Agronomy Research

Established in 2003 by the Faculty of Agronomy, Estonian Agricultural University

Aims and Scope:

Agronomy Research is a peer-reviewed international Journal intended for publication of broad-spectrum original articles, reviews and short communications on actual problems of modern biosystems engineering incl. crop and animal science, genetics, economics, farm- and production engineering, environmental aspects, agro-ecology, renewable energy and bioenergy etc. in the temperate regions of the world.

Copyright:

Agronomy Research online:

Agronomy Research is available online at: http://agronomy.emu.ee/

Acknowledgement to Referees:

The Editors of *Agronomy Research* would like to thank the many scientists who gave so generously of their time and expertise to referee papers submitted to the Journal.

Abstracted and indexed:

SCOPUS, EBSCO, CABI Full Paper and Thompson Scientific database: (Zoological Records, Biological Abstracts and Biosis Previews, AGRIS, ISPI, CAB Abstracts, AGRICOLA (NAL; USA), VINITI, INIST-PASCAL.)

Subscription information:

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

Journal Policies:

Estonian University of Life Sciences, Estonian Research Institute of Agriculture, Latvia University of Agriculture, Aleksandras Stulginskis University, Lithuanian Research Centre for Agriculture and Forestry and Editors of *Agronomy Research* assume no responsibility for views, statements and opinions expressed by contributors. Any reference to a pesticide, fertiliser, cultivar or other commercial or proprietary product does not constitute a recommendation or an endorsement of its use by the author(s), their institution or any person connected with preparation, publication or distribution of this Journal.

ISSN 1406-894X

CONTENTS

Agronomy Research **14**(4), 1247–1256, 2016

Traceability system of olive oil: a case study based on the performance of a new software cloud

L.M. Abenavoli[1,*], F. Cuzzupoli[2], V. Chiaravalloti[1] and A.R. Proto[1]

[1]Department of AGRARIA, Mediterranean University of Reggio Calabria, Località Feo di Vito, IT 89126 Reggio Calabria, Italy
[2]CFadvanced – Mosorrofa, IT 89100 Reggio Calabria, Italy
[*]Correspondence: laben@unirc.it

Abstract. For all the European agrifood establishments from the year 2005 it became mandatory the Regulation EC 178/2002 which obliges them to implement an internal system for tracking and tracing (T&T) of the products; the Regulations that has introduced an 'obligatory route' that consists of the construction of the 'certified historic' of a food or an ingredient along the supply chain. The Regulation concerns all food companies and in particular those in which there are different actors that contribute to obtaining the final product as in the case of the supply chain of olive oil.
Informatics with modern technology allows us to provide the company with a software solution, usable as a web application, everything housed on a system cloud server. The project goal was to implement a WebApplication based on Cloud Platform and centralize all information about to the context of the production of olive oil.
The results showed that the centralization of data provided by the software in question permit the various figures of the supply chain of olive oil to collaborate in an environment where you get all the information in real time. The system implements algorithms that provide notification messages that indicate if there are any delays in production/processing in terms of quality of the olive oil sought.
The operators and final customer will be equipped with an APP free for smartphones, which allow you to detect in a simple and immediate all data (in synchronize with the cloud system) and to get the product TRACEABILITY.

Key words: Traceability, safety, quality, olive growing, oil.

INTRODUCTION

Traceability is considered today a crucial factor for the agrifood sector (Papetti et al., 2012; Costa et al., 2013). The specific definition of traceability within the agricultural framework of the agrifood domain as it can be found on the OnTrace (2007), refers to it as 'The ability to locate an animal, commodity, food product or ingredient and follow its history in the supply chain forward (from source to consumer) or backward (from consumer to source)'. Food traceability implies the control of the entire chain of food production and marketing, allowing the food to be traced through every step of its production back to its origin (Holm et al., 2007; Ampatzidis & Vougioukas, 2009). The verification of food traceability is necessary for the prevention of deliberate or accidental mislabeling, which is very important in the assurance of public health. Thus, several regulations provide the basis for the assurance of a high level of protection of human health and consumers' interest in relation to food. In the case of olive oils, the increase in the demand for high-quality olive oils has led to the appearance in the market of olive oils elaborated with specific characteristics (Zohreh & Sattar, 2012).

The present study highlighted that, in spite of the requirement to enforce the above EC regulation 178 by January 1st, 2005 (subsequently extended to January 1st, 2006), a poor attention is still attached to the issue of traceability at a community level where many gaps still remain in terms of information on such systems. The Regulation is joined by other provisions, the publication of which is optional, among which the UNI, EUREPGAP and similar, which define the tracking company and/or the supply chains in different level of detail. All this in order to guarantee the food safety, optimize and adapt the production chain in case of problems or risks. Concerns all food companies and in particular those in which there are different actors that contribute to obtaining the final product as in the case of the supply chain of olive oil.

In Italy, one of the main agricultural crops is represented by the cultivation of olive trees. Olive cultivation characterizes the Italian agricultural landscape and national agricultural economics (Proto & Zimbalatti, 2010). Italy is the world's second largest producer of olive oil. With about 3,300,000 tones, Italian production of olives is situated at the second place in Europe after Spain. Three regions in southern Italy account for 66% of Italian olive production. Puglia is the most important region with approximately 373,980 ha, followed by Calabria (approx. 185,914.68 ha) and Sicily (approx. 141,810 ha) (ISTAT, 2010–2012). The total production of olive oil in these three regions accounts for approximately 73% of national production (Proto & Zimbalatti, 2015). The high economical value assumed by such cultivation in the territories where it is spread justifies the numerous researches aimed to solve problems related to the production. The main one is represented by olives harvesting and its economical and management aspects (Abenavoli & Proto, 2015).

The objective of this work is to illustrate the Software Cloud of tracking and tracing (T&T), denominated '*TraceOil*', made by the Department AGRARIA – University Mediterranea of Reggio Calabria, in the context of a regional research project. In fact, 'S.I.F.OLI.O. – System Innovative for the quality of the OLIve growing and Oil production' is a regional project funded by PSR Calabria 2007–2013 (Calabria's Rural Development Programme) under Project Action 124: 'Cooperation for development of new products, processes and technologies in the agriculture and food sector and the forestry sector'. This project set up a partnership between farms, cooperatives, and Department AGRARIA in the Calabria region to improve the use of system of traceability in the olive growing/olive oil production and supply chain.

It has relied on a preliminary in depth territorial survey meant to select those olive growing farms considered to be a representative sample of the olive-growing reality in the area under study. The above survey has been followed by the analysis of the different processing phases which envisage one or more operations: from in-field olive harvesting operations to oil mill olive handling and processing (Abenavoli & Sciarrone, 2006; Sciarrone et al., 2006; Abenavoli & Sciarrone 2008; Giametta & Sciarrone, 2009).

MATERIALS AND METHODS

The main objective of a traceability system is therefore to accurately access the history and the location of the different products along the supply chain (Dabbene & Gay, 2011).

Informatics with modern technology allows us to provide the company with a software solution, usable as a web application, everything housed on a system cloud server. The centralization of data provided by the software in question permit the various figures, such as food technologists, primary producers, oil millers and bottlers, and laboratories, to collaborate in an environment where you get all the information in real time. The system implements algorithms that provide notification messages that indicate if there are any delays in production/processing in terms of quality of the olive oil sought. The operators will be equipped with an APP for smartphones 'Android' and 'iOS', which allow you to detect in a simple and immediate all data and synchronize with the cloud system. Similarly to the final customer will be provided, through the Store 'Android' and 'iOS', a free APP that allow you to get the information and product traceability. The project goal was to implement a WebApplication based on Cloud Platform and centralize all information about to the context of the production of olive oil, from the field to the bottle, focusing the most critical phases affecting production costs and on the quality of the final product: for instance the harvesting phase (together with the pruning) is the operation more expensive and that most affects the quality of olive oil made (Abenavoli & Marcianò, 2013; Abenavoli & Proto, 2015).

