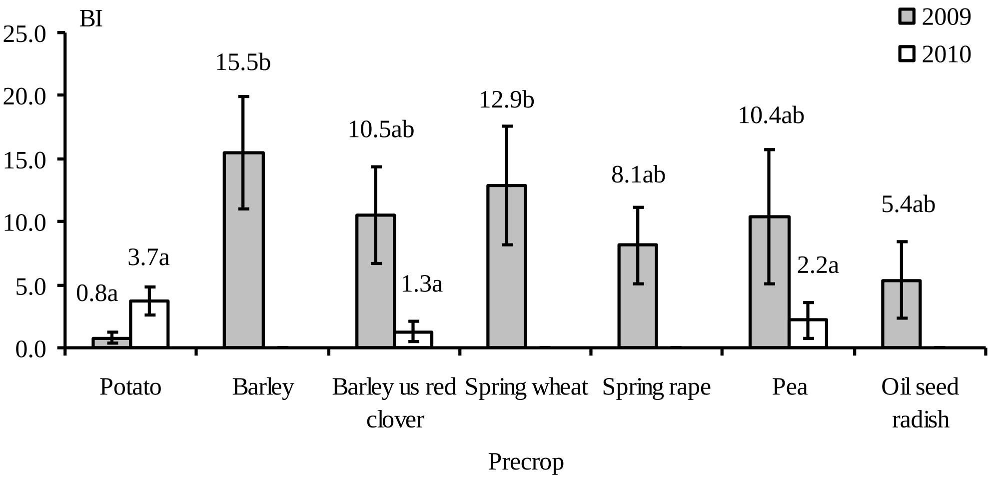

Figure 3. The effect of different pre-crops on black scurf infestation of the progeny tubers measured as BI. Vertical bars denote 0.95 standard error. Different letters indicate significant differences ($P < 0.05$) between pre-crops.

The results obtained in the study were consistent with voluminous data gathered from many experiments across the world. Tuberborne inoculum was recognised more important in causing all symptoms and signs in the present experiments since disease progression began early after planting and it was visible as stem and stolon damage. It allows to suppose that such infections were caused by tuberborne rather than by soilborne inoculum. The higher RSI_{stem}, the higher RSI_{stolon} was. If diseased plants had severe stem and stolon canker, the progeny tubers had also considerable level of black scurf. As confirmed by Hide & Cayley (1982), plants grown from seed tubers infested by black scurf (*i. e.* sclerotia) had more stem canker, stolon damage, hymenium at base of the stems and more black scurf on progeny tubers than plants grown from uninfested seed tubers. There is also a close correlation between stem and stolon canker (Lootsma & Scholte, 1996; Weinhold et al., 1982). Likewise, planting sclerotia-infested seed tubers increased number of progeny tubers with black scurf (Banville,1989; Carling et al., 1989; Brierley et al., 2016). These findings suggest that there might be links between all phases in the disease cycle but the correlations and relative importance of each phase can vary with different infestation level of seed tubers and cropping practises. Soilborne inoculum is also relevant in the disease cycle but its role is less remarkable when proper crop rotations are used and break crops between potatoes are grown. The effect of rotation crops on Rhizoctonia disease was small. In general, the influence of crop rotation on the disease ensues from period between two consecutive potato crops, *i.e.* cropping frequency (Scholte, 1992). Since AG3 has higly specilized on potato and survival without potato host is limited (Lehtonen, 2009), growing non-host rotation crops normally provides sufficient level of control. When 2 years separate potato crops, the inoculum and infections coming from soil is considerably reduced (Gilligan et al., 1996; Ahvenniemi et al., 2006a; Ritchie et al., 2013). This time is needed for breakdown of host tissues and sclerotia of *R. solani* AG3. Tuberborne inoculum can be effectively reduced or eliminated by treating seed tubers with effective fungicide. Fludioxonil (Maxim 025 FS and Maxim 100 FS) used in this study has also been evaluated for control of Rhizoctonia disease in Canada where it proved to be an effective control agent for disease management (Bains et al., 2002). Fungicides applied for seed tuber treatment have an effect on reduction of initial stages of disease (mainly stem and stolon canker) but later these have no suppressive effect on disease development if soilborne inoculum is present (Wilson et al., 2008). Treated seed tubers can be used to evaluate soil inoculum and infections affecting potatoes but disease-free mini-tubers may be better choice. Non-host rotation crops do not usually become infected by potato isolates of *R. solani* (Bains et al., 2002) but leguminous pre-crops (clover and soybean) have sometimes increased disease incidence and severity in potato (Larkin & Honeycutt, 2006). In the latter case, crop debris may serve as nutritious substrate rich in nitrogen for the fungus. Because of patchy distribution of soil inoculum it it complicated to evaluate the influence of these propagules on Rhizoctonia disease. The sufficient soil inoculum load may be achieved by growing potatoes from infested seed tubers for more than 1 year and/or using artificial inoculation of test plots. The effect of soil inoculum is highest when amount of tuber inoculum is lowest, however, it is important to take into account total inoculum load from either source (Atkinson et al., 2010). Several biocontrol agents (BCA) have been tested for control of *R. solani* (Brewer, Larkin, 2005). In Finland, *Trichoderma harzianum* clearly reduced incidence of black scurf on progeny tubers, but the best control effect was achieved by combining BCA and seed dressing with fungicide (Wilson et al., 2008). Yet, integration of all methods available for disease management provides most reliable and consistent control for the Rhizoctonia disease complex.

CONCLUSION

Results demonstrated that it was difficult to quantify soilborne infections in potato caused by *Rhizoctonia solani* if tuberborne inoculum was not completely destroyed. In 2009, fungicide solution was too dilute to kill all the sclerotia, and even in case of 500 ppm fludioxonil in 2010, laboratory test confirmed that the largest sclerotia survived and these might able to cause infections in potato crop. In this study, the influence of soilborne inoculum and infections might be confounded by tuber inoculum, however, its effect seemed to be small. Planting different non-host rotation crops (or break crops) could not reduce disease incidence and severity if tuberborne inoculum was not effectively controlled. The effective management of Rhizoctonia disease should be based on planting inoculum-free seed tubers and application cropping sequences with non-hosts.

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REFERENCES

Agrios, G.N. 2005. *Plant Pathology.* 5th edition. Elsevier Academic Press. 922 pp.

Ahvenniemi, P., Wilson, P., Lehtonen, M. & Valkonen, J. 2006a. *Perunaseitin torjuntaohjeet.* 8s. TP 4/2006 Liite (in Finnish).

Ahvenniemi, P., Wilson, P., Lehtonen, M. & Valkonen, J. 2006b. *Perunaseitin etiologia ja tehostettu torjunta*. Loppuraportti. Helsinki, 51 s. (in Finnish).

Atkinson, D., Thorton, M.K. & Miller, J.S. 2010. Development of *Rhizoctonia solani* on stems, stolons and tubers of potatoes I. Effect of inoculum source. *American Journal of Potato Research* **87**, 374–281.

Bains, P.S., Bennypaul, H.S., Lynch, D.R., Kawchuk, L.M. & Schaupmeyer, C.A. 2002. Rhizoctonia disease of potatoes (*Rhizoctonia solani)*: fungicidal efficacy and cultivar susceptibility. *American Journal of Potato Reseach* **79**, 99–106.

Banville, G.J. 1989. Yield losses and damage to potato plants caused by *Rhizoctonia solani* Kühn. *American Potato Journal* **66**, 821–834.

Brewer, M.T. & Larkin, R.P. 2005. Efficacy of several potential biocontrol organisms against *Rhizoctonia solani* on potato. *Crop Protection* **24**, 939–950.

Brierley, J.L., Hilton, A.J., Wale, S.J., Woodhall, J.W. & Lees, A.K. 2016. The relative importance of seed- and soil-borne inoculum of *Rhizoctonia solani* AG-3 in causing black scurf on potato. *Potato Research* **59**(2), 181–193.

Buskila, Y., Tsror (Lahkim), L., Sharon, M., Teper-Bamnolker, P., Holczer-Erlich, O., Warshavsky, S., Ginzberg, I., Burdman, S. & Eshel, D. 2011. Postharvest dark skin spots in potato tubers are an oversuberization response to *Rhizoctonia solani* infection. *Phytopathology* **101**, 436–444.

Campion, C., Chatot, C., Perraton, B. & Andrivon, D. 2003. Anastomosis groups, pathogenicity and sensitivity to fungicides of *Rhizoctonia solani* isolates collected on potato crops in France. *European Journal of Plant Pathology* **109**, 983–992.

Carling, D.E. & Leiner, R.H. 1986. Isolation and characterization of *Rhizoctonia solani* and binucleate *R. solani*-like fungi from aerial stems and subterranean organs of potato plants. *Phytopathology* **76**, 725–729.

Carling, D.E., Leiner, R.H. & Westphale, P.C. 1989. Symptoms, signs and yield reduction associated with Rhizoctonia disease of potato induced by tuberborne inoculum of *Rhizoctonia solani* AG-3. *American Potato Journal* **66**, 693–701.

Carling, D.E., Baird, R.E., Gitaitis, R.D., Brainard, K.A. & Kuninaga, S. 2002. Characterization of AG-13, a newly reported anastomosis group of *Rhizoctonia solani*. *Phytopathology* **92**, 893–899.

Cubeta, M.A. & Vilgalys, R. 1997. Population biology of the *Rhizoctonia solani* complex. *Phytopathology* **87**(4), 480–484.

Deckers, J.A., Driessen, P., Nachtergaele, F.O.F. & Spaarggaren, O. 2002. World reference base for soil resources in a nutshell. In: 'Soil Classification 2001'. (Eds. E. Micheli, F.O. Nachtergaele, R.J.A. Jones & Montanarella, L), *European Soil Bureau Research Report No. 7*, EUR 20398 EN, pp. 173–181.

Dijst, G. 1985. Investigations on the effect of haulm destruction and additional root cutting on black scurf on potato tubers. *Netherlands Journal of Plant Pathology* **91**, 153–162.

Frank, J.A. & Leach, S.S. 1980. Comparison of tuberborne and soilborne inoculum in the Rhizoctonia disease of potato. *Phytopathology* **70**, 51–53.

Gilligan, C.A., Simons, S.A. & Hide, G.A. 1996. Inoculum density and spatial pattern of *Rhizoctonia solani* in field plots of *Solanum tuberosum*: effects of cropping frequency. *Plant Pathology* **45**, 232–244.

Hide, G.A. & Cayley, G.R. 1982. Chemical techniques for control of stem canker and black scurf (*Rhizoctonia solani*) disease of potatoes. *Annals of Applied Biology* **100**, 105–116.

Kirkegaard, J. 2009. Biofumigation for plant disease control – from the fundamentals to the farming system. In Walters, D. (ed.): *Disease Control in Crops. Biological and Environmentally Friendly Approaches.* Wiley-Blackwell, pp. 172–195.

Larkin, R.P. & Honeycutt, C.W. 2006. Effects of different 3-year cropping systems on soil microbial communities and Rhizoctonia diseases of potato. *Phytopathology* **96**, 68–79.

Lehtonen, M.J. 2009. Rhizoctonia solani as a potato pathogen–variation of isolates in Finland and host response. Academic dissertation in plant pathology. University of Helsinki.

Lehtonen, M.J., Ahvenniemi, P., Wilson, P.S., German-Kinnari, M.& Valkonen, J.P.T. 2008. Biological diversity of *Rhizoctonia solani* (AG-3) in a northern potato-cultivation environment in Finland. *Plant Pathology* **57**, 141–151.

Lehtonen, M.J., Wilson, P.S., Ahvenniemi, P. & Valkonen, J.P.T. 2009. Formation of canker lesions on stems and black scurf on tubers in experimentally inoculated potato plants by isolates of AG 2-1, AG 3 and AG 5 of *Rhizoctonia solani*: a pilot study and literature review. *Agricultural and Food Science* **18**, 223–233.

Lootsma, M. & Scholte, K. 1996. Effects of soil disinfection and potato harvesting methods on stem infection by *Rhizoctonia solani* Kühn in the following year. *Potato Research* **39**(1), 15–22.

Menzies, J.D. 1970. Introduction – the first century of Rhizoctonia solani. In: ‘Rhizoctonia solani, Biology and Pathology’. (Ed. J.R. Parmeter), University of California Press, pp. 3–5.

Muzhinji, N., Woodhall, J.W., Truter, M. & Van der Waals, J.E. 2014. Elephant hide and growth cracking on potato tubers caused by *Rhizoctonia solani* AG 3-PT in South Africa. *Plant Disease* **98**(4), 570.

Ogoshi, A. 1996. Introduction – the genus Rhizoctonia. In: ‘Rhizoctonia species: Taxonomy, Molecular Biology, Ecology, Pathology and Disease Control’ (Eds. B. Sneh, S. Jajabi-Hare, S. Neate. & G. Dijst), Boston: Kluwer Academic Publishers, pp. 1–9.

Parmeter, J.R., Sherwood, R.T. & Platt, W.D. 1969. Anastomosis grouping among isolates of *Thanatephorus cucumeris*. *Phytopathology* **59**, 1270–1278.

Ritchie, F., Bain, R. & Mcquilken, M. 2013. Survival of sclerotia of Rhizoctonia solani AG 3 PT and effect of soil-borne inoculum density on disease development on potato. *Journal of Phytopathology* **161**(3), 180–189.

Scholte, K. 1992. Effect of crop rotation on the incidence of soil-borne fungal diseases of potato. *Netherlands Journal of Plant Pathology* **98**(2), 93–101.

Tsror (Lahkim), L. & Peretz-Alon, I. 2005. The influence of the inoculum source of *Rhizoctonia solani* on development of black scurf on potato. *Journal of Phytopathology* **153**, 240–244.

Tsror, L. 2010. Biology, epidemiology and management of *Rhizoctonia solani* on potato. *Journal of Phytopathology* **158**, 649–658.

Weinhold, A.R., Bowman, T. & Hall, D.H. 1982. Rhizoctonia disease of potato: effect on yield and control by seed tuber treatment. *Plant Disease* **66**(9), 815–818.

Wicks, T.J., Morgan, B. & Hall, B. 1995. Chemical and biological control of *Rhizoctonia solani* on potato seed tubers. *Australian Journal of Experimental Agriculture* **35**(5), 661–664.

Wilson, P.S., Ahvenniemi, P.M., Lehtonen, M.J., Kukkonen, M., Rita, H. & Valkonen, J.P.T. 2008. Biological and chemical control and their combined use to control different stages of the Rhizoctonia disease complex on potato through the growing season. *Annals of Applied Biology* **153**(3), 307–320.

Woodhall, J.W., Lees, A.K., Edwards, S.G. & Jenkinson, P. 2007. Characterization of *Rhizoctonia solani* from potato in Great Britain. *Plant Pathology* **56**, 286–295.

Woodhall, J.W., Lees, A.K., Edwards, S.G. & Jenkinson, P. 2008. Infection of potato by *Rhizoctonia solani*: effect of anastomosis group. *Plant Pathology* **57**, 897–905.

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Determining the dimensional characteristics of blueberries

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Abstract. The smoothly adjustable belt drums of belt sorters can be used in the processing of harvested blueberries. Previous tests with the smoothly-adjustable belt drums of belt sorters indicates the fact that further improvements are required to increase their sorting efficiency and uniformity. For this, the relationship between the dimensional characteristics of blueberries needs to be studied. The aim of this study is to determine connections between the dimensional characteristics of blueberries. To fulfil this aim, the length, diameter, mass, and volume are measured in an experimental group of blueberries. Based on these measuring results, mathematical equations are compiled in order to describe the connections between the dimensional characteristics of blueberries. The mathematical equations obtained are tested with a control group of blueberries. The results show that the volume of blueberries can most accurately be estimated by using a mathematical equation which takes into account the mass of blueberries. The mass of blueberries can most accurately be estimated with a mathematical equation which takes into account the diameter and length of the blueberries. Based on the results obtained, we can conclude that blueberry dimensional characteristics are linked and that these links can be used for various purposes.

Key words: 3D reconstruction, belt, modeling, shape description, sorters, volume measuring.

INTRODUCTION

Growing blueberries for harvesting originated in North America, but these days such a valuable berry is also being grown in South America, Asia, New Zealand, Australia, Africa, and Europe (Strik, 2005). Increasing blueberry cultivation will lead us into situation in which productive harvesting methods like machine harvesting or harvesting with a berry rake needs to be adopted to harvest blueberries at the right time and avoid any spoilage (Forney, 2009; Eum et al., 2013). The harvested berry mixture needs to be processed. According to Soots & Olt (in press), the post-harvesting processing of blueberries can be conducted with a non-stationary processing centre, which follows the principle scheme of post-harvesting processing given in Soots et al. (2014). One part of the processing work is fractioning, which is something that can be done using video grading sorting, roll sorting, net sorting, line sorting, drum sorting and belt sorting (Recce et al., 1998; Grote & Feldhusen, 2007; Kondo, 2009; Cubero et al., 2014; Soots et al., 2014; Soots & Olt, in press). It can be said that a suitable fractioning solution for small or medium size blueberry growers is the belt sorter, thanks to its simple construction and therefore its lower price. Belt sorters permit blueberries to be sorted according to their geometrical dimensions. For example, blueberries with a diameter above 8 mm would be separated for food stores (Starast et al., 2005). A belt sorter should be adjustable in order to ensure that it can be used with different blueberry cultivars (Soots & Olt, in press).

The development of a smoothly-adjustable belt drum on a belt sorter is a problem area that is solved with two patented technical solutions which have been developed by the scientist of the Estonian University of Life Sciences (Patent EE05642 (B1); Patent Application EE201400049 (A)). Test results for both patented smoothly adjustable belt drums given in Soots et al. (2016) and Soots & Olt (2017) indicate the fact that both patented solutions need further improvement that is common in the product development process (Ulrich & Eppinger, 2015) and fractioning tests showed that the fractionating accuracy of a belt sorter with a smoothly adjustable belt drum does not meet the requirements (Soots et al., 2014; Soots & Olt, 2017). The biggest problem in this area was the purity of fractioning when it came to large berries (Soots & Olt, 2017).

In order to further improve belt sorters and adjustable belt drums, the connection between the dimensional characteristics of blueberries must be understood. Previous research has shown that the antioxidant activity of blueberries can be estimated when measuring blueberry mass and/or diameter (Remberg et al., 2006) but the relationship between geometrical dimensions and the mass or volume of blueberries is under-investigated. On one hand, knowing these relationships enables the mass and volume of blueberries to be predict in every fraction which is separated by the belt sorter and, on the other hand, it allows for the belt sorter being adjusted while taking into account the desired mass or volume of the blueberries in a certain fraction. For example, when we want to separate blueberries with a mass greater than 2 g from other blueberries, we can adjust the distance between the belts on the belt sorter, knowing the relationship between the mass of blueberries and their geometrical dimensions.