Especially are implemented the data relating to (Fig. 1):

- Olive harvest with various methods;
- Processing inside the oil mill of olives harvested;
- Data Mining on data acquired and analysis about distribution of plants and products;
- Creation of a unique code about working process and harvest process;
- Traceability of the information from the primary producer to the consumer and contrariwise.

The information gathered by the traceability system shown become strategic when, in the unfortunate case, a product batch must be recalled. Indeed, beyond the media impact of this action, the firm has to bear the costs involved in withdrawing from the destruction of all products which are, in some way, connected with the offending batch. Currently, however, most of the firms does not have reliable methods to accurately estimate the amount of product that must be eliminated in case of a recall (Dabbene & Gay, 2011).

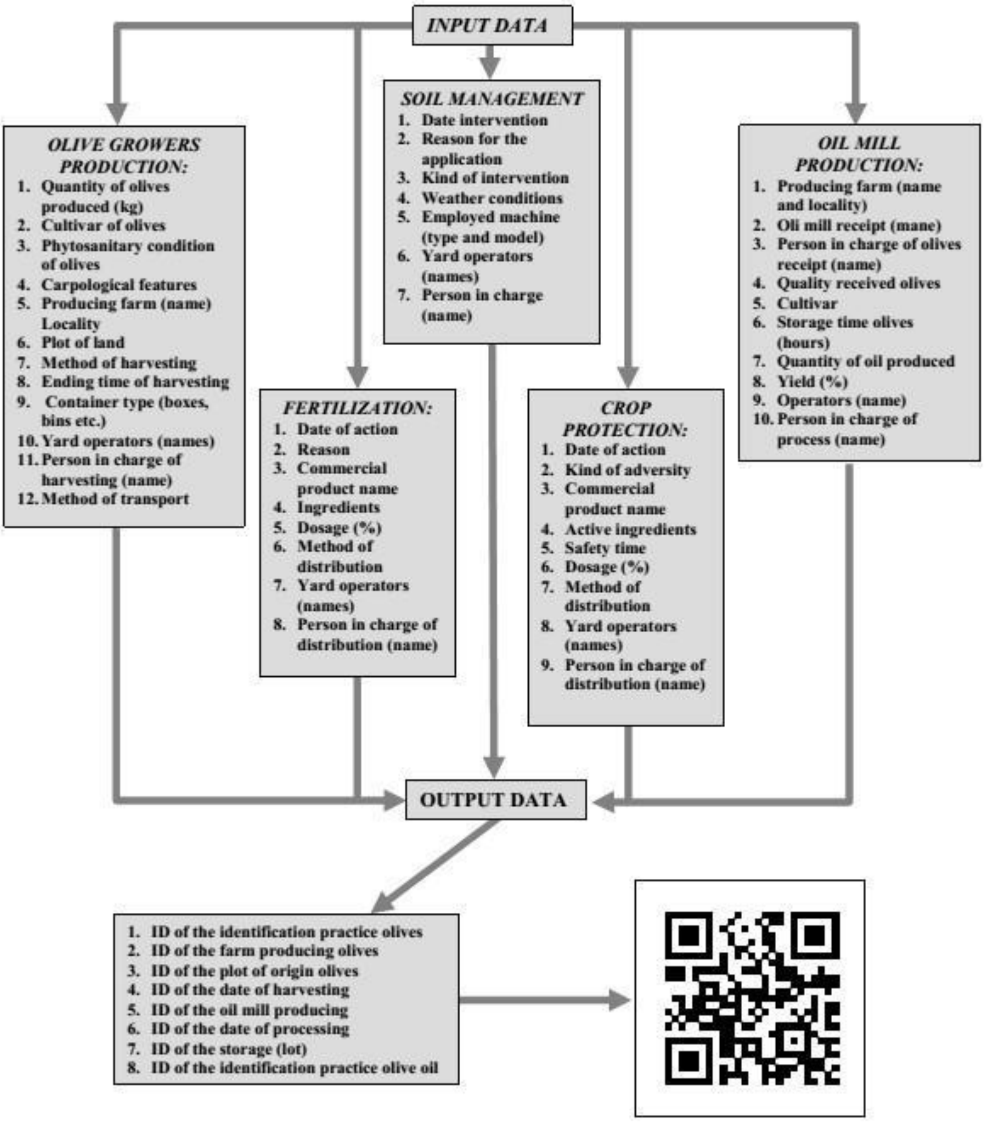


Figure 1. Model of data implementation used in the olive-oil processing chain.

RESULTS

Traceability Software

The centralization of information provided by the WebApplication allows to the actors of system (primary producer, oil mill and laboratory) to collaborate on an real time environment. The WebApplication implements a series of algorithms to provide various notification messages about the phases. The technologies/languages used to create the WebApplication are the most innovative in computing:

- The client side uses AngularJS and Material Design by Google as well as JavaScript;

- The server side uses one of the most important JavaScript framework NodeJs that has given guarantees of stability;
- While on database side, we use a NoSql database like MongoDB with high performances;
- The cloud system is very stable structure that implements a vertical scaling system.

The software '*Trace Oil*' is based on a Cloud platform that allows the scaling of the system where necessary. '*Trace Oil*' is developed for the server side with Nginx HTTP server, platform and NodeJS MongoDB; while for the client it requires the creation of a web application that is based on AngularJS (Fig. 2). It will be considered using a SSL security certificate.

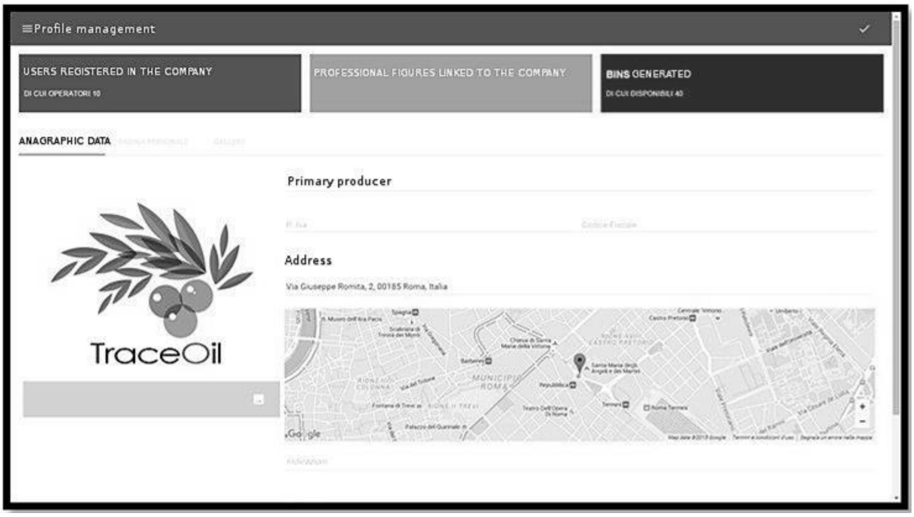


Figure 2. Farms management area of the 'TraceOil' software.