The aim of this study was to determine connections between the dimensional characteristics of blueberries. To fulfil the given aim the following tasks need to be solved:

1. Measure the mass of the experimental group of blueberries, along with geometrical dimensions and volume.
2. Determine the connection between the measured dimensional characteristics of the blueberries.
3. Compile a mathematical equation for blueberry volume, which takes into account their mass.
4. Compile a mathematical equation for blueberry mass, which takes into account their geometrical dimensions.
5. Compile a mathematical equation for blueberry volume, which takes into account their geometrical dimensions.
6. Determine the accuracy of the compiled mathematical equations with a control group of blueberries.

MATERIALS AND METHODS

Blueberries

In this study, fresh highbush blueberries (*Vaccinium corymbosum*) from Peru were used, having been purchased at a grocery store, along with frozen European blueberries (*Vaccinium myrtillus*) which were harvested in Estonia in the summer of 2016. A total of 72 randomly-chosen blueberries were used and these were divided into two groups. A total of 51 blueberries were in the experimental group and 21 were in the control group.

Measuring geometrical dimensions

The diameter and length of each blueberry was measured using a Mitutoyo Absolut AOS Digimatic Caliper (Code No. 500-161-30) with an accuracy of ± 0.02 mm (Mitutoyo, 2017). The diameter of each blueberry was measured twice so that the measuring points were perpendicular to each other.

Measuring mass

The mass of the blueberries was measured with a Mettler Toledo ME204 analytical scale with a maximum sample capacity of 220 g, a minimum sample mass (USP, typical) of 0.16 g, a repeatability of 0.1 mg (test mass 200 g) and a readability of 0.1 mg according to Mettler Toledo (2017).

Measuring volume with the displacement method

The volume of blueberries was measured using the displacement method with water (hereinafter referred to as the D Method). When the blueberry length and diameter were smaller than 10 mm, a 10 mLbeaker with a graduation of 0.1 mLwas used. If at least one dimension of a blueberry was bigger than 10 mm, then a 25 mLbeaker with a graduation of 0.5 mLwas used.

Measuring volume with a laser scanner

Nowadays coordinated metrology methods such as coordinated measuring machines, optical measuring systems, and computed tomography can be used to create 3D models of horticultural products or to measure their dimensions and volume (Carmignato & Savio, 2011; Rogge et al., 2015; Zhang et al., 2015; Marinello et al., 2016). In this study blueberry volume was also measured with a laser scanner (hereinafter referred to as the LS Method) in addition to the D Method. For this, a Nikon measuring arm MCAx20 combined with a laser scanner MMDx50 was used. The accuracy of this laser scanning system was 50 μm according to Nikon Metrology NV (2017). The scanned measurement points for blueberries were processed using Nikon Focus software and obtained 3D blueberry models were saved in the stereolithographic (STL) format. Final repairing and volume calculations for 3D blueberry models were conducted using Spaceclaim software. Due to the lack of information about the uncertainty surrounding the volume measurements which were obtained with coordinated measuring machines, in this study the volume accuracy of the 3D blueberry model was taken as 50 μm^3 (Bills et al., 2007; Carmignato & Savio, 2011).

Calculations and statistical analysis

On the basis of the experimental group's blueberry measurements for diameter, length, mass, and volume, the connections between the dimensional characteristics of blueberries were determined and described using mathematical equations. To aid visualization, graphs with the obtained mathematical equations and their trend lines were constructed in MS Excel, with the R^2 value being added to show how close the data can be to the expected trend line (Laaneots & Mathiesen, 2011). In order to analyse the accuracy of the obtained mathematical equations, the same measurements were conducted with the control group. Then the same dimensional characteristics for blueberries in the control group were also estimated on the basis of their other dimensional characteristics using mathematical equations which were obtained previously from the experimental group. The calculated control group data points were included on the aforementioned graphs. Then the calculated dimensional characteristics of the control group blueberries *y* were subtracted from their measured values *z* and the results obtained were referred to as the difference *x* in this study. The accuracy of the dimensional characteristic mathematical equations for blueberries were determined on the basis of the size differences with MS Excel. The average value $\overline{x}$ for the difference x was calculated with the Eq. (1) as follows (Kirkup, 1994; Laaneots & Mathiesen, 2011):

$$\overline{x} = \frac{1}{n}\sum_{i=1}^{n} x_i, \qquad (1)$$

where *n* is the number of parallel measurements.

The experimental standard deviation $s(x)$ was calculated with the Eq. (2) as follows (Kirkup, 1994; Laaneots & Mathiesen, 2011):

$$s(x) = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2}. \qquad (2)$$

The experimental standard deviation in the mean $s(\overline{x})$ can be taken as being equal to the type A evaluation of uncertainty $u_A(\overline{x})$ and was calculated using the Eq. (3) as follows (Kirkup, 1994; Laaneots & Mathiesen, 2011):

$$u_A(\overline{x}) = s(\overline{x}) = \frac{s(x)}{\sqrt{n}}. \qquad (3)$$

The uncertainty of the measurement devices used, u_B were calculated using the Eq. (4) as follows (*p* = 95%) (Kirkup, 1994; Laaneots & Mathiesen, 2011):

$$u_B = \frac{1.65\Delta_x}{\sqrt{3}}, \qquad (4)$$

where Δ_x is the absolute error of the measurement device.

The mathematical equations for blueberries dimensional characteristic can be expressed as the measurement function (5) as follows (Kirkup, 1994; Laaneots & Mathiesen, 2011):

$$Y = f(Z_1, Z_2, \ldots, Z_n), \qquad (5)$$

where *Y* is the output value of the mathematical equation; *Z* – the direct measurement; f – the function of the direct measurements $Z_i (i = 1, 2 \ldots n)$.

The combined uncertainty $u(y)$ for the output value of the mathematical equation *Y*, can be expressed with the Eq. (6) as follows (Kirkup, 1994; Laaneots & Mathiesen, 2011):

$$u(y) = \sqrt{\left[\frac{\partial f(z_1,\ldots,z_n)}{\partial z_1} u(z_1)\right]^2 + \ldots + \left[\frac{\partial f(z_1,\ldots,z_n)}{\partial z_n} u(z_n)\right]^2}, \tag{6}$$

where *y* is the result of mathematical equation output value *Y*; z_i – measurement results of direct measurement Z, $u(z_i)$ – the combined uncertainty for the direct measurement *Z*; $\frac{\partial f(\ldots,z_i,\ldots)}{\partial z_i}$ – partial derivatives of function $f(\ldots, Z_i, \ldots)$ according to variable Z_i when $Z_i = z_i (i = 1 \ldots n)$.

The cumulative uncertainty u_c was calculated using the Eq. (7) as follows (Kirkup, 1994; Laaneots & Mathiesen, 2011):

$$u_C = \sqrt{u_A^2 + u_B^2}. \tag{7}$$

The expanded uncertainty *U* was calculated using the Eq. (8) as follows (Kirkup, 1994; Laaneots & Mathiesen, 2011):

$$U = k u_C, \tag{8}$$

where *k* is coverage factor.

The coverage factor *k* was calculated with the function CONFIDENCE.T in Microsoft Excel and in this study *k* = 2.09 when the confidence level was 95% and *n* = 21.

The accuracy of measurements E_x was calculated using the Eq. (9) as follows (Kirkup, 1994; Laaneots & Mathiesen, 2011):

$$E_x = \frac{u_C}{\overline{x}}. \tag{9}$$

The smaller the value of E_x, the more accurate was measurement.

RESULTS AND DISCUSSION

In this study, the dimensional characteristics of blueberries in the experimental group and in the control group remained within ranges given in Table 1.

Table 1. The range of dimensional characteristics for blueberries

Dimensional characteristic	Minimum value	Maximum value
Mass	0.14 g	3.4 g
Volume obtained with D Method	0.2 mL	3.9 mL
Volume obtained with LS Method	0.13 mL	3.6 mL
Length	6.05 mm	15.68 mm
Diameter	6.2 mm	20.8 mm

The minimum mass of blueberries given in Table 1 is common for European blueberries (*Vaccinium myrtillus*) and for the lowbush blueberry (*Vaccinium angustifolium*) (Starast et al., 2007), but the maximum mass is rather common for the half-highbush blueberry (*Vaccinium corymbosum* × *Vaccinium angustifolium*) (Starast et al., 2007) and for the highbush blueberry (*Vaccinium corymbosum*) (Remberg et al., 2006). A similar difference between blueberry species and varieties applies when their diameters are studied (Starast et al., 2007), along with their volumes (Correia et al., 2016). The picture of a real blueberry fruit and the 3D model of a blueberry are shown in Fig. 1.

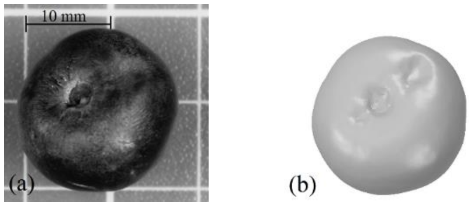

Figure 1. Real blueberry (a) and 3D model of a blueberry (b).

The following Figs 2–5 indicate the mathematical equations for the different dimensional characteristics of blueberries with their trend lines and also the data points for the control group of blueberries.

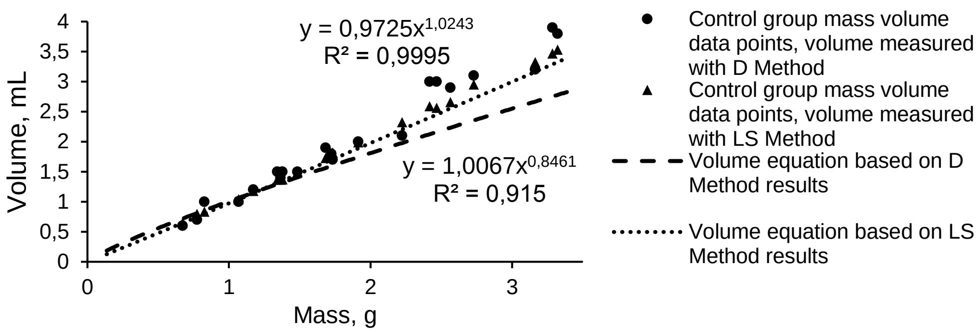

Figure 2. Mass/volume graph for blueberry volume that take into account the blueberry mass and the control group data points.

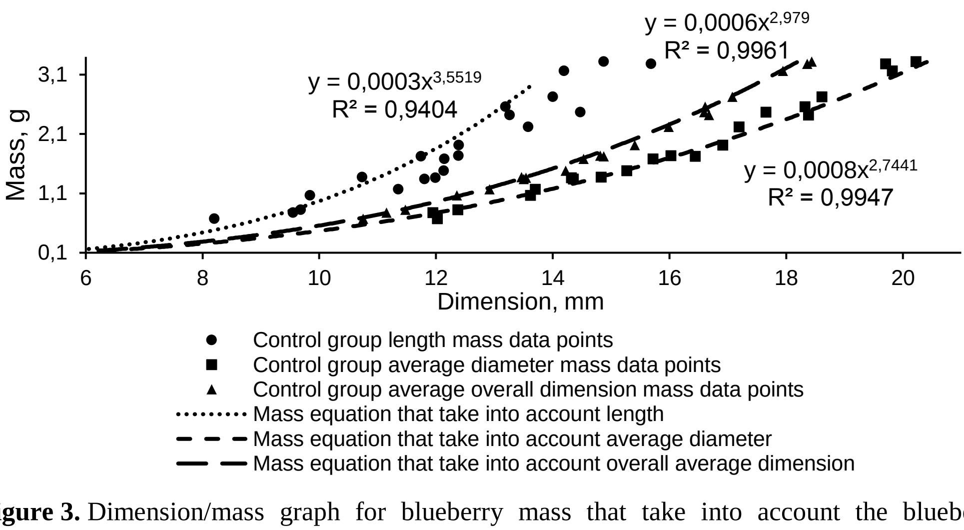

Figure 3. Dimension/mass graph for blueberry mass that take into account the blueberry dimensions and the control group data points.

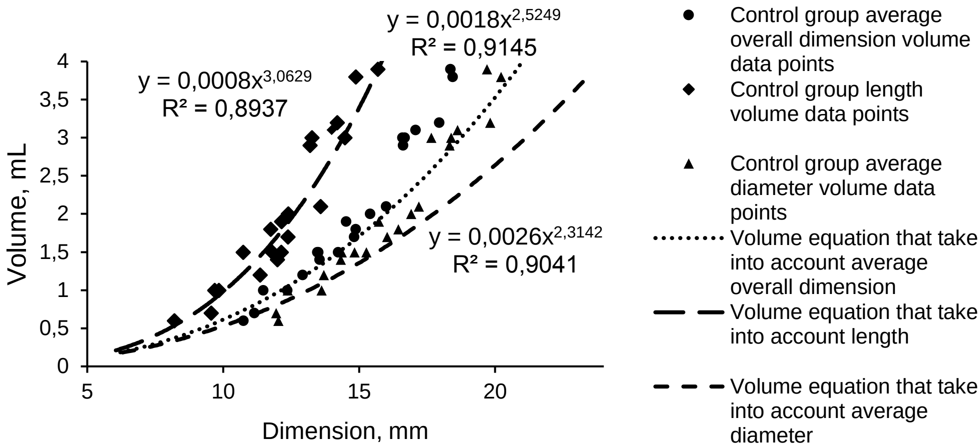

Figure 4. Dimension/volume graph for blueberry volume that take into account the blueberry dimensions and the control group, blueberry volume being measured using the D Method.

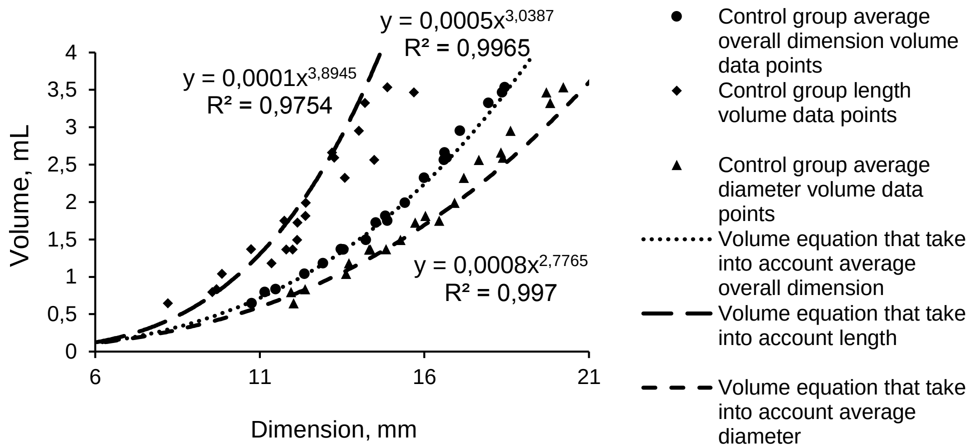

Figure 5. Dimension/volume graph for blueberry volume that take into account the blueberry dimensions and the control group data points, blueberry volume measured using the LS Method.

The accuracy of the mathematical equations obtained, which describe the relationship between the dimensional characteristics of blueberries, is shown in Table 2.

The mathematical equation for blueberry volume which takes into account blueberry mass or dimensions was more accurate when they were based on the volume measured with the LS Method due to the better accuracy of the laser scanning system used for this process. The most accurate results for blueberry volume were obtained with a mathematical equation which takes into account blueberry mass and when the mathematical equation itself was based on blueberry volume as measured with the LS Method. Blueberry volume can also be estimated using mathematical equations which take into account blueberry dimensions, but the accuracy of these mathematical equations was smaller. In this case, the most accurate results were obtained when using the mathematical equation which was based on the blueberry volume as measured with the LS Method and which takes into account the average diameter of the blueberries. Taking into account the overall average dimensions of blueberries failed to increase the accuracy of the blueberry volume mathematical equation. Due to the fact that the volume of blueberries is hard to measure, the mathematical equations presented in this study are providing an opportunity to easily predict blueberry volume in the field, which can be taken into account when adjusting berry sorter. A blueberry mass that can vary within rather wide limits (Remberg et al., 2006) can be most accurately estimated with a mathematical equation, which takes into account the overall average dimension of the blueberries.

Table 2. Accuracy of the mathematical equations, which describe the relationship between the dimensional characteristics of blueberries

Description of the mathematical equation	E_x	$\overline{x} \pm U$, 95%, k = 2.09*
Volume equation which takes mass into account (D Method)	10.73%	(0.3 ± 0.5) mL
Volume equation which takes mass into account (LS Method)	0.79%	(0.09 ± 0.03) mL
Mass equation which takes length into account	6.03%	(-0.56 ± 0.24) g
Mass equation which takes the average diameter into account	1.53%	(0.14 ± 0.06) g
Mass equation which takes the average overall dimension into account	0.87%	(-0.09 ± 0.03) g
Volume equation which takes the length into account (D Method)	10.86%	(0.2 ± 0.5) mL
Volume equation which takes the average diameter into account (D Method)	11.12%	(0.4 ± 0.5) mL
Volume equation which takes the average overall dimension into account (D Method)	10.94%	(0.3 ± 0.5) mL
Volume equation which takes length into account (LS Method)	14.69%	(0.0 ± 0.6) mL
Volume equation which takes the average diameter into account (LS Method)	7.78%	(0.1 ± 0.3) mL
Volume equation which takes the average overall dimension into account (LS Method)	14.86%	(0.0 ± 0.6) mL

* – The positive $\overline{x}$ value indicates that the mathematical equation estimated the calculated dimensional characteristic of blueberries to be smaller than the measurement results from the control group.

Based on the results obtained, we can conclude that blueberry dimensional characteristics are linked and that these characteristics can be used for various purposes. Our results confirmed a fact that blueberries have an oblate shape, one which is common for blueberries (Parra et al., 2007; Tasa et al., 2012) and that their diameter is greater than their length. This information can be used when designing a blueberry picking device (Arak & Olt, 2014) or sorting device (Soots et al., 2014; Soots & Olt, 2017). Sorting blueberries with a belt sorter should be carried out on the basis of the smallest blueberry dimensional parameter, which is its length, in order to ensure the uniformity of the separated fractions. This fact and also blueberries oblate shape indicates that during fractioning, blueberries on the belt sorter belts need to be rolled with special technical solution. On the other hand, the relations which have been discovered between the different dimensional characteristics of blueberries can be taken into account when it comes to improving or developing a measuring device which must emulate the real blueberry. Xu & Li (2015) have designed a rounded berry impact recording device (BIRD) which can be used to measure the mechanical impacts on blueberries during the post-harvesting handling process (Xu et al., 2015). The results presented in this study can be taken into account when it comes to improving or developing any similar recording devices so that the relationship between various blueberry dimensional characteristics will be as similar as possible to the real life characteristics in order to be able to increase their efficiency and reliability.