The parts of the software are subdivided in three areas:

1. Web Application.
2. Mobile Operator App and Mobile App End User.
3. Web Application (hosted on the Cloud platform).

The web application is the actual control software and interaction that allows the management of all aspects of entry and search and the implementation of operational procedures to guide subscribers. In terms of functionality and parts it is structured as follows:

- *FrontEnd*, from here you can access through login to the back office (BO) and shall provide the visitor with all the necessary information to join the system 'Trace Oil'. It will have to be present in addition to basic information, a registration form and a link to a system LOGIN;
- *BackOffice*, from here after having logged in you will have access according to the type of user to work area;
- *Login* with multi-level access that allows administrators to manage permissions of the various areas of the software. This system must include the possibility to set permissions and groups for modules and functionality of the system.

The users of the software will be divided into categories as follows:

- *Administrator*: Users can access any functionality of the system, with ability to manage permissions for all other users;
- *Oil mills*: Members who deal with stages of product processing. They can manage the system by creating access for their employees by setting the JOB or action to be followed, based on the features of the olives to be processed, and which will be available in the app operator indicated in the document;
- *Employees/Operators mills*: Members who work as employees of the oil mill;
- *Olive farms*: actors involved in the harvest phases of the product and they have access only to that stage. They can manage the system by creating access for their employees by setting the JOB to be followed, based on the features of the olives to be picked, and which will be available in the app operator;
- *Workers of olive farms*: Users who work as employees of the company mentioned above;
- *Agronomist*: Users represented by professionals who want to give advice to companies with which they have a working relationship. Such users only have access to information as a common generic data or data of the following companies with the possibility to follow the production steps in the detail of each JOB of the same companies.

For each of these categories will be possible to set the mode of access to every area of BackOffice, including ability to hide access to a module, or it visible only have full control of the same. Moreover, the various features mentioned will be managed according to the access level set to the user. The system adopted allows to describe and document organization, methodology, techniques and tools utilized to plan and monitor activities. Information on all products can be processed and transferred into barcode labels or, via the web, onto customized collective portals.

A computer system is presently being developed which is expected to:

- coordinate the flows of information on farming chains traceability;
- allow the backtracking of each individual lot of produce;
- indicate the accompanying documents (QRcodes included) required to identify the lots in question;
- SSL Certificate to the security of information exchange;
- manage the chain logistics (travel of the traced lots across the various operators);
- generate QRCode printable be affixed to the container of the final product (bottle or other) (Fig. 3);
- exporting the Job in JSON format to read and use on most platforms;
- log of operations performed on the system by the various actors and can be exported in text format.

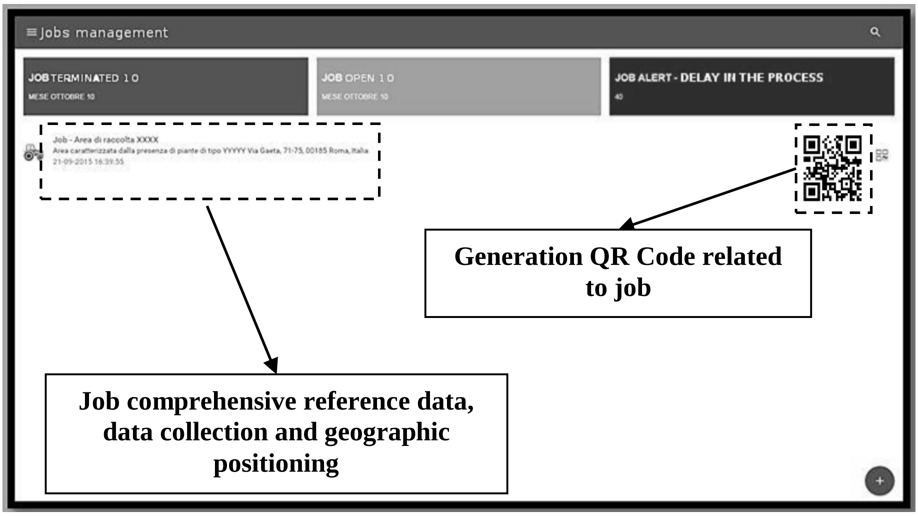


Figure 3. Jobs management area of the 'TraceOil' software.

One of the major criticalities in the model of traceability under study occurs at the time of raw material (olives) processing at the oil mill where sometimes olives can mix with other non-traced olives, i.e. drupes with different features that can happen to mix with more valuable lots. Therefore this software allows you to generate directly during harvesting phase a QRCode printable for each container (bin, crates, etc.).

Android application allows the user to perform the following tasks:

- Password access reserved to identify the operator;
- Ability to work without an internet connection and subsequent data synchronization;
- Entering the QRCode in the container in which they are harvested olives (Fig. 4);
- Geolocation of the collection point based on the GPS or through a manual insertion;
- Load up to 5/10 photos/files attached to show the detail information or details necessary.

Figure 4. Starting the 'TraceOil' software through smartphone.

After data input, the software processes a QRCode which encompasses all the data of the product, from the lot of origin to the oil mill processing operations as required by the model shown in Fig. 1. This allows for a rapid data scanning and acquisition by smartphone. After deciphering the code pass the information on the Cloud platform where it is displayed the software. The platform, which is structured in an user friendly format, can be exported to other databases containing real-time updated information to be processed, printed or published in the web. The reliability of the mathematical model used for the determination of the lot described in the previous sections has been tested on the basis of the data collected during the two-year period 2014–2015 at the olive growing farms under study. More specifically, the data collected during the above period concerned harvest operations which are considered to be crucial to the transit of information (in terms of both data implementation and transmission) from the olive growers and the oil mill.

Regarding the estimated costs of TraceOil System, these can be divided into two groups: cloud management (including maintenance and security updates) and management accounts (primary producers, analysis laboratories, oil mills, etc.). The first ones are constant up to 20,000 users, are about € 300–500 plus taxes; while the costs of accounts vary according to their numbers, and are about € 1.7 per month to around the 100 users over the 1,000 down to € 0.99.

CONCLUSIONS

This study, therefore, is focused on the analysis and the use of both tracking and tracing systems of olive and olive oil products throughout the entire territory of Calabria. The present study has been based on an in-depth analysis of the area under consideration in a view to identifying some farms typical of the territory in question. The different steps of olive processing have been analyzed, from olive harvesting to olive processing at the oil mill (Giametta & Sciarrone, 2009). The software in question has been implemented mainly to respond to the requirements of EC Regulation 178 of January 28, 2002 which set forth the principles and requirements of EU food law. Thanks to this project many farms have improved their production, starting in some cases also T&T, and they have introduced more sustainable management practices (Proto et al., 2014). Cooperation between institute of research, cooperatives, farms and the university was crucial to assess the needs for intervention. The network established among different actors along the supply chain has helped to give more safety and quality in the olive growing/olive oil production. The use of the software '*TraceOil*' enhances the typical products, accompanied by the rigorous and complete application of high quality standards, excellent presentations and various assortments (Bernardi et al., 2013). The introduction of system T&T such as that analyzed in this study, can certainly contribute for the accomplishment of cited objectives with suitable features for olive-oil supply chain.

ACKNOWLEDGEMENTS. This study is a part of the Project S.I.F.OLI.O. – No.°94752165038. 'System Innovative for the quality of the OLIve growing and Oil production' is a regional project funded by PSR Calabria 2007–2013 (Calabria's Rural Development Programme) under Project Action 124: 'Cooperation for development of new products, processes and technologies in the agriculture and food sector and the forestry sector'.