CONCLUSIONS

In this article the connections between the dimensional characteristics of blueberries were studied. In order to be able to predict blueberry volume, mathematical equations that take into account blueberry mass or geometrical dimensions were introduced in this article. The results showed that most accurate evaluations for blueberry volume were obtained when this was estimated using mathematical equations that take into account blueberry mass. The mass of blueberries can be estimated using mathematical equations that take into account the geometrical dimensions of blueberries while the most accurate results were obtained when the diameter and length of blueberries were taken into account. Those mathematical equations which have been introduced in this paper allow the mass and volume of blueberries to be estimated and taken into account while adjusting the distance between belt sorter belts. The difference in blueberry length and diameter refers to the fact that during fractioning, blueberries on the belt sorter belts should be rolled with special technical solution in order to increase the efficiency of belt sorters and ensure the uniformity of the separated fractions.

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REFERENCES

Arak, M. & Olt, J. 2014. Constructive and kinematics parameters of the picking device of blueberry harvester. *Agronomy Research* **12**(1), 25–32.

Bills, P., Blunt, L. & Jiang, X. 2007. Development of a technique for accurately determining clinical wear in explanted total hip 232 replacements. *Wear* **263**, 1133–1137.

Carmignato, S. & Savio, E. 2011. Traceable volume measurements using coordinate measuring systems. *CIRP Annals – Manufacturing 234 Technology* **60**, 519–522.

Correia, S., Gonçalves, B., Aires, A., Silva, A., Ferreira, L., Carvalho, l. & Silva, A.P. 2016. Effect of harvest year and altitude on nutritional and biometric characteristics of blueberry cultivars. *Journal of Chemistry*, Volume 2016, 12 pages.

Cubero, S., Aleixos, N., Albert, F., Torregrosa, A., Ortiz, C., Garcı´a-Navarrete, O. & Blasco, J. (2014). Optimised computer vision system for automatic pre-grading of citrus fruit in the field using a mobile platvorm. *Precision Agriculture* **15**(1), 80–94.

Eum, H. L., Hong, S.C., Chun, C., Shin, I.S., Lee, B.Y., Kim, H.K. & Hong, S J. 2013. Influence of temperature on shelf-life quality of highbush blueberries (Vaccinium corymbosum L. cvs. Bluetta, Duke). *Horticulture, Environment and Biotechnology* **54**(2), 128–133.

Forney, C. 2009. Postharvest issues in blueberry and cranberry and methods to improve market-life. *Acta Hort*, **810**, 785–798.

Grote, K.H. & Feldhusen, J. 2007. *Dubbel taschenbuch für den Maschinenbau*. Springer, Berlin, 1576 pp.

Kirkup, L. 1994. *Experimental methods: an introduction to the analysis and presentation of data*. John Wiley & Sons, New York, 216 pp.

Kondo, N. 2009. Robotization in fruit grading system. *Sensing and Instrumentation for Food Quality and Safety* **3**(1), 81–87.

Laaneots, R. & Mathiesen, O. 2011. *An Introduction to Metrology*. TUT Press, Tallinn, 283 pp.

Marinello, F., Pezzuolo, A., Cillis, D. & Sartori, L. 2016. Kinect 3d reconstruction for quantification of grape bunches volume and mass. *Engineering for Rural Development* **15**, 876–881.

Mettler Toledo. 2017. (March 31). URL: http://www.mt.com/ee/en/home.html

Mitutoyo. 2017. (March 31). URL: http://dl.mitutoyo.eu/HE/eBook/en_us/index.html?page=180

Nikon Metrology NV. 2017. (March 31). URL: http://www.nikonmetrology.com/en_EU/Products/Laser-Scanning/Handheld-scanning/ModelMakerMMDx/(specifications)

Parra, R., Lifante, Z.D. & Valdés, B. 2007. Fruit size and picking scar size in some blueberry commercial cultivars and hybrid plants grown in SW Spain. *Journal of Food Science & Technology* **42**(7), 880–886.

Recce, M., Plebe, A. & Taylor, J. 1998. Video grading of oranges in realtime. *Artificial Intelligence Review* **12**(1–3), 117–136.

Remberg, S.F., Wold, A.-B., Kvaal, K., Appelgren, M. & Haffner, K. 2006. An approach towards rapid optical measurements of antioxidant activity in blueberry cultivars. *Journal of Applied Botany and Food Quality* **80**, 36–39.

Rogge, S., Defraeye, T., Herremans, E., Verboven, P. & Nicolaï, B.M. 2015. A 3D contour based geometrical model generator for complex-shaped horticultural products. *Journal of Food Engineering* **157**, 24–32.

Soots, K. & Olt, J. 2017. Testing the adjustable drum belt sorter for blueberry size sorting. In Igor Kovačev (ed): *45th International symposium Actual Tasks on Agricultural Engineering.* University of Zagreb, Faculty of Agriculture, Agricultural Engineering Department, Croatia, pp. 199–206.

Soots, K. & Olt, J. Non-stationary processing center for small and medium sized blueberry farms. *Research in Agricultural Engineering* (in press).

Soots, K., Leemet, T., Karel, T. & Olt, J. 2016. Development of belt sorters smoothly adjustable belt drum. *Agronomy Research* **14**(3), 917–928.

Soots, K., Maksarov, V. & Olt, J. 2014. Continuously adjustable berry sorter. *Agronomy Research*, **12**(1), 161–170.

Starast, M., Karp, K., Paal, T. & Värnik, R. 2005. Kultuurmustikas ja selle kasvatamine Eestis. Eesti Põllumajandusülikool, Tartu, 65 pp. (in Estonian).

Starast, M., Karp, K., Vool, E., Moor, U., Tonutare, T. & Paal, T. 2007. Chemical composition and quality of cultivated and natural blueberry fruit in Estonia. *Vegetable Crops Research Bulletin* **66**, 143–153.

Strik, B. 2005. An expanding world berry crop. *Chronica Horticulturae* **45**(1), 7–12.

Tasa, T., Starast, M., Vool, E., Moor, U. & Karp, K. 2012. Influence of soil type on half-highbush blueberry productivity. *Agricultural and Food Science* **21**(4), 409–420.

Ulrich, K.T. & Eppinger, S. . 2015. *Product design and development* (6 ed.). McGraw-Hill Education, Boston, 432 pp.

Xu, R. & Li, C. 2015. Development of the Second Generation Berry Impact Recording Device (BIRD II). *Sensors 2015*, **15**, 3688–3705.

Xu, R., Takeda, F., Krewer, G. & Li, C. 2015. Measure of mechanical impacts in commercial blueberry packing lines and potential damage to blueberry fruit. *Postharvest Biology and Technology* **110**, 103–113.

Zhang, B., Huang, W., Wang, C., Gong, L., Zhao, C., Liu, C. & Huang, D. 2015. Computer vision recognition of stem and calyx in apples using near-infrared linear-array structured light and 3D reconstruction. *Biosystems Engineering* **139**, 25–34.

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Alcohol recovery from fermentation broth with gas stripping: system experimental and optimisation

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Abstract. Effective liquid biofuel production from various lignocellulosic waste resources is dependant not only on pre–treatment and hydrolysis but also on effective removal of alcohols from the fermentation media. Distillation and rectification is not suitable in low alcohol content systems (butanol production with clostridia) or in cases when the fermentation is performed in a continuous mode. One of the technologies offering continuous, *in situ* removal of alcohol is gas stripping. Despite the recognition of this technology, it is still under evaluation and adjustment. Thus, the aim of this study was to evaluate if gas stripping technology at rapid flow conditions is efficient enough to recover ethanol from the fermentation media. The results showed that 60 l min^{-1} flow rate was optimal to recover more than 45% of the available ethanol in 8 hours of stripping with nitrogen gas. The technology was efficient if the ethanol content in the fermentation broth was 10 wt%. At lower concentrations the recovery showed to be inefficient. Application of CO_2 as the stripping gas was not suitable for ethanol recovery and should be tested prior use. In conclusion, the application of rapid N_2 flow rate for gas stripping of ethanol from fermentation media showed to be an efficient technology and could replace long time, low flow rate stripping.

Key words: lignocellulosic biomass, biofuel, gas stripping, alcohol recovery.

INTRODUCTION

Lignocellulosic biomass pre-treatment and hydrolysis is regarded as one of the most expensive steps in lignocellulosic biofuel production. To minimize the costs and increase production yields, various chemical, mechanical and biological technologies or their combinations have been introduced and tested over the last twenty years (Mood et al., 2013). At the same time, a significant source of cost and energy consumption in current alcohol production is the collection, dewatering and purification of the main product–alcohol (Taylor et al., 2010). Ethanol content in the culture broth usually varies from 2.5 to 10 wt%, however, to be used as fuel it has to have a 99.5% purity (Sanchez & Montoya, 2013), thus, purification costs can reach up to 40–60% of total plant energy consumption (Kumar et al., 2015). Similarly, butanol production via acetone-butanol-ethanol (ABE) fermentation is limited to 2 wt% (Huang et al., 2014) of alcohol in the broth. Above this concentration it becomes inhibitory to the fermenting bacteria.

Alcohol concentration and purification can be achieved with classical distillation and subsequent rectification (Sanchez & Montoya, 2013) or with *in situ* technologies that can be run in a continuous mode and can even remove the toxic products selectively (de Vrije et al., 2013). These technologies are pervaporation, adsorption, vacuum fermentation, extraction with organic solvents or supercritical CO_2 extraction (Ritslaid et al., 2010; Sanchez & Montoya, 2013; Kumar et al., 2015). Pervaporation has been successfully applied *in situ* during ABE fermentation. Extractive fermentation can be coupled with simultaneous saccharification. Nevertheless, these technologies usually account for high energy and maintenance costs or, as for adsorption, the search for the most efficient and selective material is still ongoing (Sanchez & Montoya, 2013; de Vrije et al., 2013).

Another possibility for recovery of alcohols *in situ* is gas stripping, where oxygen free gas (N_2, CO_2 or H_2) circulates through the fermentation liquor. It is a relatively simple process that does not harm the fermenting culture and can be operated in a continuous mode even on an industrial scale (Quershi & Blaschek, 2001). Moreover, there is no need for an expensive equipment or reagents. Gas is sparged into the bioreactor through a sparger, which creates bubbles and these after breaking induce vibration of the liquid and subsequent volatile removal (Ezeji et al., 2005). Parameter sensitivity analysis has shown that the dominant variable in the process is gas flow rate (Liao et al., 2014). Unfortunately, rapid gas flow rate in the reactor removes large amount of water together with the ethanol, resulting in ethanol concentrations below 60% (Ponce et al., 2014), and can induce foaming in the bioreactor (Ezeji et al., 2005). Thus, the aim of this study was to evaluate if gas stripping technology at rapid flow conditions is efficient and suitable for recovery of ethanol from the fermentation media. A special attention to alcohol concentration in the bioreactor, overall energy consumption and overall product yields was made during the research.

MATERIALS AND METHODS

Experimental set-up.

To examine the potential of gas stripping, an experimental pilot scale unit was constructed (Fig. 1). It consisted of a glass bioreactor (Biotechnical Centre, Latvia) with a working volume of 2–4.5 l and equipped with one speed–controlled standard Rushton turbine type agitator with 6 blades and ring microsparger with ten 1 mm jets. Temperature and oxygen in the bioreactor were controlled with a programmable logic controller. To prevent the penetration of fermentation liquid into gas stripping system, a separator with adjustable working volume (0.5 5 l) and variable gas flow capacity was installed. Afterwards gaseous chemicals were condensed in a gas cooling system which consisted of a copper pipe inserted in a refrigerated water bath and collected into a collector.

Flow circulation of gas was performed with an air pump (Alita, USA). The flow rate was measured with a flow meter (Cole-Parmer, USA) with a measuring range of 0–150 l min^{-1} and accuracy of 1 l min^{-1}.

Energy consumption of the gas stripping system was measured by 3–phase indicator (Orno OR–WE–505, Poland).

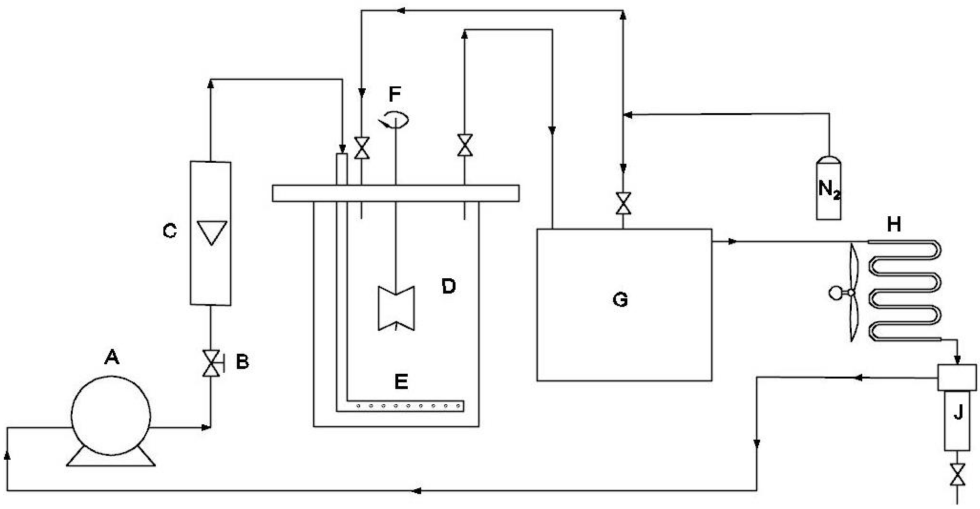

Figure 1. Experimental set–up of gas–stripping system: A–air pump; B–flow control valve; C–flow meter; D–reactor; E–gas sparger; F–agitator and motor; G–separator; H–cooler; J–product collector.

Gas stripping tests

To perform gas stripping tests a model fermentation broth consisting of 2; 10 or 22 wt% of ethanol in water was prepared. Total working volume was 3.5 l. The separation of alcohol from the fermentation broth was performed in a batch regime. Before all stripping experiments the cooling system and gas-circulation line was manually flushed with O_2–free–N_2 (> 99.95%) or CO_2 (99.99%) gases, to make it anaerobic. The temperature in the bioreactor was maintained at 36.7–37 °C, 50 rpm agitator speed and minus 4 to 2 °C in the cooling system. To estimate the efficiency of the gas stripping, 30; 50 and 60 l min^{-1} gas flow regimes were tested at various alcohol concentrations in the fermentation broth (Table 1). Each test giving a positive result was repeated at least once.

Sampling was performed at regular intervals from the product collector and bioreactor and measured with a hydrometer (Vinoferm, Belgium) to determine the final ethanol concentration. Energy consumption was read on an hourly basis all through the testing period. The overall testing time of each run was 8 hours.

Table 1. Experimental test regimes

No	Ethanol concentration wt %	Flow rate l min^{-1}	Gas type	Separator volume	No runs performed
1	22	60	N_2	Low	2
2	10	60	N_2	Low	3
3	10	60	N_2	High	2
4	10	50	N_2	Low	2
5	10	30	N_2	Low	1
6	10	60	CO_2	Low	1
7	2	60	N_2	Low	1

Statistical analyses

MS Excel 2007 *t–test* (two tailed distribution) and ANOVA single parameter tool (significance level ≤ 0.05) were used for analysis of variance on data from various sample setup`s.

RESULTS AND DISCUSSION

Despite the observation that gas stripping is directly related to the gas flow rate, the reported flow regimes are usually below 10 l min^{-1} (Qureshi & Blaschek, 2001; Abdehagh et al., 2014) and can be as low as 1.25 l min^{-1} (Lu et al., 2012). In these conditions gas stripping is usually performed for more than 24 hours. The rationale behind this is to control constant–low levels of the alcohol in the system, thus, preventing the accumulation of the inhibitors (Ezeji et al., 2005). At the same time, such treatment generates low concentration of alcohol in the recovered condensate. Lu et al. (2012) reported only 10–16% for the recovered butanol. Others had between 11 till 24% for the recovered ethanol (Taylor et al., 2010; Ponce et al., 2014). Within this study flow regimes of 30; 50 and 60 l min^{-1} were tested to evaluate the efficiency of alcohol extraction in a short period of time (in less than 8 hours). 10 wt% ethanol concentration in the reactor was selected to simulate yeast tolerance level. The results showed that at 30 l min^{-1} the overall ethanol recovery is low and it did not reached even 10% of the amount of absolute alcohol available in the reactor (Fig. 2), thus, corresponding to the previous observations. At the same time with 50 and 60 l min^{-1} flow rates it was possible to recover 37.8% and 45.4% of all available alcohol respectively, thus, decreasing the concentration of ethanol in the reactor to around 5 wt%. Only a slight difference ($p > 0.05$) was observed between the two fastest flow regimes. Despite the fact that 60 l min^{-1} allowed to collect from 2–24% more ethanol in all samplings, further increase in flow rate was omitted due to possible excess foaming (Ezeji et al., 2005) and potential damage to cells as a result of gas bubble breaking (Chisti, 2000).

The amount of water in the samples collected after 2 hours of gas stripping was below 40% (50 l min^{-1} and 60 l min^{-1} flow rate) and it had the tendency to increase with the stripping time irrespective of the flow rate. Correspondingly, after 8 hours of treatment more than 60% of the collected sample volume was represented by water. In distillation ethanol content after the first column is only around 50% (Sanchez & Montoya, 2013), thus, a second system for product treatment is necessary for both technologies.

After 8 hours of stripping the samples had only 25–30 wt% ethanol (50 l min^{-1} and 60 l min^{-1} flow regimes) (Fig. 2) and that represented less than 20% of all the collected amount of ethanol within previous 6 hours. Again no significant difference ($p > 0.05$) between 50 l min^{-1} and 60 l min^{-1} was observed. Moreover, no significant difference ($p > 0.05$) was observed for the overall energy consumption to perform gas stripping at 50 or 60 l min^{-1} flow rate. The average consumption rates in one hour work of the pilot scale system were around 0.94 MJ.