REFERENCES

Abenavoli, L.M. & Marcianò, C. 2013. Technical and economic analysis of alternative pruning systems in high dimensions olive trees in Calabria. *Agronomy Research* **11**(1), 7–12.

Abenavoli, L.M. & Proto, A.R. 2015. Effects of the divers olive harvesting systems on oil quality. *Agronomy Research* **13**(1), 7–16.

Abenavoli, L.M. & Sciarrone, G. 2006. La tracciabilità di filiera: Un'opportunità per l'olivicoltura. *In IV Convegno AISSA: Qualità e sostenibilità delle produzioni agrarie,alimentari e forestali*; Mosciano Sant'Angelo (TE).

Abenavoli, L.M. & Sciarrone, G. 2008. Studio teorico-pratico di un modello di tracciabilità di filiera nelle produzioni olivicole. *Il Perito Agrario- Rivista del Collegio Nazionale dei Periti Agrari e dai Periti Agrari Laureati* **1**, 7–14.

Ampatzidis, Y.G. & Vougioukas, S.G. 2009. Field experiments for evaluating the incorporation of RFID and barcode registration and digital weighing technologies in manual fruit harvesting. *Computers and Electronics in Agriculture* **66**, 166–172.

Bernardi, B., Zimbalatti, G., Proto, A.R., Benalia, S. & Fazari, A. 2013. Mechanical calibration in 'PGI Tropea red onion' post-harvest operations. *Journal of Agricultural Engineering* **44**(63), 317–322.

Costa, C., Antonucci, F., Pallottino, F., Aguzzi, J., Sarriá, D. & Menesatti, P. 2013. A Review on Agri-food Supply Chain Traceability by Means of RFID Technology. *Food Bioprocess Technol.* **6**(2), 353–366.

Dabbene, F. & Gay, P. 2011. Food traceability systems: Performance evaluation and optimization. *Computers and Electronics in Agriculture* **75**, 139–146.

Giametta, F. & Sciarrone, G., 2009. An integrated technological traceability model in the olive growing production chain. *Journal of Agricultural Engineering* **4**, 19–26.

Holm, S., Brungot, J., Rønnekleiv, A., Hoff, L., Jahr, V. & Kjølerbakken, K.M. 2007. Acoustic passive integrated transponders for fish tagging and identification. *Aquacultural Engineering* **36**, 122–126.

ISTAT. 2010–2012. Agricultural census. Rome, Italy: National Statistical Institute.

OnTrace. 2007. Traceability Backgrounder. Web Page. Accessed 14 January 2008. Available at http://www.Ontraceagrifood.Com/Documents/Traceability%20 Bkgder-Apr%2007.pdf

Papetti, P., Costa, C., Antonucci, F., Figorilli, S., Solaini, S. & Menesatti, P. 2012. A RFID web-based infotracing system for the artisanal Italian cheese quality traceability. *Food Control* **27**, 234–241.

Proto, A.R. & Zimbalatti, G. 2010. Risk assessment of repetitive movements in the citrus fruit industry. *Journal of Agricultural Safety and Health – Ed. American Society of Agricultural and Biological Engineers (ASABE)* **16**(4), 219–228.

Proto, A.R. & Zimbalatti, G. 2015. Risk assessment of repetitive movements in olive growing: analysis of annual exposure level assessment models with the OCRA checklist. *Journal of Agricultural Safety and Health – Ed. American Society of Agricultural and Biological Engineers (ASABE)* **21**(4), 241–253.

Proto, A.R., Zimbalatti, G., Abenavoli, L., Bernardi, B. & Benalia, S. 2014. Biomass Production in Agroforestry Systems. V.E.Ri.For Project. *Advanced Engineering Forum* **11**, 58–63.

Sciarrone, G., Abenavoli, L.M. & Proto, A.R. 2006. Implementazione di un sistema di tracciabilità nella filiera olivicola: prime applicazioni. *In IV Convegno AISSA: Qualità e sostenibilità delle produzioni agrarie, alimentari e forestali*. Mosciano Sant'Angelo (TE).

Zohreh, R. & Sattar, T.E. 2012. Traceability of Origin and Authenticity of Olive Oil. *Olive Oil – Constituents, Quality, Health Properties and Bioconversions* Edited by Dr. Dimitrios Boskou, 163–184.

Agronomy Research **14**(4), 1257–1265, 2016

The properties of wheat straw combustion and use of fly ash as a soil amendment

J. Bradna, J. Malaťák* and D. Hájek

Czech University of Life Sciences Prague, Faculty of Engineering, Department of Technological Equipment of Buildings, Kamýcká 129, CZ 16521 Prague, Czech Republic
*Correspondence: malatak@tf.czu.cz

Abstract. Agriculture is one of possible producers of by-products suitable for energy purposes, such as rapeseed and wheat straw. But on the other hand, not only thanks to the support of energy from biomass grown specifically for this purpose, arable land is exposed to intense cultivation of wide-row crops indirectly supporting soil erosion and nutrient elution. The issue of recycling ash from biomass combustion on agricultural and forest land is very important to resolve. Experience with this problem is found in countries in Northern Europe such as Finland or Sweden, as well as in North America. Due to ash characteristics, it is considered a valuable soil component and a potential replacement for conventional fertilizers.
Elemental analyses of samples from wheat straw pellets were followed by combustion and emission measurements. The effects of temperature and volume of air in the combustion of wheat straw was analysed, focusing on emission concentrations and the ash content. Effect of excess air coefficient on the composition of end products after combustion was assessed in three modes (small, optimum and high coefficient of excess air). During the measurements, the excess air coefficient ranged between the values from 3.95 to 14.89. The average net calorific value of the wheat straw samples was 15.55 MJ kg^{-1} in the original state. Mineral composition analysis of solid combustion products, necessary for using these residues as a fertilizer or soil component, was performed as well.

Key words: wheat straw, elemental analysis, ash, soil amendment, excess air coefficient.

INTRODUCTION

The possibility of using agricultural by-products for energy purposes is largely possible thanks to their suitable physical and chemical properties (Liu et al., 2013). An important criterion when choosing correct processing method and selecting a suitable type of combustion device are water and ash contents in the original state of fuel, ie the biomass from which the biofuel is produced (Olsson & Kjällstrand, 2006).

Combustion under real conditions does not take place with pure oxygen, but in the presence of air, which contains nitrogen as well in addition to oxygen. Nitrogen is not participating in the reactions and passes as a ballast component into flue gases, or combines with oxygen to produce harmful components NO and NO_2 (Malaťák & Bradna, 2014).

Suitable utilization of fly ash produced as a waste product of the biomass combustion would be beneficial not only to larger operators of combustion devices but also to smaller and residential users. In most cases at present time these materials are landfilled in the Czech Republic (Tlustoš et al., 2012). However, there are not only the rising costs of energy production due to landfilling of these materials, but also significant loss of nutrients needed for the development of biomass and restoration of soil fertility. One of the possible uses for ashes from biomass energy utilization is application to agricultural soil, which returns nutrients and modifies soil reactions (Zemanová et al., 2014). Application of ash is possible only under the condition that it does not endanger the quality of soil, crops and human health (Obernberger & Supancic, 2009).

This article responds to current topic of energetic utilization of by-products from agriculture and discusses the issues of how to provide the material composition and homogeneity, as well as adequate heating value in the combustion chamber, as well as subsequent use of the combustion products as a soil component. Evaluation of the solid biofuel samples of wheat straw pellets is followed by operational measurements in which temperatures and amount of combustion air were determined and their effects analysed in the combustion process of each sample, with focus on emission levels, particularly on nitrogen oxides, and also on fly ash properties.