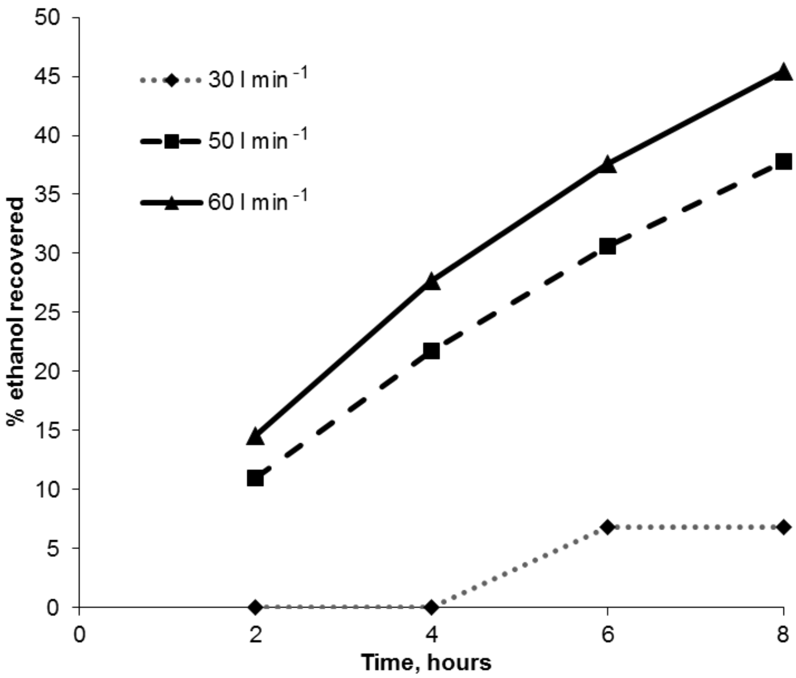

Figure 2. The percentage of total absolute ethanol (99.5%) recovered during 8 hours of gas stripping at 30, 50 and 60 l min^{-1} flow rate. Initial ethanol concentration in the reactor was 10 wt%. Values represent the average.

To decrease the amount of water in the collected liquid and limit water presence in the condensation system, an additional separator volume was installed (0.5 l min^{-1} was increased to 5 l). The function of the separator was to decrease liquid or foam entrance into the condensation system and increase separation intensity as such. This modification was tested only at 60 l min^{-1} flow. Test results showed no significant difference in the ethanol recovery with or without increased separator volume ($p > 0.05$) (Fig. 3). Like before, the amount of recovered ethanol decreased with gas stripping time. Thus, the increase in separator volume did not have any positive effect on the ethanol percentage in the liquid collected after gas stripping. At the same time it should be noted that the modification could be important in systems with high foaming intensity or in situations when prolonged gas stripping is performed.

Further, two additional ethanol concentrations – 2 and 22 wt% were tested to simulate the upper tolerance limit of ABE fermenting clostridia and a very high alcohol concentration, respectively. Both concentrations were tested at 60 l min^{-1} flow rate. It was impossible to collect enough samples after 2 and 4 hours with a reactor having 2 wt% alcohol. The overal amount of absolute ethanol recovered was only 2.4 mL(3.3% of all available ethanol). The amount of water in these samples was almost 90% (Fig. 3), thus, the selected approach showed to be unsuitable for the systems with low volatile content.

The increase in the reactor ethanol concentration to 22 wt% resulted in an increased amount of recovered ethanol. More than 120 mL(18.3% of available ethanol) were collected after 2 hours of gas stripping and after 6 hours almost 44% (317 ml) of available ethanol was recovered (Fig. 3). The increased volatile concentration resulted in higher process efficiency, however, the possibility that such concentrations will be regular in fermentation broth is low. Nevertheless, the results demonstrated that elevated concentrations (above 20 wt%) are suitable for gas stripping at 60 l min^{-1} gas flow regimes (Fig. 3).

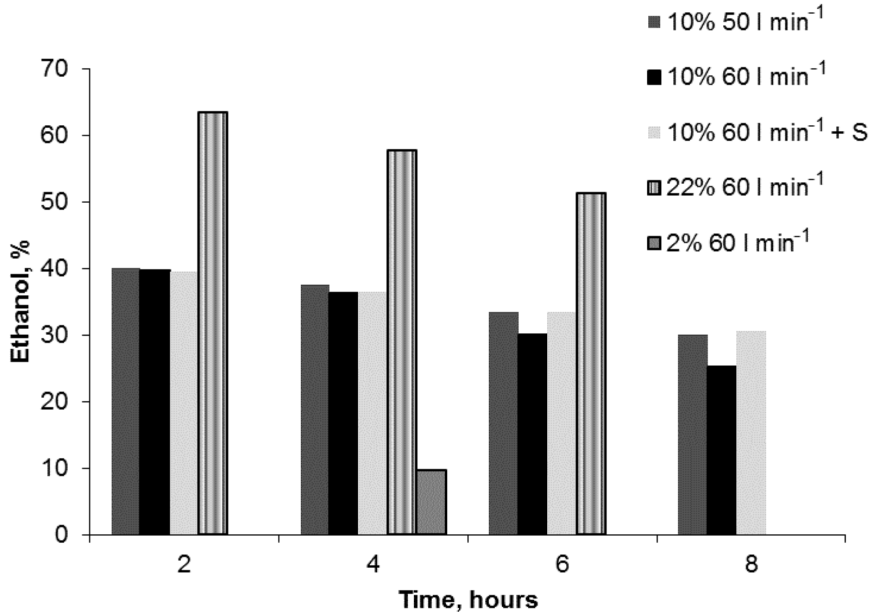

Figure 3. The percentage of absolute ethanol in samples collected after 2, 4, 6 and 8 hours of gas stripping at 50 or 60 l min^{-1} with or without extra separator. Ethanol concentration in the reactor was 2; 10 or 22 wt% depending on the run. Values represent the average from at least 2 runs.

To perform gas stripping, application of gases like CO_2, N_2 or even H_2 has been suggested and evaluated (Liao et al., 2014). In general, the application of CO_2 is advised because the gas is produced during the fermentation process itself, thus, no extra gas source is necessary (Xue et al., 2012). Moreover, it has been estimated that there is no economic reason to exchange CO_2 with any other gas (Taylor et al., 2010). However, it has been demonstrated that CO_2 can be inhibitory to yeast growth (Zhang et al., 2005) and nitrogen is a more suitable gas in both yeast ethanol production and ABE (Liao et al., 2014). To evaluate if other type of gas can increase the alcohol recovery at high gas flow regime, CO_2 was tested. The results showed that there is an increased consumption of CO_2 (at least 2 times more than N_2) to maintain anaerobic conditions in the whole system. Moreover, no increase in ethanol recovery was observed – even 13% lower recovery rate was observed with CO_2 than N_2. Also the same amount ($p > 0.05$) of water content was observed in the collected samples, thus, indicating on no superiority of CO_2. Thus, N_2 showed to be a more appropriate source of gas.

Efficient recovery of alcohol from the fermentation media is usually a struggle between the recovery efficiency, costs and system longevity. Introduction of gas stripping can be a good choice to maintain a continuous system and do not increase the production costs. Despite the problems with high water content, foaming or technological parameters, the resultant product yields can be on the same quality level as classical distillation. Introduction of a subsequent technology, like, membrane separation (Nigaz & Durmaz, 2016) will enable the production of alcohol above 99.5% that is a suitable fuel alcohol.

CONCLUSIONS

The study demonstrated that the efficiency of gas stripping is strongly dependent on the technological parameters, like, alcohol concentration in broth, gas flow rate and treatment time. High flow rate (60 l min^{-1}) is suitable for rapid extraction of ethanol from the reactor and does not introduce any excess foaming. Moreover, there was no significant ($p > 0.05$) increase in process energy consumption when the flow rate was increased from 30 to 60 l min^{-1}. The recovery rate of ethanol after 8 hours reach up to 45.4% of the available ethanol. CO_2 did not showed to be superior for ethanol recovery. The study showed that downstream process optimisation in lignocellulosic biofuel production can significantly decrease production costs.

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REFERENCES

Abdehagh, N., Tezel, F.H. & Thibault, J. 2014. Separation techniques in butanol production: Challenges and developments. *Biomass and Bioenergy* **60**, 222–246.

Chisti, Y. 2000. Animal-cell damage in sparged bioreactors. *Trends in Biotechnology* **18**, 420–432.

De Vrije, T. Budde., M. van der Wal, H., Claassen, P.A.M. & Lopez-Contreras, A.M. 2013. '*In situ'* removal of isopropanol, butanol and ethanol from fermentation broth by gas stripping. *Bioresource Technology* **137**, 153–159.

Ezeji, T.C., Karcher, P.M., Qureshi, N. & Blaschek, H.P. 2005. Improving performance of a gas stripping-based recovery system to remove butanol from Clostridium beijerinckii fermentation. *Bioprocess Biosyst Eng*. **27**, 207–214.

Huang, H.J., Ramaswamy, S. & Liu, Y. 2014. Separation and purification of biobutanol during bioconversion of biomass. *Separation and Purification technology* **132**, 513–540.

Kumar, S., Dheeran, P., Singh, S.P., Mishra, I.M. & Adhikari, D.K. 2015. Continuous ethanol production from sugarcane bagasse hydrolysate at high temperature with cell recycle and in-situ recovery of ethanol. *Chemical Engineering Science* **138**, 524-530.

Liao, Y.C., Lu, K.M. & Li, S.Y. 2014. Process parameters for operating 1-butanol gas stripping in a fermentor. *Journal of Bioscience and Bioengineering* **118**, 558–564.

Lu, C., Zhao, J., Yang, S.T. & Wei, D. 2012. Fed-batch fermentation for n-butanol production from cassava bagasse hydrolysate in a fibrous bed bioreactor with continuous gas stripping. *Bioresource Technology* **104**, 380–387.

Mood, S.H., Golfeshan, A.H., Tabatabaei, M., Jouzani, G.S., 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.

Nigiz, F.U. & Durmaz Hilmioglu, N. 2016. Anhydrous fuel ethanol production by a combined hydrophobic–hydrophilic pervaporation system, *Energy Sources*, Part A: Recovery, Utilization and Environmental Effects, **38,** 3348–3353.

Ponce, G.H.S.F., Miranda, J.C.C., Alves, M., Wolf, M.R.M., Filho, R.M., De Andrade, R.R. & De Conto, L.C. 2014. Simulation, analysis and optimization of an in situ gas stripping fermentation process in a laboratory scale for bioethanol production. *Chemical Engineering Transactions* **37**, 295–300.

Qureshi, N. & Blaschek, H.P. 2001. Recovery of butanol from fermentation broth by gas stripping. *Renew Energy* **22**(4), 557–564.

Ritslaid, K., Küüt, A. & Olt, J. 2010. State of the Art in Bioethanol Production. *Agronomy Research* **8**(1), 236–254.

Sanchez, O.J. & Montoya, S. 2013. Production of Bioethanol from Biomass: An Overview. In Gupta, V.K. & Tuohy, M. G. (ed.): *Biofuel Technologies.* Springer–Verlag, Berlin, Heidelberg, pp. 397–441.

Taylor, F., Marquez, M.A., Johnston, D.B., Goldberg, N.M. & Hicks, K.B. 2010 Continuous high-solids corn liquefaction and fermentation with stripping of ethanol. *Bioresource technology* **101**, 4403–4408.

Xue, C., Zhao, J., Lu, C., Yang, S.-T., Bai, F. & Tang, I.-C. 2012. High-titer n-butanol production by clostridium aceto butylicum JB200 in fed-batch fermentation with intermittent gas stripping. *Biotechnology and Bioengineering* **109**, 2746–2756.

Zhang, J., Liu, H.J. & Liu, D.H. 2005. Effect of different types of gas in gas stripping ethanol fermentation (GSEF). *The Chinese Journal of Process Engineering* **5**, 349–352.

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Hydrolysed biomass waste as a potential biosorbent of zinc from water

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Abstract. In the last 10 years recycling of various materials and metal recovery from waste with low cost biosorbents or agricultural biomass has become popular trend. Lignocellulosic biomass is regarded as a sustainable resource for biofuel production. In this process, lignocellulosic biomass is partly degraded during chemical or biological hydrolysis, as a result, these agricultural waste materials usually present a disposal problem and have no economic value. Therefore, reuse of lignocellulosic waste materials as inexpensive and alternative sorbent for heavy metals in polluted aqueous solution.
The aim of this research was to evaluate the applicability of hydrolysed biomass waste for zinc removal from water solution. To evaluate the potential use of lignocellulosic biomass for biosorption, experiments were performed with dry, washed from organic matter and hydrolysed hay. The results showed that hydrolysed hay have lower biosorption capacity than washed and dried hay, however, it still can be used as a low-cost biosorbent for the removal of Zn in polluted aqueous solutions, because it showed relatively high cink sorption capasity (336–391 mg g^{-1}).

Key words: biosorbent, lignocellulosic biomass, waste, heavy metal, zinc.

INTRODUCTION

Recycling of various materials and metal recovery from waste is applied more and more often in the World. The most popular methods for the recovery are chelator-forming agents (Xu & Zhang, 2006); ion exchange (Kang et al., 2004); ultrafiltration (Landaburu-Aguirre et al., 2010); reverse osmosis (Shahalam et al., 2002); nanofiltration (Murthy & Chaudhary, 2008); electro dialysis (Sadrzadeha et al., 2009); coagulation and flocculation (Charerntanyarak, 1999); flotation, dissolved air flotation (DAF) (Lundh et al., 2000); ionic flotation (Polat & Erdogan, 2007), electrocoagulation (Chen, 2004) or filtration through various materials. The most popular sorbents used as filter media are activated carbon (Kang et al., 2008), carbon nanotubes (first method is described in Iijima, 1991) and low-cost materials as kaolinite (Bhattacharyya & Gupta, 2008). However, most of these methods are expensive and often include the use of specific materials or chemicals. A good alternative is the application of biological materials (biosorbents) as filter media. Biosorbents can be divided into the following groups: (1) biological material, that can be used in bioreactors: fungi (Dhillon et al., 2016), yeasts (Amirnia et al., 2015), algae (Apiratikul & Pavasant, 2008) and bacteria (Kotrba et al., 2011), (2) agricultural material, that can be used as filter media: traditional biomass as peat (Brown et al., 2000), garden grass (Hossain et al., 2012) or mixture of hay, manure or different agricultural wastes (Wang et al., 2009). The most important factor for the selection of the biosorbent is its applicability and cost-effectiveness.

Insufficiently treated industrial wastewater or various metallic waste (metal details, batteries etc.) (Sud et al., 2008) are one of the causes how various metal ions get into the environment. Many of them have a negative effect on human health due to their toxicity even at low concentrations and bioaccumulation properties (Kasiuliene et al., 2016). One of such metals is zinc. Despite zinc as a trace element is necessary for the human health and organism`s biochemical processes (Chapman, 2006), at high doses it is toxic and can cause problems such as stomach cramps, skin irritations, vomiting, nausea and anaemia (Oyaro et al., 2007). Zinc has excellent anti-rust properties and is usually used in the galvanization (zinc coating) of steel; therefore, it has great potential to be recycled (van Beers et al., 2007). The maximum concentration limit (established by USEPA) for Zn in the discharged wastewater is 0.80 mg L^{-1} (Babel & Kurniawan, 2003), however, industrial wastewater can have Zn concentrations of more than 100 mg L^{-1}, and thus, the biosorbent must be not only affordable but also efficient.

Along with the human health aspects and recovery of valuable chemicals, a major problem in global communities is an efficient production of energy. Plant biomass is regarded as a sustainable resource for biofuel production due to its wide abundance and high energetic value (Hahn–Hägerdal et al., 2006); Pauly & Keegstra, 2008). At the same time efficient fuel production is linked to generation of partially degraded lignocellulose or solid wastes that are usually discharged in the environment. However, re-introduction of this waste into industry would be of high importance.

Partially degraded lignocellulose or solid wastes that are not used further after chemical or biological extraction are usually discharged. The aim of this research was to evaluate if lignocellulosic biomass waste after hydrolysis can be used as a potential biosorbent for zinc recovery.

MATERIALS AND METHODS

Biosorbent preparation

Hay (Dry weight (DW) – 92.8 ± 1.3%) harvested in Latvia in June 2015 was used as the test material. The hay was grinded by mechanical cutting mill (Retsch SM100, Haan, Germany) with 1.5 kW drive and parallel section rotor with peripheral speed 9.4–11.4 ms^{-1}. Particle size was controlled by 10 mm-sieve size square holes. One part of the biomass was directly used further ('dried') at room temperature (RT) another was washed for 24 h with tap water at a flow rate of 15 mL min^{-1} ('washed'). Hydrolysed biomass was obtained after 24 h of enzymatic hydrolysis. In brief, 3% w/v of the biomass was diluted in 0.05 M sodium citrate buffer (mono–sodium citrate pure, AppliChem, Germany) and boiled for 5 min (1 atm) to eliminate any indigenous microorganisms. After cooling to RT, an enzyme (Viscozyme, Novozymes) was added and incubated on an orbital shaker (New Brunswick, Innova 43) for 24 h at 37°C and 150 rpm. Afterwards the solid fraction was collected, air-dried at RT and used for biosorption studies.

Experimental setup

Biosorption experiments were conducted in a glass column of 25 cm length and 3.2 cm of inner diameter, filled with of dry hay, washed hay and hydrolysed hay. Zn(II) solutions with an initial concentration of 10 and 100 mg L^{-1} with pH 7.0 ± 0.5 were fed through the up-flow fixed-bed column at a flow rate of 15 mL min^{-1}. Samples were taken periodically and then analysed with Perkin Elmer AAnalyst 200 Atomic Absorption Spectrometer (AAS) for the determination of residual zinc concentration. Operation of the column was stopped when equilibrium between influent and effluent Zn(II) ion concentration was achieved (99% of an initial Zn(II) concentration). The pH, conductivity and temperature of the influent and effluent of collected samples were measured by using digital bench top meter (inoLab® Multi 9420 IDS, WTW, Germany). Each experiment was performed in triplicate.

Zn determination

The concentration of Zn was analysed using the AAnalyst 200 AAS (Perkin Elmer, USA) using a mixture of air-acetylene flame technique.

Samples of Zn(II) solution were taken periodically from the top of the column and have been acidified with concentrated nitric acid (HNO_3 65%, Lach-Ner Ltd., Czech Republic) to reach a concentration of 2% v/v; then the samples were filtered with 0.45 μm membrane filter (Filtropur S, Sarstedt, Germany). All the results were expressed in milligrams of Zn(II) per litre (mg L^{-1}).

Zn solution

The synthetic Zn(II) solutions were prepared by dissolving the appropriate amount of $ZnSO_4 \cdot 7H_20$ (Reachem Slovakia, Slovakia) in tap water to simulate real water contamination. According to standard method maximal concentration for Zn determination in samples was 1 mg L^{-1}, thus dilutions were performed when necessary.

TOC determination

Total organic carbon (TOC) measurements were performed with a Scalar Primacs MCS TOC analyser based on high temperature and acidification of sample and by the difference of the total carbon and inorganic carbon measurement, according to standard method EN 1484:1997 (LVS EN 1484:2000). For TOC determination samples were filtered thought the 0.45 μm pore size membrane filters (Millipore Corporation, USA). Each sample was tested in duplicate and the mean values were calculated ($CV \leq 2\%$). The blank and control solutions were analysed with each series of sample in order to verify the accuracy of the results obtained by the method.

Statistical data analysis

The efficiency of Zn(II) removal or adsorption yield was calculated from the ratio of the amount of Zn(II) ions adsorbed and the biosorbent amount in fixed-bed column.

Total feed volume V (L) is calculated by the following equation:

$$V = Q \cdot T \tag{1}$$

where T is the total operating time in the biosorption experiment or retention time in hours (h), Q is the flow rate of Zn(II) ion solution which passed through the column in mL min^{-1}.

The total feed amount of Zn (g) biosorbed into the biosorbent in fixed-bed column experiments is calculated by the following integration:

$$\text{Total feed amount of Zn} = C \cdot V \qquad (2)$$

where C is the adsorbed concentration of Zn (mg L^{-1}) and V is total feed volume (L).

The Zn capacity (mg g^{-1}), the weight of Zn(II) sorbated per unit dry weight of biosorbent can be determined as following:

$$\text{Zn capacity} = \frac{\text{Total feed amount of Zn}}{m} \cdot 1{,}000 \qquad (3)$$

where m is the total mass of biosorbent in the column in g.

The efficiency of Zn(II) removal or adsorption yield (%) was calculated from the ratio of the amount of Zn(II) ions biosorbed and the total mass of biosorbent (g) in fixed-bed column using the following equation:

$$\text{Adsorption yield} = \frac{\text{Amount of Zn(II) biosorbed}}{m} \cdot 100 \qquad (4)$$

General MS Excel statistical data analysis was used for data processing. Probabilities of ≤ 0.05 were considered as significant.

RESULTS AND DISCUSSION

In this study, the application of hydrolysed biomass waste for zinc removal from water solution was evaluated with the aim to determine the potential of lignocellulosic biomass as a biosorbent.

Biosorption experiments were conducted in a glass column, filled with dry, washed and hydrolysed hay. Zn(II) solutions with an initial zinc concentration of about 10 and 100 mg L^{-1} (pH 7.0 ± 0.5) were fed through the up-flow fixed-bed column. The concentrations were selected to represent moderately or heavily polluted water. The comparison of dried, washed and hydrolysed hay showed similar tendencies of Zn adsorption (Figs 1, 2). The efficiency of adsorption process was determined as the changes in Zn concentration in influent and effluent samples.

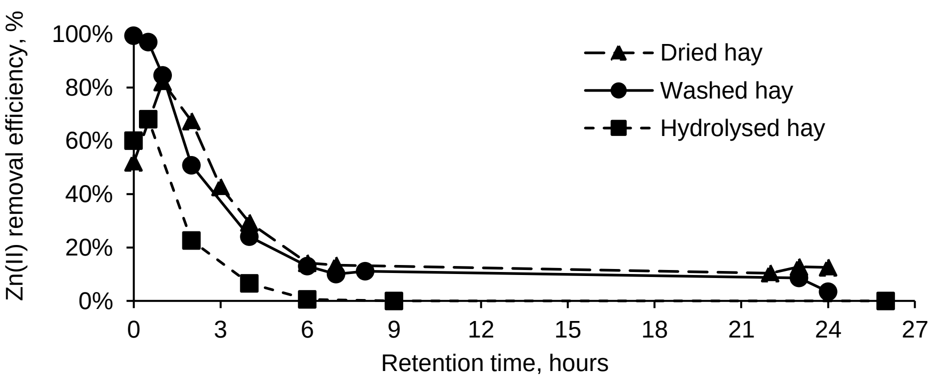

Figure 1. Zinc removal efficiency from solution with initial concentration of around 100 mg Zn mg L^{-1} during the biosorption process. The data are the mean of three separate experiments.

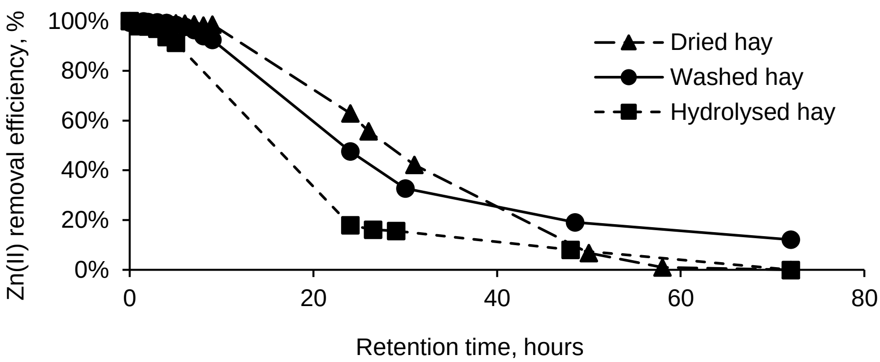

Figure 2. Zinc removal efficiency from solution with initial concentration of around 10 mg Zn mg L^{-1} during the biosorption process. The data are the mean of three separate experiments.

At high initial zinc concentration (around 100 mg L^{-1}), Zn(II) removal for dried, hydrolysed and washed hay at the initial stage was 52, 60 and 99%. During the next 60 minutes of biosorption, Zn removal efficiency with dried hay biosorbent increased to 82%, and to 68% for the hydrolysed one. The residual concentration of Zn increased to the initial concentration after 24 hours of treatment through both hay types.

The experiments with dried and hydrolysed hay showed that in the first effluent samples high amount of humic substances (HS) that affected biosorption capacity were observed (Table 1). To determine the effect of HS on the biosorption process, hay samples were washed with tap water at a flow rate of 15 mL min^{-1}. Concentration of HS, determined as TOC, reached up to 6,999 mg L^{-1} (with dried hay and 100 mg Zn L^{-1} solution). Higher TOC concentration was observed in the first minutes of biosorption process and afterwards it slowed down. The final concentration of TOC stayed at the same level with influent solution 6–8 mg L^{-1}.

Table 1. Average pH, EVS and TOC values during the biosorption process

Hay	pH		EVS range, µS cm^{-1}		TOC range, mg L^{-1}	
*Zn, mg L^{-1}**	*10*	*100*	*10*	*100*	*10*	*100*
Dried	7.58 ± 0.24	7.29 ± 0.38	614–9,574	839–10,586	8–1,640	8–6,999
Washed	7.56 ± 0.18	7.45 ± 0.16	640–716	759–884	8–29	8–43
Hydrolysed	10.94 ± 1.14	6.49 ± 0.94	952–2,612	864–2,516	6–1,100	7–1,268

* – initial zinc concentration, mg L^{-1}.

At low initial zinc concentration (10 mg L^{-1}), 99% removal was observed for dried and hydrolysed hay after 9 h and 3 h, respectively. Zn removal efficiency decreased after 24 h to 63% for dried and 18% – for hydrolysed hay. Biosorbent capacity was exhausted after 51 h for dried and after 72 h – for hydrolysed hay, when Zn increased to initial concentration.

Washed hay showed higher Zn(II) adsorption rates in the first 60 minutes (100 mg L^{-1} Zn(II)). Afterwards the adsorption kinetics slowed down and the effluent had Zn(II) at the same level as in the inlet water. In samples with 10 mg L^{-1} Zn(II) the greatest decrease was obtained within the first 24 h. Afterwards the decrease slowed down. After 30 hours no significant reduction in Zn concentration was observed ($p < 0.05$).

Similar tendency was observed for electro conductivity (EVS) measurements (Table 1). Higher EVS (10,586 μS cm^{-1}) was obtained in solutions with higher TOC concentration (with dried and hydrolysed hay). EVS was the highest during the first minutes of biosorption process and afterwards it slowed down and the final concentration of EVS stayed at the same level as in the inlet water – 614–952 μS cm^{-1}. At the same time zinc removal efficiency at the highest TOC and EVS levels was low in systems with dried and hydrolysed hay.

The total adsorbed Zn(II) on three types of hay was calculated as the difference in Zn between the inlet sample and the Zn value in the effluent sample during the overall biosorption cycle (Table 2). The efficiency of Zn(II) removal or adsorption yield was calculated from the ratio of the amount of Zn(II) ions adsorbed and the biosorbent amount in fixed-bed column.

Table 2. Comparison of Zn load and adsorption yield depending on the biosorbent used.

	Hay					
Parameters	Dried		Washed		Hydrolysed	
*Zn, mg L^{-1}**	*10*	*100*	*10*	*100*	*10*	*100*
Flow rate, mL min^{-1}	15	15	15	15	15	15
Retention time, h	51	24	72	25	48	26
Total feed volume, L	45.9	21.6	64.8	22.5	43.2	23.4
Adsorbed concentration of Zn, mg L^{-1}	193	398	206	642	84.8	184
Total feed amount of Zn, g	8.9	8.6	13.4	14.4	3.7	4.3
Biosorbent mass, g	18	16	17	17	11	11
Zn capacity, mg g^{-1}	494	538	788	847	336	391
Adsorption yield, %	50	53	81	88	33	40

* – initial zinc concentration, mg L^{-1}.

Differences in the retention time can be explained by operation mode: the column experiments were stopped when an equilibrium between the influent and effluent Zn(II) ion concentration was achieved (99% of an initial Zn(II) concentration).

The results showed that pH level increased up to 10.94 ± 1.14, higher EVS level (952 μS cm^{-1}) and lower TOC (6 mg L^{-1}) in effluent samples from fixed-bed column with hydrolysed hay and 10 mg L^{-1} Zn(II) effluent solution. The hydrolysed biomass prior biosorption was only slightly washed and it is possible that certain amount of enzymes and hydrolysis intermediates have remained and in the presence of metal ions, resulted in formation of certain basic products that caused pH increase. Partially thermally and enzymatically degraded biomass reaction with lower Zn(II) concentration in influent solution can be the reason for these results. The scanning electron microscope (SEM) analysis in other parallel studies (Gruskevica et al., 2017) have shown than sorbent is covered by thin white film with some drop shaped inclusions, as well as energy dispersive X-ray spectroscopy (EDX) analysis confirmed that the film consist of organic substances and inclusion were made of Zn. Some other studies (Denisova et al., in Press) showed that reaction with lower influent concentration can be more intensive and also the Zn(II) biosorption capacity was higher at lower Zn(II) influent concentration. Some other reaserchers (Singha & Guleria, 2015) have shown a decrease in feasibility of adsorption at higher temperatures, and also the percentage removal of Zn ions increases in the pH range of 5.0–7.0.

Adsorption is an effective and economic method for heavy metal wastewater treatment, when it is possible to produce high-quality treated effluent (Fu & Wang, 2011). The obtained results showed that it was possible to immobilize at least 84.8 mg L^{-1} of Zn on hydrolysed hay during the biosorption cycle from a solution with 100 mg L^{-1} Zn(II) (Zn capacity is 336 mg g^{-1} or adsorption yield – 33%). Maximal adsorbed Zn concentration (642 mg L^{-1}), maximal Zn capacity (847 mg g^{-1}) and adsorption yield (88%) was obtained in columns with washed hay and 10 mg Zn L^{-1} solution. The obtained adsorption capacity of hay was higher than reported in other studies (Chen et al., 2011), where Zn removal was performed by biochar and varied at about 10–55%. The capacity was as low as 11 mg g^{-1}. Some other researchers presented Zn sorption capacities on different sorbents: HCl-treated clay – 63.2 mg g^{-1} (Vengris et al., 2001), pecan shells activated carbon – 13.9 mg g^{-1} (Bansode et al., 2003), bacillus – bacterial biomass – 418 mg g^{-1} (Ahluwalia & Goyal, 2006). According to other studies (Gruskevica et al., 2017) the obtained Zn adsorption capacity of hay was by 30% higher in experiments with standard solutions than in multicomponent solution or real wastewater. Partially degraded lignocellulose or solid wastes that are not used further after chemical or biological extraction are usually discharged. Thus, the key factor to investigate the possibility of potential recovery of the biosorbent material is the regeneration of the biosorbent. Usually desorption efficiency for lignocellulose biosorbents was is higher than 99 % (Denisova et al., in Press).

Thus, the highest Zn adsorption capacity was obtained with washed hay that had low free organic content. Zn adsorption capacity in experiments with dried hay that had high free TOC content was lower. Subsequently, the lowest capacity was determined in samples with hydrolysed hay.

Some studies showed that the modification of the adsorbent can increase the removal efficiency of pollutants: modified rice husk – 80% (Roy et al., 1993) or algal was greater than 90% (Guo et al., 2002). Of course, all sorbent modifications increase the costs of metal removal processing technology (Bailey et al., 1999). Other authors have reported that heat-treatment of biosorbents could affect sorption capacity significantly. As example, Sharma et al. (2013) showed that NaOH and HCl washed soybean and cottonseed hulls were better adsorbents for Zn (sorption capacity varied from 69.5 to 90.3%) than water-washed (control) hulls (51.9 and 59.5% respectively) and heat-treated cottonseed and soybean hulls (sorption capacity varied from 33.3 to 59.8%).

Zinc pollution of water is a major problem faced worldwide. Zinc adsorption capacity on low cost adsorbents has been presented in different studies and depends on various environmental conditions, such as, pH, temperature, contact time and sorbent modifications.

This study showed that hay and hydrolysed hay can be used as a potential low-cost biosorbent for the removal of Zn(II) in moderately and heavily polluted aqueous solutions.

The advantages of used biosorbent are the ease of production, low price, availability of raw materials including waste materials such as recycling waste and the potential to use agricultural wastes for immobilization of heavy metals from polluted environmental solutions with different engineering systems. Further research on the hay properties and adsorption capacities for other metals should be performed to evaluate the full potential of this waste-resource.

CONCLUSIONS

The present study showed a potential for the removal of heavy metals from wastewater using washed, dried and hydrolysed hay. Biosorption efficiency of hay decreased with the increase of organic matter concentration. As well as the sorption capacity depended on this type of the adsorbent. Washed hay was a better adsorbent than dried and hydrolysed hay.

The highest Zn adsorption capacity was obtained with washed hay with low free organic content, Zn adsorption capacity obtained in experiments with dried hay and high free TOC content was lower, and finally, the lowest – with hydrolysed hay. Adsorption yield of Zn was 81–88% for washed hay, 50–53% for dried hay and 33–40% for hydrolysed hay.

This study showed that the hydrolysed hay can be used as a potential low-cost biosorbent for the removal of Zn(II) in polluted aqueous solutions, but non-modified hay (washed and dried) still showed higher Zn sorption potential.

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REFERENCES

Ahluwalia, S.S. & Goyal, D. 2006. Microbial and plant derived biomass for removal of heavy metals from wastewater. *Bioresource Technology* **98**(12), 2243–2257.

Amirnia, S., Ray, M.B. & Margaritis, A. 2015. Heavy metals removal from aqueous solution using *Saccharomyces cerevisiae* in a novel continuous bioreactor-biosorption system. *Chemical Engineering Journal* **264**, 863–872.

Apiratikul, R. &Pavasant, P. 2008. Batch and column studies of biosorption of heavy metals by *Caulerpalentillifera*. *Bioresource Technology* **99**(8), 2766–2777.

Babel, S. & Kurniawan, T.A. 2003. Low-cost adsorbents for heavy metals uptake from contaminated water: a review. *Journal of Hazardous Materials* **9**, 219–243.

Bailey, S.E., Olin, T.J., Bricka, R.M. & Adrian, D.D. 1999. A review of potentially low-cost sorbents for heavy metals. *Water Research* **33**(11), 2469–2479.

Bansode, P.R., Losso, J.N., Marshall, W.E., Rao, R.M. & Portier, R.J. 2003. Adsorption of metal ions by pecan shell-based granular activated carbons. *Bioresource Technology* **89**, 115–119.

Bhattacharyya, K.G. & Gupta S.S. 2008. Adsorption of a few heavy metals on natural and modified kaolinite and montmorillonite: A review. *Advances in Colloid and Interface Science* **140**, 114–131.

Brown, P.A, Gill, S.A, & Allen, S.J. 2000. Metal removal from wastewater using peat. *Water Research* **34**(16), 3907–3916.

Chapman, D. 2006. *Water Quality Assessments: A guide to the use of biota, sediments and water in environmental monitoring*. Taylor & Francis London, United Kingdom, Second Edition, ISBN13 9780415512244, 626 pp.

Charerntanyarak, L. 1999. Heavy metals removal by chemical coagulation and precipitation. *Water Science and Technology* **39**(10), 135–138.

Chen, G.H. 2004. Electrochemical technologies in wastewater treatment. *Separation and Purification Technology* **38**, 11–41.

Chen, X., Chen, G., Chen, L., Chen, Y., Lehmann, J., McBride, M.B. & Hay, A.G. 2011. Adsorption of copper and zinc by biochars produced from pyrolysis of hardwood and corn straw in aqueous solution. *Bioresource Technology* **102**(19), 8877–8884.

Denisova, V., Tihomirova, K., Mezule, L. 2017 Biosorption of Zn(II) by Sphagnum Peat. *Chemical Engineering Transaction* **57**, in Press.

Dhillon, G.S., Rosine, G.M.L., Kaur, S., Hegde, K., Brar S.K., Drogui, P. & Verma, M. 2016. Novel biomaterial from citric acid fermentation as biosorbents for removal of metals from waste chromated copper arsenate wood leachates. *International Biodeterioration & Biodegradation*, in Press.

Fu, F. & Wang, Q. 2011. Removal of heavy metal ions from wastewaters: A review. *Journal of Environmental Management* **92**(3), 407–418.

Gruskevica, K., Bumanis, G., Tihomirova, K., Bajare, D., Juhna, T. 2017. Alkaline activated material as the adsorbent for uptake of high concentration of zinc from wastewater. *Key Engineering Materials* **721**, 123–127.

Guo, Y., Qi, S., Yang, S., Yu, K., Wang, Z. & Xu, H. 2002. Adsorption of Cr(VI) on micro- and mesoporous rice husk-based active carbon. *Materials Chemistry and Physics* **78**(1), 132–137.

Hahn–Hägerdal, B., Galbe, M., Gorwa-Grauslund, M.F., Lidén, G. & Zacchi, G. 2006. Bio–ethanol–the fuel of tomorrow from the residues of today. *Trends in Biotechnology* **24**(12), 549–556.

Hossain, M.A., Ngo, H.H., Guo, W.S. &Setiadi, T. 2012. Adsorption and desorption of copper(II) ions onto garden grass. *Bioresource Technology* **121**, 386–395.

Iijima, S. 1991. Helical microtubules of graphitic carbon. *Nature* **354**, 56–58.

Kang, K.C., Kim, S.S., Choi, J.W. & Kwon, S.H. 2008. Sorption of Cu2+ and Cd2+ onto acid- and base-pretreated granular activated carbon and activated carbon fiber samples. *Journal of Industrial and Engineering Chemistry* **14**(1), 131–135.

Kang, S.Y., Lee, J.U., Moon, S.H. & Kim, K.W. 2004. Competitive adsorption characteristics of Co2+, Ni2+, and Cr3+ by IRN-77 cation exchange resin in synthesized wastewater. *Chemosphere* **56**(2), 141–147.

Kasiuliene, A., Paulauskas, V. & Kumpiene, J. 2016. Influence of nitrogen fertilizer on Cd and Zn accumulation in rapeseed (Brassica napus L.) biomass. *Agronomy Research* **14**(2), 418–427.

Kotrba, P., Mackova, M. & Macek, T. 2011. *Microbial Biosorption of Metals*. Springer, ISBN13 9789400704428, 329 pp.