MATERIALS AND METHODS

Wheat straw pellets have been chosen for the experimental measurement as most suitable from the known by-products from agriculture. They were produced by the pelletizing line LSP 1800 from the company ATEA PRAHA. This line is used for production of straw fuel pellets having a diameter of 8 mm and a length of 15–30 mm.

The first task was to determine the elemental composition of samples.We examined basic parameters of fuel and monitored especially content of water, ash, volatile and non-volatile combustible matter, carbon, hydrogen, nitrogen, sulfur, oxygen and chlorine.

The elements carbon, hydrogen and nitrogen were determined by a CHN analyzer Perkin-Elmer 2400. For the determination of chlorine and sulfur, samples were burned in oxygen-hydrogen flame in Wickbold apparatus. Non combustible substances of fuels, i.e. the ash and total water content were determined by burning, respectively drying of the appropriate sample. Gross calorific value was determined by calorimetric method in the calorimeter IKA 2000.

After the elemental analysis stoichiometric calculations were made and the net calorific value of fuel was calculated as well as the amount of oxygen (air) required for complete combustion of fuel, quantity and composition of flue gas and flue gas density. Calculations of individual samples are converted to normal conditions (temperature = 0 °C and pressure = 101.325 kPa).

Emission concentration measurements were carried out on an automatic hot-air combustion device KNP made by company KOVO NOVAK. The stove is equipped with a burner, automatic ignition and automatic fuel supply by screw from pellet hopper. The combustion device is designed to burn pellets and energy grain. Combustion process can be influenced by adjusting the combustion air and the fuel supply.

During combustion tests on this combustion device, emission concentrations of carbon dioxide, carbon monoxide, oxygen, nitrogen monoxide, nitrogen dioxide, sulfur dioxide, hydrogen chloride and excess air coefficient (n) were all being measured. The entire measurement was monitored by a multifunction analyzer of flue gas Madur GA-60. This analyzer is based in principle on the use of electrochemical converters. This device also enables to measure both ambient (T_a) and flue gas (T_{fg}) temperatures. Based on these temperatures and chemical parameters this device performs calculation of combustion characteristics. The emission concentration values are calculated for normal conditions of dry flue gas and reference oxygen content in flue gas. Individual points in combustion characteristics were determined during tests with changing excess air coefficient.

Subsequently, the results of measurements were processed by statistical regression analysis for expressing the mathematical relationship between carbon monoxide and dioxide, flue gas temperature and total nitrogen oxides against excess air coefficient. The coefficient of determination characterizes the explanatory power of the applied regression model and variance of measured values around the model curve.

During specific periods fly ash carried by flue gas was captured by a cyclone separator. The composition and quality of the fly ash were taken into consideration. Laboratory tests were completed by an analysis of the mineral composition of the solid product with regard to its utilization as a soil amendment. The total element concentrations in fly ash were determined according to Száková et al. (2013). Available metal fractions were determined by extraction (Trakal et al., 2013). The concentrations of other elements in the fly ash samples are determined by flame atomic absorption spectrophotometry on the device Varian-400 SpectrAA.

RESULTS AND DISCUSSION

The water content contained in the samples is quite low, which has a positive impact on fuel efficiency. The ash content in the samples is relatively higher when compared with typical wood whose ash content is under one percent (Olsson & Kjällstrand, 2006). Using wheat straw pellets in the combustion device has increased the demand for removal of solid residues from combustion process and in general it also increases the amount of particulate emissions.

Moisture affects behavior during combustion and the volume of flue gas produced per unit of energy. Generally the moisture content of wood chips does not exceed 30% wt. For straw the acceptable moisture content is up to 20% wt. Biomass fuels should generally be drier for ~~a~~ combustion devices with lower heat output (Olsson et al., 2003).

The average calorific value of the analysed straw is 15.55 MJ kg^{-1} at the proportion of water and ash in the original sample. Other assessed properties of samples were the proportions of volatile and non-volatile combustibles. For assessed samples the proportion of these characteristics is different than for example in wood. These differences make it clear that it is not possible to replace wood by differing biomass fuels in combustion devices for wood (Malaťák & Passian, 2011).

For the samples of wheat straw four sets of elemental analyses were carried out. First for uncompressed wheat straw whose analysis is used for comparison to processed wheat straw. Other three samples were already compacted straw pellets. One immediately after the pelleting process, one after thirty day storage and the last one just prior to the combustion tests. The resulting values of the elemental analysis are indicated in Table 1. These values confirm the fact that for energy use of wheat straw pellets the major factor is the calorific value, which depends on water and ash contents in the fuel (Ružbarský et al., 2014).

Table 1. Elemental analysis of wheat straw samples

Sample	Water Content (% wt.)	Ash (% 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
Wheat straw	13.1	5.08	66.43	16.5	16.03	14.64
Wheat straw pellets 1 (diameter 8 mm)	6.64	6.59	70	15.77	16.96	15.48
Wheat straw pellets 2 (diameter 8 mm)	5.28	6.9	70.4	16.42	17.12	15.99
Wheat straw pellets 3 (diameter 8 mm)	5.99	6.57	71.31	15.13	16.51	15.17
Average values wheat straw pellets	5.97	6.69	70.57	15.77	16.86	15.55
Statistical dispersion wheat straw pellets	0.68	0.19	0.67	0.65	0.32	0.41
Sample	Carbon C (% wt.)	Hydrogen H (% wt.)	Nitrogen N (% wt.)	Sulphur S (% wt.)	Oxygen O (% wt.)	Chlorine (% wt.)
	C	*H*	*N*	*S*	*O*	*Cl*
Wheat straw	40.67	4.89	0.49	0.11	35.56	0.1
Wheat straw pellets 1 (diameter 8 mm)	41.63	5.96	0.34	0.035	38.695	0.11
Wheat straw pellets 2 (diameter 8 mm)	43.38	4.58	0.63	0.09	38.96	0.18
Wheat straw pellets 3 (diameter 8 mm)	43	5.49	0.54	0.05	38.07	0.29
Average values wheat straw pellets	42.67	5.34	0.50	0.06	38.58	0.19
Statistical dispersion wheat straw pellets	0.92	0.70	0.15	0.03	0.46	0.09

The amounts of sulfur, chlorine and nitrogen in elemental composition of wheat straw pellets are the most important in terms of the emission concentrations. In the examined samples higher concentrations of nitrogen were found, causing noticeable increase in nitrogen emissions.

Table 2 shows the average values from emission measurements of the wheat straw pellet samples. These values confirmed the fact that maintaining the optimum excess air coefficient is essential during the combustion process. This state guarantees such combustion conditions which do not generate high emission concentrations of unburned components and do not increase the heat losses (Nordin, 1994; Friberg & Błasiak, 2002; Gonzalez et al., 2004).