Landaburu-Aguirre, J., Pongracz, E., Peramaki, P. & Keiski, R.L. 2010. Micellar-enhanced ultrafiltration for the removal of cadmium and zinc: Use of response surface methodology to improve understanding of process performance and optimization. *Journal of Hazardous Material* **180**, 524–534.

Lundh, M., Jönsson, L. & Dahlquist, J. 2000. Experimental studies of the fluid dynamics in the separation zone in dissolved air flotation. *Water Research* **34**(1), 21–30.

LVS EN 1484:2000 Water analysis – Guidelines for the determination of total organic carbon (TOC) and dissolved organic carbon (DOC). 2000.

Murthy, Z.V.P. & Chaudhari, L.B. 2008. Application of nanofiltration for the rejection of nickel ions from aqueous solutions and estimation of membrane transport parameters. *Journal of Hazardous Materials* **160**(1), 70–77.

Oyaro, N., Juddy, O., Murago, E.N.M. & Gitonga, E. 2007. The contents of Pb, Cu, Zn and Cd in meat in Nairobi, Kenya. *International journal of food, agriculture and environment* **5**, 119–121.

Pauly, M. & Keeqstra, K. 2008. Cell-wall carbohydrates and their modification as a resource for biofuels. *The Plant Journal* **54**(4), 559–568.

Polat, H. & Erdogan, D. 2007. Heavy metal removal from waste waters by ion flotation. *Journal of Hazardous Materials* **148**, 267–273.

Roy, D., Greenlaw, P.N. & Shane, B.S. 1993. Adsorption of heavy metals by green algae and ground rice hulls. *Journal of Environmental Science and Health. Part A: Environmental Science and Engineering and Toxicology* **28**(1), 37–50.

Sadrzadeha, M., Mohammadi, T., Ivakpour, J. & Kasiri, N. 2009. Neural network modeling of Pb2+ removal from wastewater using electrodialysis. *Chemical Engineering and Processing: Process Intensification* **48**(8), 1371–1381.

Shahalam, A.M., Al-Harthy, A. & Al-Zawhry, A. 2002. Feed water pretreatment in RO systems: unit processes in the Middle East. *Desalination* **150**(3), 219–303.

Sharma, P.K., Ayub, S. & Tripathi, C.N. 2013. Agro and horticultural wastes as low cost adsorbents for removal of heavy metals from wastewater: A review. *International Refereed Journal of Engineering and Science* **2**(8), 18–27.

Singha, A.S., Guleria, A. 2015. Utility of chemically modified agricultural waste okra biomass for removal of toxic heavy metal ions from aqueous solution. *Engineering in Agriculture, Environment and Food* **8**, 52–60.

Sud, D., Mahajan, G. & Kaur, M.P. 2008. Agricultural waste material as potential adsorbent for sequestering heavy metal ions from aqueous solutions – A review. *Bioresource Technology* **99**, 6017–6027.

van Beers, D., Kapur, A. & Graedel, T.E. 2007. Copper and zinc recycling in Australia: potential quantities and policy options. *Journal of Cleaner Production* **15**, 862–877.

Vengris, T., Binkiene, R. & Sveikauskaite, A. 2001. Nickel, copper, and zinc removal from wastewater by a modified clay sorbent. *Applied Clay Science* **18**, 183–190.

Wang L.K., Chen, J.P., Hung, Y-T. & Shammas, N.K. 2009. *Heavy Metals in the Environment*. Taylor & Francis Inc, ISBN 9781420073164, 516 pp.

Xu, Y. & Zhang, F. 2006. Experimental research on heavy metal wastewater treatment with dipropyl dithiophosphate. *Journal of Hazardous Materials* **137**, 1636–1642.

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Disinfection of solid fraction of cattle manure in drum-type bio-fermenter

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Abstract. In the context of increased intensification of production and disruption of established ties between livestock and crop farms there is an urgent need to introduce novel, more efficient, economically viable and environmentally sound techniques of animal and poultry manure processing. As a part of the ongoing work on implementation of best available techniques (BAT) in various sectors of Russian economy, agriculture included, the bioconversion technology of organic waste in a drum-type bio-fermenter was considered as one of BAT candidates, which is most adapted to the natural and climatic conditions of North-West Russia and feature the minimal environmental impact. The main purpose was to investigate the influence of bioconversion of solid fraction of cattle manure on selected microbial parameters and parasitic purity in the raw material, semi-finished and final products. The study was conducted in the IEEP Organic Waste Bioconversion Laboratory on a patented drum-type bio-fermenter. After 18 hours the digested material self-heated to 55 °C, i.e. the lower limit of the range of thermophilic microbial activity. By the 30th hour after the experiment started the temperature had reached the maximum level of 71 °C, then it dropped to 62–66 °C and stabilized in this range. 48 hours after the temperature reached 55 °C, the content of coliform bacteria reduced to acceptable limits, and that of *Enterococcus* dropped more than 10 times. After 120 hours the digested product was completely disinfected.

Key words: cattle manure, disinfection, biofermentation, microbial parameters, parasitic purity.

INTRODUCTION

Continuing population growth poses a challenge for agriculture to ensure the food security. In current situation it can be achieved only by making the production more intensive. However this process results not only in the bigger amount of produced food stuffs but also in the increased generation of waste, such as animal and poultry manure, the share of which in the total negative environmental effect from agro- industrial complex is up to 85% (Uvarov, 2016). This stimulates stipulates the active development and testing of new, more efficient technologies for animal waste recycling.

Russia is actively working on introduction of best available techniques (BAT) in the various sectors of economy, agriculture included. Practical application experience is one of the criteria for identifying a technology as BAT, but there are some other promising techniques for manure treatment, which have not been widely implemented so far as they are under-explored yet. With the aim to increase the number of BAT candidates the team of authors assessed the potential of one of the most efficient and environmentally friendly technologies for animal waste recycling –manure treatment in a drum-type bio-fermenter, which is regularly used to produce fertilizers and bedding. (Uvarov & Briukhanov, 2015; Subbotin et al., 2016).

MATERIALS AND METHODS

The main purpose was to investigate the influence of bioconversion of solid fraction of cattle manure on selected microbial parameters (the presence of *Bacillus* and *Proteus* pathogens, *Salmonella*, *Staphylococcus* and Enteropathogenic *E. coli* types; the Index of coliform bacteria and *Enterococcus*) and the parasitic purity (the presence of pathogenic intestinal protozoa cysts; viable larvae and pupae of synanthropic flies; eggs and larvae of helminths) in the raw material, semi-finished and final products (Gannon et al., 2004; Cliver, 2009).

The study was conducted in 2015–2016 in the IEEP Organic Waste Bioconversion Laboratory on a patented drum-type bio-fermenter (Fig. 1) (Briukhanov et al., 2014). Bio-fermenter is a movable drum with insulating coating, mounted with rollers on the fixed frame. The power unit and motor reduction unit drive the drum. Bio-fermenter is equipped with the composted mass aeration system in the form of a perforated pipe placed inside the drum along its full length.

The finished product is discharged by an auger, with special blades evenly spaced around the inner diameter of the drum to direct the ready compost to it.

The breadboard model of bio-fermenter with the dimensions of 4,300 × 2,100 × 1,650 mm, effective capacity of 2.2 m^3, and the daily output of 0.7 m^3, allows to study the biofermentation process of different types of organic waste in real time mode.

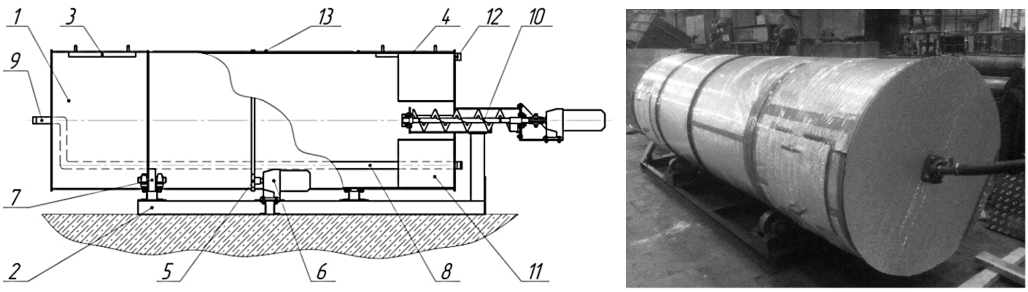

Figure 1. Breadboard model of an experimental drum-type bio-fermenter: 1 – rotating cylindrical drum; 2 – frame; 3 – charge hole; 4 – checking hole; 5 – power unit; 6 – motor reduction unit; 7 – mounting assemble; 8 – aeration pipe; 9 – air duct for outside air supply; 10 – discharging auger conveyor; 11 – blades; 12 – exhaust duct; 13 – heat insolation.

Initial raw material was solid fraction of cattle manure from a dairy farm with the animal stock of 900 head, manure output of 90 m^3 per day and the system of mechanical manure separation into solid and liquid fractions in place.

The raw material, semi-finished and final products were analysed in Leningrad Interregional Veterinary Laboratory and the analytical laboratory of IEEP.

The experiment was conducted under a cyclic operation mode of the bio-fermenter with three replications. The method of static full factorial experiment was applied, the optimization factor of which was reduction of microbial parameters and parasites in the final product to acceptable level in the course of bioconversion.

The mass of fermented product of 1,470 kg was taken with due account for the reasonable minimum critical mass value required for the successful conversion, and the design features of the laboratory-scale bio-fermenter (The composting process, 1996; Mironov & Khmirov, 2002).

The study was conducted under previously substantiated operation mode of the bio-fermenter: air supply – 12.86 $m^3 h^{-1}$, aeration – 5 min h^{-1}, drum rotation frequency – 3 revolutions every 12 hours (Uvarov et al., 2016).

Samples were taken following the State Standard GOST R 54519-2011 'Organic fertilizers. Sampling methods'.

Dynamic pattern of temperature, mass, moisture content and chemical composition was determined in the real time mode. The initial parameters were set according to the experiment planning matrixes. To improve the accuracy of acquired data the randomized matrixes were used in the experiments. The data obtained were processed by the method of statistical analysis in MS Excel, Statgraphics Centurion XIV & Mathcad 13.1 (Valge, 2013; Valge et al., 2015).

In the experiment the following equipment was used: ТЦМ 9410/М2 thermometer with ±0.5°C sensitivity; strain sensor 3410-2000-C3 with 0.02% error; laboratory scales Pioneer with 0.005% error; pH-meter/ionometer ЭКСПЕРТ-001 3(01) with 0.02% error, spectrophotometer ПЭ-5400 В with the accuracy of 0.001%, as well as atomic absorption spectrophotometer Shimadzu AA-680, with 0.001% error.

RESULTS AND DISCUSSION

Previous studies have shown that bioconversion in the drum-type biofermenter allows to save most of the nutrients, otherwise lost during other processing methods, owing to the higher intensity of bioconversion process (Uvarov et al., 2016; Subbotin et al., 2016).

Fermentation process of solid fraction of cattle manure is characterized by high dynamics of the temperature rise. After 18 hours the digested material self-heated to 55 °C, i.e. the lower limit of the range of thermophilic microbial activity (Kovalev & Baranovskiy, 2006; Selimbasic et al., 2012). By the 30th hour after the experiment started the temperature had reached the maximum level of 71 °C, then it dropped to 62–66 °C and stabilized in this range (Fig. 2).

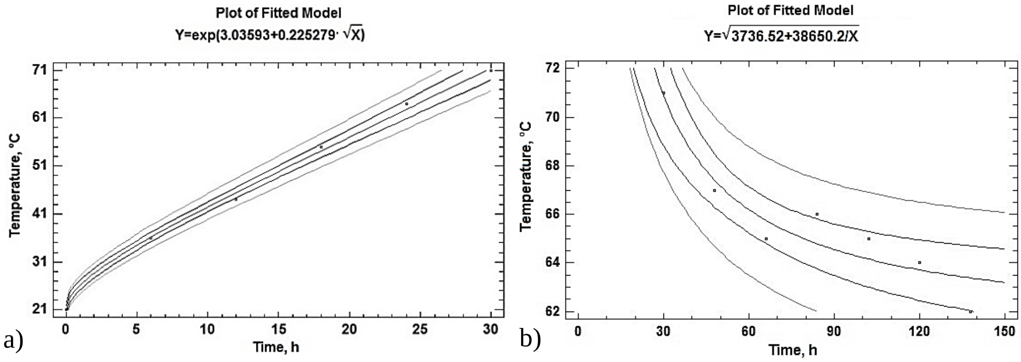

Figure 2. Heating (a) and maturation (b) of the solid fraction of cattle manure in the course of biofermentation.

Forty-eight hours after the temperature reached 55 °C (66 hours from the beginning of the experiment) the first sample was taken; after 120 hours (138 hours from the beginning of the experiment) – the second one. Results of laboratory analysis of the raw material, semi-finished and final products are presented in Table 1.

Table 1. Results of laboratory analysis of the raw material, semi-finished and final products of biofermentation of the solid fraction of cattle manure

Indicator	Experimental result, in 1 g			Permissible content in 1 g
	Raw material	Semi-finished product (48 hours fermentation)	Final product (120 hours fermentation)	
Microbiological indicators				
Bacillus pathogen	Detected	Detected	Not detected	Not allowed
Coliform bacteria Index	1,000	1–9	1–9	1–9
Proteus pathogen	Detected	Not detected	Not detected	Not allowed
Salmonella	Not detected	Not detected	Not detected	Not allowed
Staphylococcus	Not detected	Not detected	Not detected	Not allowed
Enterococcus Index	1,000	100	1–9	1–9
Enteropathogenic E. Coli types	Detected	Not detected	Not detected	Not allowed
Parasitic purity				
Pathogenic intestinal protozoa cysts	Not detected	Not detected	Not detected	Not allowed
Viable larvae and pupae of synanthropic flies	Not detected	Not detected	Not detected	Not allowed
Eggs and larvae of helminths	Not detected	Not detected	Not detected	Not allowed

The conducted investigation demonstrated that fermentation under the temperature above 55 °C for 48 hours reduced the Coliform bacteria Index to acceptable level, eliminated *Proteus* pathogen and Enteropathogenic *E. coli* types and resulted in 10 times lower *Enterococcus* Index.

Longer (up to 120 hours) fermentation period allowed achieving the elimination of *Bacillus* pathogen in the final product; *Enterococcus* Index was reduced to acceptable level.

At the same time the effect of biofermentation process on *Salmonella* and *Staphylococcus* as well as on pathogenic intestinal protozoa cysts, the viable larvae and pupae of synanthropic flies, the eggs and larvae of helminthes was not revealed as they were not present in the raw material.

CONCLUSIONS

1. Drum-type bio-fermenter is an efficient tool for disinfection of organic waste from some microbial cultures (Bacillus and Proteus pathogen; coliform bacteria; Enterococcus and Enteropathogenic E. coli types).

2. More research is needed to explore the biofermentation effect on some microbial cultures (*Salmonella* and *Staphylococcus*) and parasites (pathogenic intestinal protozoa cysts; viable larvae and pupae of synanthropic flies and the eggs and larvae of helminthes).

3. Improvement of bio-fermenter design parameters and operating modes will increase the potential of its application and achieve a shorter disinfection period by reducing the duration of heating and/or by increasing the processing temperature (Briukhanov & Uvarov, 2016).

4. One of the focuses of further research is the effect of the resulting final product on the structure and fertility of soil, as well as the possibility of its use as a bedding in cow barns.

5. In the future, the bioconversion of other types of waste in the drum-type biofermenter will be studied, such as poultry manure, solid fraction of pig manure, and some types of food waste.

REFERENCES

Briukhanov, A.Yu., Vasilev, E.V., Maksimov, N.V. & Uvarov, R.A. 2014. *Continuous-action bioreactor for conversion of organic waste materials*. Patent RU 146604. 03.06.2014.

Briukhanov, A.Yu. & Uvarov, R.A. 2016. Mathematical model of accelerated composting technology of farm animal waste in closed type installations. *KGTU News* **41**, 137–147. (in Russian).

Cliver, D.O. 2009. Disinfection of animal manures, food safety and policy. *Bioresource Technology* **100**, 5392–5394.

Gannon, V.P., Humenik, F., Rice, M., Cicmanec, J.L., Smith Jr., J.E. & Carr, R. 2004. Control of zoonotic pathogens in animal wastes. In: Cotruvo, J.A., Dufour, A., Rees, G., Bartram, J., Carr, R., Cliver, D.O., Craun, G.F., Fayer, R. & Gannon, V.P.J. (Eds.). *Waterborne Zoonoses: Identification, Causes and Control*. IWA (International Water Association) Publishing, London, pp. 409–425.

Kovalev, N.G. & Baranovskiy, I.N. 2006. *Organic fertilizers in the XXI century: bioconversion of organic material*. ChuDo Publishers, Tver, 304 pp. (in Russian).

Mironov, V.V. & Khmirov, V.D. 2002. Influence of active aeration on the intensity of biothermal processes in composted mixture. *Transactions of Tambov State Technical University* **4**, 668–672. (in Russian).

Selimbasic, V., Marić, S., Petric, I. & Djozic, A. 2012. Anaerobic batch fermentation of cattle manure. Effect of ammonia. *Journal of environmental protection and ecology* **13**(1), 211–218 pp.

Subbotin, I.A., Briukhanov, A.Yu. & Uvarov, R.A. 2016. Losses of nutrients at intensive processing of poultry manure. *International Research Journal* **1**–**3**(43), 41–42. DOI: 10.18454/IRJ.2016.43.132.

The composting process. 1996. Factsheet №382.500–2. Ministry of Agriculture and Food, British Columbia, 70 pp.

Uvarov, R.A. 2016. Bio-Fermentation of Manure in Closed Systems. *Poultry Journal* **10**, 53–56. (in Russian).

Uvarov, R.A. & Briukhanov, A.Yu. 2015. Advanced technologies of biofermentation manure/litter for North-West Russia. *Science Review* **16**, 26–31. (in Russian).

Uvarov, R., Briukhanov, A. & Shalavina, E. 2016. Study results of mass and nutrient loss in technologies of different composting rate: case of bedding poultry manure. In: *15th International Scientific Conference Engineering for rural development*. Latvia University of Agriculture, Jelgava, pp. 851–857.

Valge, A.M. 2013. *Use of EXCEL and MATHCAD in investigations related to mechanisation of agricultural production.* IEEP Publishers, St.Petersburg. 200 pp. (in Russian).

Valge, A.M., Jabborov, N.I. & Eviev, V.A. 2015. *Basics of statistical analysis of experimental data in investigations related to mechanisation of agricultural production with examples in STATGRAPHICS and EXCEL*. Kalmyk State University Publishers, Elista. 140 pp. (in Russian).

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The nexus between food insecurity and socioeconomic characteristics of rural households in Western Indonesia identified with Food and Nutrition Technical Assistance´s approach by USAID

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Abstract. This study investigated correlation and regression analyses designed to asses the respective relationships between the Household Food Insecurity Access Scale/ Prevalence (HFIAS/ HFIAP) as a measure of food access, the Household Dietary Diversity Score, the Months of Adequate Household Food Provisioning (MAHFP) as a measure of food stability and (i) gender, (ii) education level, (iii) household income and (iv) agricultural strategies of households in North Sumatra province. Cross-sectional survey was conducted in Tobasa and Samosir Regency and its purpose was (1) to assess the food security status of rural households (N = 192), (2) to identify the influence of selected factors on their food security condition and (3) to deliver outcomes which might play an important role in establishing appropriate policies and intervention strategy to prevent and reduce food insecurity. Due to the proven applicability in many studies, Food and Nutrition Technical Assitance's method was implemented for the comprehensive household food security analysis. The findings showed that 51.6% (n = 99) households were considered as moderately or severely food insecure, 18.8% of the sample as mildly food insecure (n = 36) and less than a third (n = 57) of households was food secure. Further analysis investigated the correlation between household food security status and selected variables. The results higlighted the role of rural education, agriculture extension services, creation of employment opportunities and improved dietary diversity in reducing household food insecurity.

Key words: Food Insecurity, Food Access, Dietary Diversity, Indonesia.

INTRODUCTION

Despite global economic crises, Indonesia has witnessed economic growth in recent years, making the list of lower middle income countries in 2009 (Gillespie & Van Den

Bold, 2015; WB, 2016). However, poverty, food insecurity and malnutrition have been still serious topics and remain with large disparities between provinces and districts (Campbell et al., 2011; Sibhatu et al., 2015). Yusuf & Sumner (2015) point out that between September 2014 and March 2015 the share of the Indonesian population in poverty increased even though economic growth was close to 5%. In addition, Global Hunger Index identified Indonesia as one out of 52 countries in the world where hunger remains at serious or alarming levels (IFPRI, 2015). The agricultural sector is very important for the country; it currently employs 35% of the workforce and contributes around 14.4% to national GDP (WB, 2016). This situation denotes a relatively low level of labor productivity compared to other sectors, particularly to manufacturing sector. The position also reflects the reality that more than 60% of poor Indonesians live in the rural areas where they mostly rely on agriculture for their livelihood (FAO, 2015).

Unfortunately, food insecurity affect especially smallholder farmers, farm workers and fishers who are financially and materially unable to use the opportunities provided by the national economic growth (IFAD, 2015). Therefore with the collaboration of the UN, the Indonesian government adopted the new Medium-Term Development Plan (RPJMN) 2010–2014 with the vision 'development for all', with no groups left behind. The RPJMN is an inclusive development strategy targeted on several outcomes including sustainable livelihoods where food security is an important priority for the UN. The goals of the strategy are linked to the Sustainable Development Goals (SDGs), particularly to SDG 2 ('end hunger, achieve food security and improved nutrition, and promote sustainable agriculture') (FSVA, 2009; UN, 2016). Besides RPJMN's targets, the National Food Security Council (FSC) in collaboration with the United Nations World Food Programme (WFP) produced and launched the first Food Insecurity Atlas (FIA) in 2005. The publication identified 100 priority districts as food insecure requiring an urgent attention of policy makers. Based on results of the FIA, The Government of Indonesia allocated 32 million USD to the most vulnerable districts. The first FIA 2005 and its updated version titled as Food Security and Vulnerability Atlas 2009 (FSVA) confirmed that despite Indonesia's economic and food security achievements, attaining food security for all remains to be a major challenge (USDA, 2012; FAO, 2015). In 2015, the third edition of the FSVA was launched and the discussion on nutrition was expanded to reflect its importance, as Indonesia officially launched its Scaling Up Nutrition movement and has prioritized stunting in the RPJMN. In the following National Medium Term Development Plan 2015–2019, the Indonesian government formulated a number development initiatives aimed at strengthening food sovereignty through five major strategies: (i) increase food availability by enhancing domestic production of key crops, (ii) improve quality of food distribution and the food accessibility, (iii) improve the overall quality and nutrition value of the Indonesian diet, (iv) protect food security through preparedness against natural disasters and plant diseases and (v) improve livelihoods of smallholders, fisherman and food producers.

Food insecurity is a serious social and public health problem in rural Indonesia as a whole. The geographic patterning of food insecurity such as the alarming rates in North Sumatra province, as well as the variation in rates that is found among districts, suggest that reducing the prevalence of food insecurity requires attention and action by all levels in government (FSVA, 2009; FSVA, 2015). The Indonesian minister of agriculture assured that food security in the country is one of the government priorities and through agriculture, forestry and fishery revitalization, the government has been consistently increasing food availability. The result was that Indonesia was able to escape from global food crisis and to regain self-sufficiency (FSVA, 2015). The government has been also improving basic infrastructure to smooth and expedite food distribution, improvement of people access to basic health facilities which results in improvement of health and nutrition indicators. As the president of the Republic of Indonesia states that food is human basic necessity therefore its fulfillment is not only to satisfy basic human rights or moral obligation of the Indonesian people but it also becomes economic as well as social investment to have better generation in the future (FAO, 2010).

This study aims to investigate the food insecurity in Western Indonesia at micro level and to assess the relationship between the socioeconomic characteristics and food security condition of households. Despite the warning food security situation in Indonesia, there is very poor empirical evidence focused on causes of household food insecurity. FSVA and other national reports give a comprehensive overview about food security situation on macro level. However, the scientific evidence oriented solely on household level remains neglected. Therefore, the data in this study provide an impetus for discussion that is critical to the development of programs and policies by all sectors aimed at tackling food insecurity in rural Indonesia.

MATERIALS AND METHODS

Data Collection

In two time periods; August 2013 and July 2014, a cross-sectional was conducted survey in two regencies of North Sumatra province; Samosir Regency and Tobasa Regency, in eight municipalities (Table 1). Semi-structured questionnaire, with both close and open ended questions, was developed and translated into local Batak language and then used for the data collection. To avoid later misunderstandings related to questions and ensure the accurate answers, the phase of pilot testing was included into the survey. The group of ten respondents was observed when filling the questionnaire; their hesitation, erasures and skipped questions. Random sampling was implemented to select households in each municipality, using the most recent household list available for the municipality and as the result, 192 households was used as the sample for upcoming analysis. The sample size in each regency (Table1) was independent of the size of the regency. Therefore, representativeness at regency level was not controlled.

Table 1. The Sites Participating in the Cross-sectional Survey (N = 192)

Regency	Subregency	Municipality
Samosir	Simanindo	Ambarita (n = 22)
(n = 68)	(n = 68)	Garoga (n = 27)
		Martoba (n = 19)
	Sigumpar	Sigumpar Dangsina (n = 30)
	(n = 79)	Dolok Jior (n = 26)
		Nauli (n = 23)
	Laguboti	Pasar Laguboti (n = 25)
	(n = 45)	Gasaribu (n = 20)

Survey Tools

From the collected data, frequently used food security indicators were computed to assess the food security status of the households. For this assessment a method developed by USAID's Food and Nutrition Technical Assistance (FANTA) was used. Its validity and applicability was used in many development studies such as De Cock et al., 2013; Maxwell et al., 2014; Salarkia at al., 2014; Desiere et al., 2015; Frayne & McCordic, 2015; Musemwa et al., 2015. Maxwell et al. (2014) point out that combining of indicators improves the measurement of food insecurity. Therefore, we computed the following three food security indicators and one categorization capturing different elements of the multidimensional notion of food security.

The Household Food Insecurity Access Scale (HFIAS) consists of nine questions which represent apparently universal domains of the household food insecurity (access) experience and it is used to assign households and populations along a continuum of severity, from food secure to severely food insecure (Radimer et al., 1990; Coates et al., 2007). The set of questions examines whether the household experienced a form of insufficient access to food in the past 30 days and with what frequency if the situation occurred. Based on these nine questions we computed the HFIAS score which measures the level of household food (access) insecurity (Coates, 2004). The respondents could choose four possible answers to each of nine questions; never, rarely, sometimes and often. The higher frequency means the greater score (0–27) and the higher household food (access) insecurity (Coates, 2004; Coates et al., 2007). According to the empirical evidence (Maxwell et al., 2014), the HFIAS indicator was found as well correlated capturing a mix of sufficiency and psychological factors of food insecurity.

The Household Food Insecurity Access Prevalence (HFIAP) classifies the households into four grades of food insecurity; food secure, mildly/ moderately and severely food insecure (Coates et al., 2007). The advantage of the tool is that it is not time consuming and invasive method compared e.g. anthropometry and it is the only tool that measures a direct experience of household food security (Coates, 2004).

*The Household Dietary Diversity Score (HDD*S) captures food quality and diversity (Maxwell et al., 2014). It mirrors the number of different food groups consumed by the households over a given reference period. These 15 food groups includes cereals, tubers and roots, vegetables, fruits, meat, eggs, fish and seafood, pulses/legumes and nuts, milk and milk products, oil/fats, sugar/honey and miscellaneous (Hoddinott & Yohannes, 2002; Swindale & Bilinsky, 2006).

The Month of Adequate Household Food Provisioning (MAHFP) measures how many months of the past year a household was not able to access enough food to meet their household needs (Bilinsky & Swindale, 2010).

The questionnaire data were captured and analyzed in the field using the SPSS Data Entry BuilderTM and the the latter data were analyzed using StatSoft's STATISTICA™12 and Gretl 1.9.14. Food security indicators (HFIAS, HFIAP, HDDS and MAHFP) were computed based on data collected and assessed the household food security status in various dimensions. The next stage of data analysis included several statistical methods to assess the correlations between calculated food security indicators and variables. Statistical significance was assessed using descriptive statistics, frequency distributions, two-sample t-tests, and chi-square test in contingency table. For further analysis, we selected multivariate linear models through the evaluation of variables proposed and retention of those variables that improved model performance. We used multivariate linear models where the HFIAS is interpreted as a regression function of constant, average total household income and diversity of off-farm activities adopted by the households.

RESULTS AND DISCUSSION

A basic exploratory analysis (Table 2) shows means, standard deviations and maximum values of used food security indicators. The average HFIAS score is 6.11 which falls into the first quarter of 0–27 possible range (the higher the score the more food insecure the household is). Average of the HDDS is 5.3 which means that average household consumes only less than a third of the different food groups available to them. This result confirmed a statement of The Economist's Global Food Security Index which identified five challenges for improving food security in Indonesia; (i) public expenditure on agricultural research and development, (ii) corruption, (iii) gross domestic product per capita, (iv) protein quality and (v) diet diversification (GFSI, 2015). According to Rah et al. (2010) low dietary diversity is a strong predictor of stunting among children aged 6–59 months and it also plays an important role for development of mental disorders (Poorrezaeian, 2015). Therefore, diet diversification should be considered as a high priority for improving food and nutrition security in North Sumatra Province. The MAHFP indicates that households are able to provide for themselves with adequate food for 11.41 months per year in average.

Table 2. Summary Statistics of the 3 Food Security Indicators

Indicator	Mean	Stdev	Max. value recorded
HFIAS[a]	6.11	6.59	27
HDDS[b]	5.30	2.57	15
MAHFP[c]	11.41	1.07	12

[a] Household Food Insecurity Access Scale; [b] Household Dietary Diversity Score;
[c] Months of Adequate Household Food Provisioning.

Following figures (Figs 1–3) show frequency distribution of the food security indicators. The frequency distribution of the HFIAS and the MAHFP is unimodal (Figs 1 and 3) while the data distribution of the HDDS (Fig. 2) is right-skewed. This shape in Fig. 2 indicates overall poor dietary diversity among households in both regencies. Fig. 4 shows a bimodal distribution; the highest peak is represented by severely food insecure households (31.6% of total respondents) and the second one by food secure households (30%). Fig. 4 indicates that (i) there is similar number of households in both regencies who are considered as severely food insecure and food secure (ii) there is nearly the same number of moderately and mildly food insecure households.

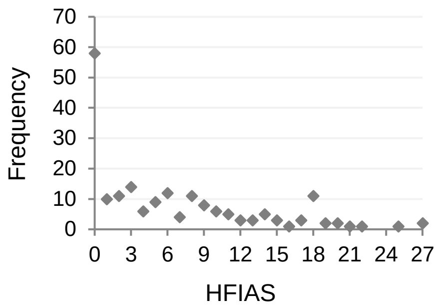

Figure 1. The HFIAS Score Distribution.

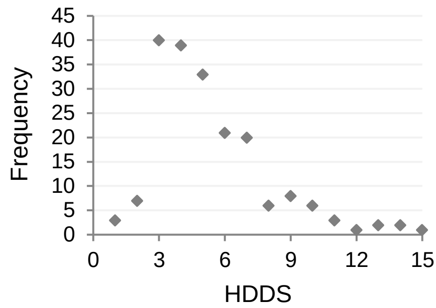

Figure 2. The HDDS Score Distribution.

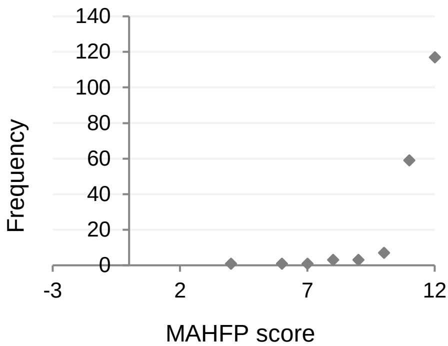

Figure 3. The MAHFP Distribution.

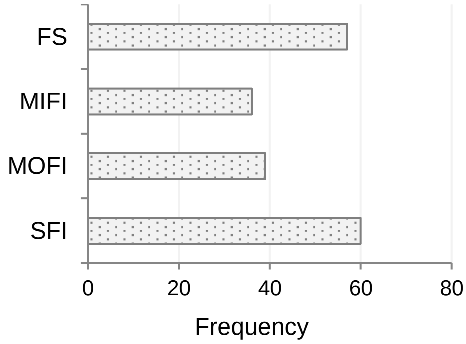

Figure 4. The HFIAP Distribution, Food secure (FS), Mildly food insecure (MIFI), Moderately food insecure (MOFI), Severely food insecure (SFI).

In accordance with the survey's objectives, the correlation between HFIAS, HDDS, MAHFP, HFIAP and selected variables was assessed.

(i) Gender

Two-sample t-tests were used for testing difference between male-headed and female-headed households in each indicator. In general, status of women in Indonesia is disadvantaged; particularly in terms of their socioeconomic situation (Retnaningsih, 2013; Swamy, 2014; Guilmoto, 2015; Sohn, 2015) and it is also reflected it their deteriorative nutrition security condition (Vaezghasemi et al., 2014). Results of these studies are supported by the UNDP´s Gender Inequality Index which is 0.49, ranking Indonesia 110 out of 186 (UNDP, 2015). Table 3 gives results about differences in terms of gender depending on household food security status. On each indicator the female-headed households experience more severe status of food insecurity than male-headed households. However, differences between male-headed and female-headed household related to two out of three food security indicators (the HFIAS and the HDDS) are not statistically significant. In culture of Batak Ethnicity, there are no expressive differences in livelihoods of men and women, particularly in gender division of labor which may explain low statistical differences between the gender and the HFIAS and the HDDS.

Batak women are used to working in the field, carry out most home food processing and have primary responsibility for raising children. This labor division and livelihood strategies adopted by Batak women make them and their households less vulnerable to food insecurity in the case of death of a spouse or separation. However, in the case of the MAHFP indicator, the difference between male and female-headed households is statistically significant ($\alpha = 0.01$). It indicates that female-headed households have disadvantaged access to food during the year to meet their dietary needs; 10.69 months per year compared to male-headed households' access – 11.47 months per year. This result is in contradiction with the findings about low statistical differences between remaining food security indicators (the HFIAS and the HDDS) and gender. The difference may be explained by the different on-farm activities adopted by men and women. In North Sumatra, women direct their on-farm activities on growing of traditional crops while men as farmers are more likely to grow cash crops which enable them to generate cash for purchasing of food easily.

Table 3. Food Security Indicators in Relation to Gender

	Male-Headed Households		Female-Headed Households		t-stat
	Mean	Stdev	Mean	Stdev	
HFIAS[a]	5.96	6.52	7.44	7.50	0.856
HDDS[b]	5.27	2.58	5.81	2.67	0.810
MAHFP[c]	11.47	0.86	10.69	2.26	2.856***

[a] Household Food Insecurity Access Scale; [b] Household Dietary Diversity Score;
[c] Months of Adequate Household Food Provisioning; ***1% significance level.

For the confirmation of these findings, we extended analysis on testing of correlation between the HFIAP categorization and gender. Because of low frequencies, the HFIAP categories were coupled into two groups; (i) food secure and mildly food insecure and (ii) moderately food insecure and severely food insecure. For this analysis, we used chi-square test in contingency table (power of performed test with $\alpha = 0.050$). The test confirmed the previous result that level of household food insecurity was not associated with gender (*p-value* = 0.155).

(ii) Education Level

In general, education contributes to development in social, institutional and also to economic spheres. Based on this theory, education is expected to have a significant explanatory power in relation to food security in rural areas (Tawodzera, 2011; Chatterjee et al., 2012; Akerele et al., 2013) However, there is empirical evidence with the opposite tendency (De Cock et al., 2013; Musemwa et al., 2015). Table 4 displays the average values of the food security indicators for different education levels of the head of households. In the case of the HFIAS, the clear interaction between level of food security and education is obvious; the higher education level, the lower the HFIAS (the milder the household food insecurity). This indicates that households headed by educated people achieve higher levels of food security. If we compare the values of the HFIAS (scaled on a range of 0 to 27) at the primary (11.1) and a master education (0.7), we conclude that there is a strong correlation between household food security and education as a representative of households' human capital. In the case of the HDDS, some fluctuations may be observed. Based on the results, households headed by people who achieved master degree consumes in average purely 4.0 food groups out of 15 possible food groups. While heads of households with educational attainment at vocational school consume in average 7.5 food groups. This finding may be related to increased consumption of wild crops by people with lower educational levels.

According to FSVA (2015), wild foods obtained from hunting and gathering can significantly contribute to food and nutrition security, particularly in remote areas. Gathered wild crops are believed to contribute substantially to calorie intake and hunted rodents, mammals and insects provide important sources of animal protein. The MAHFP returns with its tendency to the HFIAS and affirms the initial hypothesis. Households headed by people with higher educational levels have an improved food provisioning. For comparison, people with master degree and their households have and adequate access to food in 12 months per year whiles those with primary education experience adequate food availability 11.1 months per year in average. Despite these results, a statistically significant difference was not observed. However, overall results confirmed the importance of education as human capital and support an assumption that rural people with more education are more likely to experience higher levels of food security.