Table 2. The average values of thermal properties and emission concentration of wheat straw pellets (8mm)

	Average	s^2	s	Max.	Min.
$T_{\_a}$ (°C)	41.93	4.90	2.21	45.00	37.00
$T_{\_fg}$ (°C)	180.11	643.78	25.37	217.00	123.40
O_2 (%)	17.75	1.25	1.12	19.59	15.69
n (-)	7.35	8.04	2.84	14.89	3.95
CO_2 (%)	2.33	0.73	0.85	3.87	0.91
CO (mg m^{-3})	1,040.64	341,820.15	584.65	2,444.00	157.78
SO_2 (mg m^{-3})	99.62	6,746.23	25.97	150.07	34.81
NO_x (mg m^{-3})	1,017.41	5,220.68	72.25	1,194.00	880.00

The amount of combustion air affects the combustion process itself, however, in practice it is very difficult to measure the real value of the combustion air amount required for complete combustion. This value is expressed in the form of excess air coefficient which gives the ratio of actual to theoretical air quantity for complete combustion. The excess air coefficient 1.91, which corresponds to the reference oxygen content in the flue gas of 10%, is set by legislation as nominal for small combustion devices with automatic fuel supply to combustion chamber (Act No. 201/2012 Coll., 2012).

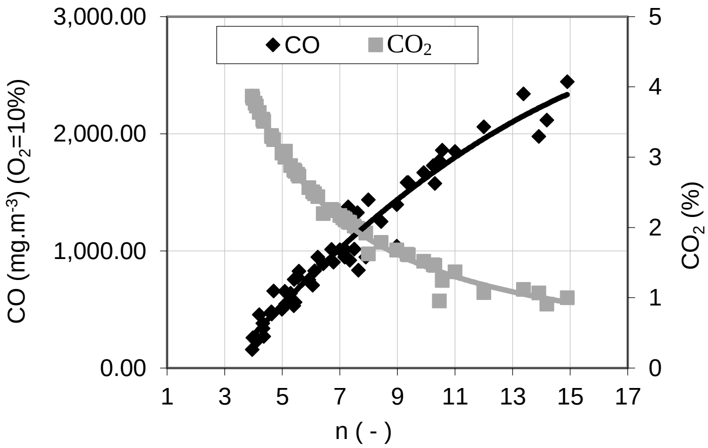


Figure 1. Dependence of carbon monoxide and carbon dioxide on the excess air coefficient – combustion of wheat straw pellets.

When burning pellets from wheat straw (see. Fig. 1) increasing the excess air coefficient *n* will decrease the emission concentration of carbon monoxide according to the equation:

$$CO = -7.2123n^2 + 324.48n - 897.67 \text{ (mg m}^{-3}\text{)} \qquad (1)$$

With determination coefficient of R^2 = 0.949 when increasing *n* in range from 3.5 to 15.

This also leads to reduction in the carbon dioxide concentration (dampening the combustion process) according to the equation:

$$CO_2 = 17.427n^{-1.082}\ (\%) \qquad (2)$$

With increasing excess air coefficient, which is confirmed by Figure 2, there starts dampening of combustion processes and reduction of flue gas temperature below 200 °C. This flue gas cooling can be defined by the equation:

$$T_{flue\text{-}gas} = 0.3007n^2 - 13.658n + 261.88\ (^{\circ}C) \qquad (3)$$

With determination coefficient of $R^2 = 0.8993$.

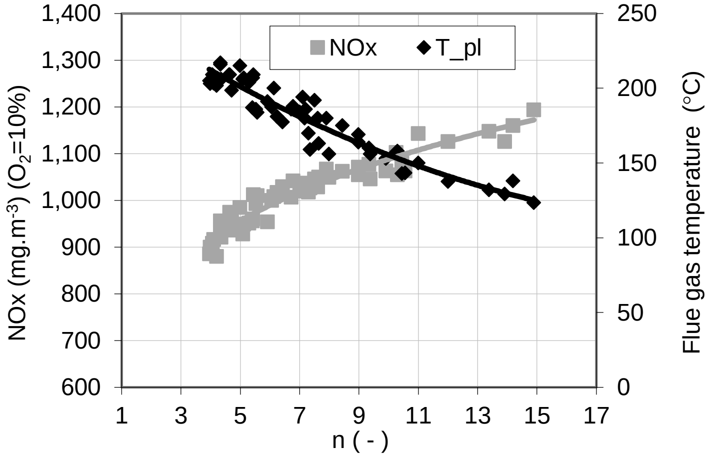


Figure 2. Dependence of nitrogen oxides and flue gas temperature on the excess air coefficient – combustion of wheat straw pellets.

The sharp increase in NO_x emissions depending on the amount of supplied combustion air was mainly caused by large quantities of supplied combustion air (see. Fig. 2). Under these conditions nitrogen reacted with oxygen to produce nitrogen oxides. Dependence of concentration of nitrogen oxides on the excess air coefficient is described by the equation:

$$NO_x = 709.25n^{0.1859}\ (\mathrm{mg\ m^{-3}}) \qquad (4)$$

With determination coefficient of $R^2 = 0.9126$.

The results of Eskilsson (2004), Gonzalez et al. (2004) and other researchers confirm the fact, that each type of combustion device has a characteristic course of the carbon monoxide emissions. Largest emission concentrations arise mainly during ignition or extinguishing of the combustion process (Fiedler & Persson, 2009). The highest concentration of carbon monoxide emissions is achieved at high excess air coefficients. High amount of combustion air cools the combustion chamber and thus results in high carbon monoxide emissions in the flue gases (Friberg & Blasiak, 2002).

Combustion device should work at nominal parameters as demonstrated by research work of Johansson et al., 2004. Any change in material supply into combustion chamber or in the flow of combustion air leads to high emissions of carbon monoxide (Wihersaari, 2005). On the other hand higher temperature and high input of combustion air has a substantial effect on the increased production of nitrogen oxides (Ponzioa et al., 2009). Decreasing the amount of combustion air has an effect on reducing nitrogen oxides emissions, but increases emissions of carbon monoxide in the flue gas (Diasa et al., 2004).

Experimental combustion tests were followed by analysis of the mineral composition of the combustion end product (fly ash). Fly ash was caught in ~~the~~ three different combustion modes: at large, small and optimum excess air (see. Table 3). The measured values were compared with the limits set in the applicable legislation.

Table 3. The average values of mineral composition of the fly ash

Wheat straw pellets	Small excess air	Large excess air	Optimal excess air
Al (mg kg^{-1})	477.28	985.69	792.24
As (mg kg^{-1})	2.47	0.69	1.27
B (mg kg^{-1})	155.06	296.12	65.93
Cd (mg kg^{-1})	0.22	0.24	0.04
Cr (mg kg^{-1})	4.52	5.37	3.20
Cu (mg kg^{-1})	19.23	23.74	23.25
Fe (mg kg^{-1})	2,386.68	1,953.00	1,102.95
Mn (mg kg^{-1})	604.83	687.46	686.63
Mo (mg kg^{-1})	1.85	1.99	1.99
Ni (mg kg^{-1})	2.54	3.47	2.21
Pb (mg kg^{-1})	3.36	3.65	0.38
S (mg kg^{-1})	925.43	1,243.19	415.26
Zn (mg kg^{-1})	77.89	66.65	11.69
P (mg kg^{-1})	4,071.26	4,924.94	5,939.50
K (mg kg^{-1})	17,964.31	16,720.70	35,219.43
Ca (mg kg^{-1})	15,801.02	16,053.62	28,517.81
Mg (mg kg^{-1})	4,296.68	4,952.62	7,245.79

When comparing results of analyses to the limits given by Act No. 271/2009 Coll. (2009) applicable for soil amendments, we find that the values of cadmium and lead in fly ash from wheat straw are on average significantly below the limit of 1 mg *Cd* kg^{-1} and 10 mg *Pb* kg^{-1} respectively. These elements in fly ash would therefore pose no threat when applied to soil.

Biedermann & Obernberger (2005) recorded contents of arsenic in fly ash from combustion of wood and straw between 0.1–0.2 mg kg^{-1}. In comparison with their results, the content of fly ash in our case was higher. Chromium (maximum content in soil substance is limited to 50 mg kg^{-1}) would meet the limit in this case. Phosphorus was present between 4,000–6,000 mg kg^{-1}, the highest content was found in the fly ash of wheat straw at optimum excess air coefficient. A higher potassium content is due to higher levels of this nutrient within the input material.

The higher calcium content in fly ash lead to increased *pH* values and these materials could be used for treatment of soil reaction in particular strongly acidic or heavy soils (Obernberger & Supancic, 2009). Magnesium content in fly ash ranged from 4,300–7,300 mg kg^{-1}. Higher values were obtained when the optimum excess air coefficient was used during combustion process. Scientific literature also indicates the magnesium content in fly ash from the combustion of biomass around 1%. For instance higher values of magnesium were found in the fly ash of rape straw 2.1% (Hytönen, 2003) or cereal grains 10.4% (Eichler-Löbermann et al., 2008).

CONCLUSIONS

Eskilsson (2004) found compromise between production of non-combusted carbon monoxide and nitrogen oxides, similar trends have been measured in this paper. Decreasing the amount of air in combustion chamber reduces the amount of nitrogen oxides in the flue gas, but on the other hand it increases emissions of non-combusted carbon monoxide. Finding the optimum setting of the excess air coefficient for different types of biofuels could solve the problem of nitrogen oxides and carbon monoxide emissions. The content of carbon dioxide can show the quality (efficiency) of combustion. For each type of fuel there is a maximum attainable proportion of carbon dioxide (ie. $CO_{2\mathrm{max}}$) in the flue gas, which is given by the elemental composition of combustible matter in the fuel. Olsson & Kjällstrand (2006) confirmed that this value is unattainable in combustion devices in practice.

Based on the results of analyses of selected samples of fly ash from biomass can be categorized by the raw material put into the process. These end products of combustion can be recommended for direct application into the soil, according to applicable legislation on fertilizers. Ash from biomass thanks to its physical and chemical properties offers not only a wide range of potential applications. It also closes the nutrient cycle by returning nutrients to the soil, reduces the landfill of such materials and not at the least causes the reduction in expenses for mineral fertilizers in agricultural production. If the ash from the combustion of biomass returns back into the soil, then the energy production from biomass can truly be a sustainable technology.

ACKNOWLEDGEMENTS. The article was financially supported by the Internal Grant Agency of the Czech University of Life Sciences Prague TF (IGA) no. 2016:31170/1312/3114.

REFERENCES

Act No. 201/2012 Coll., Air Procetion Act. 2012. Ministry of Environment of the Czech Republic.

Act No. 271/2009 Coll., Requirements for fertilizer, 2009, Ministry of Agriculture of the Czech Republic.

Biedermann, F. & Obernberger, I. 2005. Ash-related problems during biomass combustion and possibilities for a sustainable ash utilisation. http://www.bios-bioenergy.at/en/downloads-publications/ashes-ash-utilisation.html. Accessed 10.11.2015.

Diasa, J., Dostav, M. & Azevedob, J.L.T. 2004. Test of a small domestic boiler using different pellets. *Biomass and Bioenergy* **27**, 531–539.

Eichler-Löbermann, B., Schiemenz, K., Makadi, M., Vago, I. & Köppen, D. 2008. Nutrient cycling by using residues of bioenergy production-II. Effects of biomass ashes on plant and soil parameters. *Cereal Res Commun* **36**, 1259.

Eskilsson, D. 2004. Optimisation of efficiency and emissions in pellet burners. *Biomass and Bioenergy* **27**, 541–546.

Fiedler, F. & Persson, T. 2009. Carbon monoxide emissions of combined pellet and solar heating systéme. *Applied Energy* **86**, 135–143.

Friberg, R. & Blasiak, W. 2002. Measurements of mass flux and stoichiometry of conversion gas from three different wood fuels as function of volume flux of primary air in packed-bed combustion. *Biomass and Bioenergy* **23**, 189–208.

González, J.F., González-García, C.M., Ramiroa, A., González, J., Sabioa, E., Ganan, J. & Rodrígueza, M.A. 2004. Combustion optimisation of biomass residue pellets for domestic heating with a mural boiler. *Biomass and Bioenergy* **27**, 145–154.

Hytönen, J. 2003. Effects of wood, peat and coal ash fertilization on Scots Pine foliar nutriet concentrations and growth on afforested former agricultural peat soils. *Silva Fennica* **37**, 219.

Johansson, L.S., Leckner, B., Gustavsson, L., Cooper, D., Tullin, C. & Potter, A. 2004. Emission characteristics of modern and old-type residential boilers fired with wood logs and wood pellets. *Atmospheric Environment* **38**(25), 4183–4195.

Liu, H., Chaney, J., Li, J. & Sun, C. 2013. Control of NOx emissions of a domestic/small-scale biomass pellet boiler by air staging, *Fuel* **103**, 792–798.

Malaták, J. & Bradna, J. 2014. Use of waste material mixtures for energy purposes in small combustion devices. *Research in Agricultural Engineering* **60**(2), 50–59.

Malaťák, J. & Passian, L. 2011. Heat-emission analysis of small combustion equipments for biomass. *Research in Agricultural Engineering* **57**(2), 37–50.

Nordin, A. 1994. Chemical elemental characteristics of biomass fuels. *Biomass Bioenergy* **6**, 339–347.

Obernberger, I. & Supancic, K. 2009. Possibilities of ash utilisation from biomass combustion plants. In: *Proceedings of the 17th European Biomass Conference and Exhibition.* Hamburg, ETA-Renewable Energies (Ed.), pp. 1–12 (in Italy).

Olsson, M., Kjällstrand, J. & Petersson, G. 2003. Specific chimney emissions and biofuel characteristics of softwood pellets for residential heating in Sweden. *Biomass and Bioenergy* **24**, 51–57.

Olsson, M. & Kjällstrand, J. 2006. Low emissions from wood burning in an ecolabelled residential boiler. *Atmospheric Environment* **40**(6), 1148–1158.

Ponzio, A., Senthoorselvan, S., Yang, W., Blasiak, W. & Eriksson, O. 2009. Nitrogen release during thermochemical conversion of single coal pellets in highly preheated mixtures of oxygen and nitrogen. *Fuel* **88**(6), 1127–1134.

Ruzbarsky, J., Müller, M. & Hrabe, P. 2014. Analysis of physical and mechanical properties and of gross calorific value of Jatropha curcas seeds and waste from pressing process. *Agronomy Research* **12**(2), 603–610.

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.

Tlustoš, P., Ochecová, P., Száková, J., Perná, I., Hanzlíček T., Habart, J. & Straka, P. 2012. Monitoring the quality of ashes from biomass combustion. *Certified methodology, Czech University of Life Sciences Prague*, 26, ISBN 978-80-213-2327-8

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.

Wihersaari, M. 2005. Greenhouse gas emissions from final harvest fuel chip production in Finland. *Biomass-and-Bioenergy* **28**(5), 435–443.

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.