Table 4. Relation of Food Security Status and Education Level of Head of Household

Head of Household Education Level	HFIAS [a]	HDDS [b]	MAHFP [c]
	Means (Stdev)		
Primary school	11.1 (7.7)	5.0 (3.1)	11.1 (1.0)
Junior high school	7.6 (6.9)	5.7 (2.8)	11.5 (0.6)
Senior high school	5.8 (6.5)	5.0 (2.4)	11.4 (0.9)
Vocational school	5.5 (3.5)	7.5 (3.5)	11.5 (0.7)
Associate bachelor	6.3 (6.6)	5.9 (2.2)	12.0 (0.0)
Undergraduate degree	3.2 (5.4)	5.3 (2.1)	11.6 (1.3)
Master degree	0.7 (0.6)	4.0 (1.7)	12.0 (0.0)
No data	3.8 (4.3)	6.3 (3.7)	10.0 (2.9)

[a] Household Food Insecurity Access Scale; [b] Household Dietary Diversity Score; [c] Months of Adequate Household Food Provisioning.

(iii) Household Income

Low income is considered as one of the main determinants driving households into food insecurity (Alderman, 2009). Many studies conducted in developing countries confirmed that economically vulnerable households are more likely to be food insecure (Rosen & Shapouri, 2001; Rose & Charlton, 2002; Labadarios et al., 2011), particularly in rural areas. Low-income households have limited access to agricultural inputs which is influencing the quality and volume of their agricultural production as 82.3% of respondents direct their livelihood on on-farm activities. Based on these, it is expected that low-income rural households in Tobasa Regency and Samosir Regency achieve low levels of food security.

Table 5 gives the income quintiles for the sample. For a clearer analysis, data set was divided into five groups with the approximately equal frequency of households, ranked by amount of household total cash income. Results document that high-income households (quintile 5) have eleven fold higher average total household cash income than low-income households (quintile 1) which indicates high income inequality in the region. Indonesia has one of the fastest rising rates of inequality in the East Asia region. Its Gini coefficient has increased from 0.32 in 1999 to 0.41 in 2012. Therefore The World Bank has been working closely with the Government of Indonesia in analyzing the trends and consequences of inequality (Miranti et al., 2014; WB, 2016). The phenomenon of high inequality among households was confirmed in our survey.

Table 5. Income Quintiles (in IDR and USD)

Income Quintile	Avg. HH Total Income (IDR)	Lower Limit (IDR)	Upper Limit (IDR)	Avg. HH Total Income (USD)	Lower Limit (USD)	Upper Limit (USD)
20% (1)	662,500	75,000	1,000,000	51.3	5.8	77.4
40% (2)	1,314,063	1,000,000	1,600,000	101.7	77.4	123.8
60% (3)	2,007,813	1,650,000	2,500,000	155.4	127.7	193.5
80% (4)	3,368,750	2,500,000	4,500,000	260.7	193.5	348.2
100% (5)	7,400,000	5,000,000	35,000,000	572.7	387.0	2,708.6

Table 6 shows a clear correlation between food security indicators and household income. The most significant differences may be observed in case of the HFIAS when the higher is the score, the more severe household food insecurity is. Low-income households achieve in average score of 12.4 while high-income households attain only score of 2.4 out of maximal score of 27. These results may be taken as evidence supporting the claim that food accessibility and availability increase with household income. Similar findings associating food insecurity and income are reported in other studies (Tawodzera, 2011; Chatterjee et al., 2012; Akerele et al., 2013). However there is also evidence about the opposite tendency when food secure households are considered as low-income (De Cock et al., 2013; Musemwa et al., 2015).

Table 6. Food Security Indicators in Relation to Total Household Income Quintile

	Income Quintile 1	Income Quintile 2	Income Quintile 3	Income Quintile 4	Income Quintile 5	No Data
	Means (stdev)					
HFIAS [a]	12.4 (7.6)	7.9 (6.5)	4.4 (5.7)	4.2 (4.7)	2.4 (3.2)	5.3 (6.2)
MAHFP [b]	10.9 (1.2)	11.3 (0.9)	11.4 (1.2)	11.8 (0.6)	11.9 (0.3)	11.2 (1.5)
HDDS [c]	5.2 (3.0)	5.2 (2.2)	5.5 (2.4)	6.0 (2.4)	5.8 (3.1)	4.2 (2.0)

[a] Household Food Insecurity Access Scale; [b] Months of Adequate Household Food Provisioning; [c] Household Dietary Diversity Score.

(iv) Agricultural Strategy

In Table 7, the differences in the HFIAP scores depending on on-farm activity are given. Because of low frequencies, we merged the original four categories into two categories with higher frequencies. Groups depending on certain type of livelihood strategy were divided into four clusters as it is described in Table 7. Households which drive their livelihoods on no crop and no livestock production (Crop production=0, Livestock production=0) provably attain the highest levels of food security. These households tend to be from 61.8% food secure or mildly food insecure and from 38.8% moderately or severely food insecure. While households which focus their livelihoods on both crop and livestock production are more likely to be moderately of severely food insecure – from 57.7%.

Table 7. The HFIAP Categorization in Relation to Crop and Livestock Production

Livelihood strategy	FS[a] + MIFI[b] %	MOFI[c] + SFI [d] %	n=	u-statistics
Cluster 1: Crop production=0, Livestock production=0	61.8	38.2	34	1.336
Cluster 2: Crop production=0, Livestock production=1	53.3	46.7	15	0.258
Cluster 3: Crop production=1, Livestock production=0	51.3	48.7	39	0.160
Cluster 4: Crop production=1, Livestock production=1	42.3	57.7	104	-1.151

[a] Food secure; [b] Mildly food insecure; [c] Moderately food insecure; [d] Severely food insecure.

Regression Analysis

To predict the correlation between food security status of households (represented by the HFIAS), diversity of off-farm activities and total household cash income we prepared several regression methods and used multivariate linear models and ordinary least squares method. This model interprets the HFIAS as a regression function of constant, average total household cash income and number of off-farm activities. We expect that the higher is the total household cash income and number of various off-farm activities, the milder the level of household insecurity is,i.e. the lower is the HFIAS. Therefore, estimated regression model is: $\boldsymbol{\hat{y} = 8.461 - 0.573\, x_1 - 1.004\, x_2}$, where y is the HFIAS, x1 is average total household income and x_2 is the number of off-farm activities. Estimated regression coefficients confirm that relation between the HFIAS and average total household income is indirect, and the same relation is for the HFIAS and the number of off-farm activities. An increase of the average household total income by 1 million IDR, an equivalent of 76.24 USD, results in the HFIAS decreasing by 0.57 points. Scores of the HFIAS are scaled on a range of 0 to 27. Similarly, an increase in number of various off-farm activities adopted by households by one causes a decrease of the HFIAS by 1.004 point. The quality of the regression model was approved by the *F-test* (*p-value* = 0.000035). Individual t-tests are statistically significant for constant and b_1 and statistically insignificant for b_2, i. e. average total household income is a suitable predictor for the HFIAS. The coefficient of determination is rather low, i. e. only lower proportion of variability of observed data was explained by the model. These findings confirm the importance of off-farm activities and higher household incomes for improving of food security in rural areas. In addition, the regression model developed can play an important role in food insecurity reduction as a tool in hands of policy makers. According to empirical evidence of McCarthy & Sun (2009), rural people who direct their livelihood on off-farm activities tend to be more educated than those focused on on-farm activities. This fact highlights the education as one of the key means how to mitigate household food insecurity. On the other hand, results of our survey showed that heads of households with higher education levels suffered the lower dietary diversity (Table 4).

CONCLUSIONS

This study aimed to assess the extent and determinants of household food insecurity in rural areas of North Sumatra Province. Cross-sectional survey involved 192 households from two regencies in North Sumatra province. The combination of several food security indicators used for data analysis ensured capturing different aspects of the multidimensional concept of food security. The results revealed that 20.3% of the households were classified as moderately food insecure and 31.3% as severely food insecure. 82.3% of the households drive their livelihood on on-farm activities and 17.7% is focused on off-farm activities. Further analysis showed that on-farm activities adopted by the households supported dietary diversity but did not contribute in alleviating food insecurity, particularly in the terms of availability and access. Households with neither crop nor livestock production were found as significantly more resistant to food insecurity. The average values of the food security indicators confirmed the alarming situation in North Sumatra province; the HFIAS (scaled on a range of 0 to 27) takes average value of 6.11, the HDDS 5.30 and the MAHFP 11.41. The low value of the average HDDS testifies poor dietary diversity among the rural households. On the contrary, obtained average value of the MAHFP indicates an excellent availability of adequate food during the year. The other results demonstrated food security condition of households depending on education level of head of household, total household cash income and gender. Despite disadvantaged status of women in Indonesia, statistically significant difference between male-headed and female-headed households was confirmed only in the case of the MAHFP. Overall analysis of correlation between the gender and household food security condition demonstrated that female-headed households did not tend to be more vulnerable to food insecurity. Further results highlighted the importance of education as a representative of human capital. Households headed by member with low education level experienced severe food insecurity; the average HFIAS for master degree was 0.7 while for primary school was 11.1. In spite of this conclusion, dietary diversity of households headed by more educated members was lower. Other results confirmed that household food insecurity increased with poor household cash income. Since the empirical evidence about household food security situation in North Sumatra has been currently very poor and therefore establishing an intervention strategy is difficult in the area, there are few recommendations coming from the study. Based on the analysis, the promotion of education in rural areas has power to mitigate the severe levels of household food insecurity, as education is significantly correlated with food security. Policy makers should take steps to support household income security as one of the main food insecurity determinants. Cash management seminars for head of households may contribute to better household income distribution and its effective utilization. Other policies should be focused on supporting labor market in rural areas with employment opportunities since higher number of off-farm activities adopted by households were significantly correlated with milder levels of food insecurity. The study produced a regression model demonstrating correlations among household income, off-farm activities and the HFIAS, as the measure of food access. Accordingly, the model should be considered as a tool to establish appropriate policies and intervention strategy in an effort to reduce the number of food insecure households in rural areas of Indonesia.

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REFERENCES

Alderman, H. 2009.The economic cost of a poor start to life. *Journal of Developmental Origins of Health and Disease* **1,** 19–25.

Akerele, D., Momoh, S., Aromolaran, A.B., Oguntona, C.R.B. & Shittu, A.M. 2013. Food insecurity and coping strategies in South-West Nigeria. *Food Security* **5**, 407–414.

Bilinsky, P. & Swindale, A. 2010. Months of Adequate Household Food Provisioning (MAHFP) for Measurement of Household Food Access. Indicator Guide, version 4. Washington D.C.: Food and Nutrition Technical Assistance Project, Academy for Educational Development.

Campbell, A.A., Akhter, N., Sun, K., De Pee, S., Kraemer, K., Moench-Pfanner, R., Rah, J.H., Badham, J., Bloem, M.W. & Semba, R.D. 2011. Relationship of household food insecurity to anemia in children aged 6–59 months among families in rural Indonesia. *Annals of Tropical Pediatrics* **31**, 321–330.

Chatterjee, N., Fernandes, G. & Hernandez, M. 2012. Food insecurity in urban poor households in Mumbai, India. *Food Security* **4**, 619–632.

Coates, J. 2004. Experience and Expression of Food Insecurity across Cultures: Practical Implications for Valid Measurement. Washington D.C.: Food and Nutrition Technical Assistance Project, Academy for Educational Development.

Coates, J., Swindale, A. & Bilinsky, P. 2007. Household Food Insecurity Access Scale (HFIAS) for Measurement of Food Access. Indicator Guide, version 3. Washington D.C.: Food and Nutrition Technical Assistance Project, Academy for Educational Development.

De Cock, N., D'Haese, M., Vink, N., van Rooyen, C.J., Staelens, L., Schonfeldt, H.C. & D'Haese, L. 2013. Food security in rural areas of Limpopo province, South Africa. *Food Security* **5**, 269–282.

Desiere, S., D'Haese, M. & Niragira, S. 2015. Assessing the cross-sectional and inter-temporal validity of the Household Food Insecurity Access Scale (HFIAS) in Burundi. *Public Health Nutrition* **18**, 2775–2785.

Food and Agriculture Organization (FAO). 2010. Household food security and community nutrition. Nutrition and consumer protection. Available at: http://www.fao.org/ag/agn/nutrition/household_en.stm

Food and Agriculture Organization (FAO). 2015. Food and Nutriton Security Profiles. Indonesia. Available at: http://www.fao.org/countryprofiles/index/en/?iso3=idn

Food Security and Vulnerability Atlas of Indonesia (FSVA). 2009. World Food Programme and Dewan Ketahanan Pangan. Available at: http://documents.wfp.org/stellent/groups/public/documents/ena/wfp236710.pdf

Food Security and Vulnerability Atlas of Indonesia (FSVA).(2015). World Food Programme and Dewan Ketahanan Pangan. Available at: http://documents.wfp.org/stellent/groups/public/documents/ena/wfp276246.pdf

Frayne, B. & McCordic, C. 2015. Planning for food secure cities: Measuring the influence of infrastructure and income on household food security in Southern African cities. *Geoforum* **65**, 1–11.

Gillespie, S. & Van Den Bold, M. 2015. Stories of change in Nutrition: A Tool Pool. IFPRI Discussion Paper 01494. Poverty, Health and Nutrition Devision.

Global Food Security Index (GFSI). 2015. Indonesia. The Economist: The Intelligence Unit. Available at: http://foodsecurityindex.eiu.com/Country/Details#Indonesia

Guilmoto, C.Z. 2015. Mapping the diversity of gender preferences and sex imbalances in Indonesia in 2010. *Population Studies – A Journal of Demography* **69**, 299–315.

Hoddinott, J. & Yohannes, Y. 2002. Dietary Diversity as a Household Food Security Indicator. Washington, D.C.: Food and Nutrition Technical Assistance Project, Academy for Educational Development.

IFPRI. 2015. Global Hunger Index. Indonesia. Available at: http://ghi.ifpri.org/countries/IDN/

International Fund for Agricultural Development (IFPRI). 2015. Investing in Rural People. Available at: http://www.ifad.org/operations/projects/regions/PI/factsheets/id.pdf

Labadarios, D., Mhciza, Z.J.R., Steyn, N.P., Gericke, G., Maunder, E.M.W., Davids, Y.D. & Parker, W.A. 2011. Food security in South Africa: a review of national surveys. *Bulletin of the World Health Organization* **89**, 891–899.

Maxwell, D., Vaitla, B. & Coates, J. 2014. How do indicators of household food insecurity measure up? An empirical comparison from Ethiopia. *Food Policy* **47**, 107–116.

McCathy, N. & Sun, Y. 2009. Participation by Men and Women in Off-farm Activities.An Empirical Analysis in Rural Northern Ghana.IFPRI Discussion Paper 00852.Environment and Production Technology Division.

Miranti, R., Duncan, A. & Cassells, R. 2014. Revisiting the Impact of Consumption Growth and Inequality on Poverty in Indonesia during Decentralization. *Bulletin of Indonesian Economic Studies* **50**, 461–482.

Musemwa, L., Muchenje, V., Mushunje, A., Aghdasi, F. & Zhou, L. 2015. Household food insecurity in the poorest province of South Africa: level, causes and coping strategies. *Food Security* **7**, 647–655.

Poorrezaeian, M., Siassi, F., Qorbani, M., Karimi, J., Koohdani, F., Asayesh, H. & Sotoudeh, G. 2015. Association of dietary diversity score with anxiety in women. *Psychiatry Research* **230**, 622–627.

Radimer, K. L., Olson, C.M. & Campbell, C.C. 1990. Development of indicators to assess hunger. *Journal of Nutrition* **120**, 1544–1548.

Rah, J.H., Akhter, N., Semba, R.D., de Pee, S., Bloem, M.W., Campbell, A.A., Moench-Pfanner, R., Sun, K., Badham, J. & Kraemer, K. 2010. Low dietary diversity is a predictor of child stunting in rural Bangladesh. *European Journal of Clinical Nutrition* **64**, 1393–1398.

Retnaningsih, U.O. 2013. Indonesian Educated Unmarried Career Women: Gender Inequality, Discrimination, and Prejudices. *Asian Women* **29**, 5–25.

Rose, D. & Charlton, K.E. 2002. Quantitative indicators from a food expenditure survey can be used to target the food insecure in South Africa. *Journal of Nutrition* **132**, 3235–3242.

Rosen, S.L. & Shapouri, S. 2001. Effects of Income Distribution on Food Security. Agricultural Information Bulletins 33717. United States Department of Agriculture, Economic Research Service.

Salarkia, N., Abdollahi, M., Amini, M. & Neyestani, T.R. 2014. An adapted Household Food Insecurity Access Scale is a valid tool as a proxy measure of food access for use in urban Iran. *Food Security* **6**, 275–282.

Sibhatu, K.T., Krishna, V.V. & Qaim, M. 2015. Production diversity and dietary diversity in smallholder farm households. *Proceedings of the National Academy of Sciences of the United States of America* **112**, 10657–10662.

Sohn, K. 2015. Gender Discrimination in Earnings in Indonesia: A Fuller Picture. *Bulletin of Indonesian Economic Studies* **51**, 95–121.

Sumatera Utara Dalam Angka (SUDA). 2015. Medan: Badan Pusat Statistik Provinsi Sumatera Utara.

Swamy, V. 2014. Financial Inclusion, Gender Dimension, and Economic Impact on Poor Households. *World Development* **56**, 1–15.

Swindale, A. & Bilinsky, P. 2006. Household Dietary Diversity Measurement of Household Food Access. Indicator Guide, version 2. Washington D.C.: Food and Nutrition Technical Assistance Project, Academy for Educational Development.

Tawodzera, G. 2011. Vulnerability in crisis: urban household food insecurity in Epworth, Harare, Zimbabwe. *Food Security* **3**, 503–520.
United Nations (UN). 2016. Sustainable Development Goals. Available at: https://sustainabledevelopment.un.org/?menu=1300
United Nations Development Programme (UNDP). 2015. Human Development Reports. Gender Inequality Index. Available at: http://hdr.undp.org/en/data
United States Department of Agriculture (USDA). 2012. Indonesia.Food Law 2012.Global Agricultural Information Network.
Vaezghasemi, M., Ohman, A., Eriksson, M., Hakimi, M., Weinehall, L., Kusnanto, H. & Ng, H. 2014. The Effect of Gender and Social Capital on the Dual Burden of Malnutrition: A Multilevel Study in Indonesia. *Plos One* **9**, e103843.
World Bank (WB). 2016. Indonesia. Available at: http://www.worldbank.org/en/country/indonesia
Yusuf, A.A. & Sumner, A. 2015. Growth, Poverty, and Inequality under Jokowi. *Bulletin of Indonesian Economic Studies* **51**, 323–348.

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Frey, R. 1958. Zur Kenntnis der Diptera brachycera p.p. der Kapverdischen Inseln. *Commentat.Biol.* **18**(4), 1–61.

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