Agronomy Research **14**(4), 1266–1273, 2016

Diatom cultivation and lipid productivity for non-cryopreserved and cryopreserved cells

Z. Demirel*, C. Demirkaya, E. Imamoglu and M. Conk Dalay

Ege University, Faculty of Engineering, Department of Bioengineering, TR 35100 Bornova-Izmir, Turkey
*Correspondence: zelihademirel@gmail.com

Abstract. Many freshwater and marine algae can be cryopreserved, but typically with lower post-thaw viability levels. However, most of the algae groups (dinoflagellates, cryptophytes, synurophytes, and raphidophytes) cannot be successfully cryopreserved in these days. Marine diatoms can be cryopreserved and frequently have shown great viability. The aim of this study is to compare the cultivation and lipid productivity for non-cryopreserved and cryopreserved marine diatom cells. Diatoms preserved in the EGEMACC (Ege University Microalgae Culture Collection) are usually maintained by serial sub-culturing. In this study, the cryopreservation of marine diatom algae (*Amphora cf. capitellata*, *Cylindrotheca closterium, Nanofrustulum shiloi*) using the passive freezing system procedure was studied. Investigation into the cause of the freezing injury at the cellular level was made at different salt concentrations. Passive freezing method used in sea salts liquid media at the percentage of 1%, 2% and 3% containing cryoprotectant of 10% Me_2SO for six months in liquid nitrogen. *C. closterium* was obtained with the highest viability however *N. shiloi* was revival extended period of time. All of the diatom cells were grown in 1 L sterile bottle containing 900 mL of F/2 medium under the light intensity of 20 μmol photons $m^{-2}\ s^{-1}$ at 22 ± 2 °C with the air flow rate of 1 L min^{-1} for 15 days. The growth rate and biomass productivity were determined at the end of the batch production process. Also, lipid content of *A. capitellata* was obtained at the highest concentration compared to that of the other diatoms.

Key words: *Cylindrotheca closterium*, *Amphora* cf. *capitellata*, *Nanofrustulum shiloi*, cryopreservation, growth rate, lipid content.

INTRODUCTION

Microalgal biotechnologies are quickly developed for commercial exploitation of a range of products including health supplements, animal feeds, biofuels and chemical feed stocks (Bui et al., 2013). Diatoms have significant biotechnological potential as many taxa produce high levels of lipids, including high levels of triacylglycerols, making them candidates for aquaculture feeds, functional foods and even as a potential feedstock for biodiesel (Levitan et al., 2014; d'Ippolito et al., 2015).

Microalgae preserved in the Ege University Culture Collection (EGEMACC) are usually maintained by serial sub-culturing. This method is time consuming and expensive. Additionally, the risk of bacterial contamination due to repeated manipulations is high; transfer of stocks is time consuming and exhausting over long periods. Many species do not survive periodic, routine transfer of subcultures (Day et al, 1997; Tanniou et al., 2012; Piasecki et al., 2009).

Cryopreservation, with its potential for long-term conservation of biological resources, provides an invaluable tool to ensure the biosecurity and genotypic stability of model diatom taxa. *Thalassiosira pseudonana* and *Phaeodactylum tricornutum* have been successfully cryopreserved using methodologies as two-step freezing protocols (Day & Brand, 2005). The preservation of organisms without change in their morphological, physiological, biochemical and genetic properties is a first function of culture collections. Moreover, a second function is a significant amount of research on the fundamental cause of cryopreservation induced injuries such as chilling injury, injury at subfreezing temperatures, extracellular ice formulation, intracellular ice formulation and osmatic stress in algae (Mori et al., 2002; Brand & Diller, 2004; Hedoin et al., 2006).

The optimum conditions to use during freezing and thawing with algae have developed experimentally. Some basic procedures have been used to cope with or minimize the many undesirable effects of freezing and thawing: (a) Organisms should be transferred to fresh growth media; (b) cryoprotectants in concentrations of 5 to 15% should be added to growth media; (c) time must be allowed for osmotic equilibrium between the cells and the cryoprotective medium; (d) the freezing rate must be controlled. Successful procedures avoid all changes in membrane permeability, gas solubility and salt concentrations within the cell (Saks, 1978; Taylor& Fletcher, 1999).

Microalgal cell is preparated before freezing where a cryoprotective agent (CPA) can be added to the cell suspension to avoid cellular damage due to ice formation. Two forms of artificial cryoprotectants may be distinguished, the penetrating (passively move through the plasma membrane to equilibrate between the extracellular solution and the cell interior) and the non-penetrating types (do not pass through the plasma membrane and remain in the extracellular solution). The second category of non-penetrating CPAs, such as polyvinylpyrrolidone (PVP) and polyethylene glycol (PEG), less toxic for the cell, are scarcely used in cryopreservation (Fuller, 2004; Tanniou et al., 2012).

The maintenance of subculture algae collections based on agar, though well-established, is labour intensive, costly and subject to contamination and genetic change (Bui et al., 2013). Although studies are available on cryopreservation effect on marine algae, work on marine diatoms is inadequate (Redekar & Wagh, 2000).

The aim of this study was to investigate the potential of using cryopreservation to conserve marine diatoms, comparing the cultivation and lipid productivity of non-cryopreserved and cryopreserved applied to diatom cells.

MATERIAL AND METHODS

Organism

The three local strains isolated from Aegean Sea, *Amphora cf. capitellata* (EGEMACC 2), *Cylindrotheca closterium* (EGEMACC 45), *Nanofrustulum shiloi* (EGEMACC 44), were obtained from Ege Microalgae Culture Collection (http://www.egemacc.com/).

Cryopreservation protocols

All of the diatom cultures were harvested in the latter part of the logarithmic growth phase after incubation for 14 days. Harvested cell were resuspended with 1 ml of F/2 medium and cell were counted with *Neubauer* hemocytometer, adjusted to 1 x 10^7 cells ml^{-1}, prepared three repeatedly (Day & Stacey, 2007).

Freezing and Thawing: Dimethyl sulfoxide (Me_2SO) was used as a cryoprotectant in the study. The cultures were centrifuged, the excess media was removed, then 10% Me_2SO solution was added to media containing 1%, 2% and 3% sea salt, respectively, held at -20 °C for 30 minutes, held at -80 °C for an overnight, and then plunged the culture into liquid nitrogen at 196 °C during six months.

Recovery procedure: Thawing was carried out by immersing the vials in a 40 °C water bath, In order to remove cryoprotectant, the thawed cell suspensions were centrifuged and supernatant was removed. After that cells were resuspended with 5 ml of F/2, and then incubated in the dark for 24 hours at 22 ± 2 °C. The cells were incubated under 20 μmol photons m^{-2} s^{-1} at 22 ± 2 °C for 1 week.

Viability assay: After one day thawing, cell viability measured by a staining protocol using fluorescein diacetate (FDA). 50 μL of FDA stain stock solution was added to 1 ml culture, incubated at room temperature for 5 min, and the cells were observed by blue-light fluorescence microscopy. Viable cells seemed fluoresce green (FDA positive) and nonviable cells appear red or colorless. The images of living cells were taken under 485/535 nm with fluoresce in microscope (Olympus BX53, Japan) at 60X magnification. Viability was expressed as a percentage of control (nontreated unfrozen culture) vs FDA positive cells (Day & DeVille 1995).

Cultures

The thawed and non-cryopreserved strains were cultured in 1 L sterile bottle containing 900 ml of F/2 (Guillard and Ryther 1962, Guillard 1975), at 22 ± 2 °C, under white led lamps at an intensity of 20 μmol photons m^{-2} s^{-1} with the air flow rate of 1 L min^{-1} for 15 days.

Analytical Procedures

Cell growth (cells ml^{-1}) was estimated daily using a *Neubauer* counting chamber under an inverted microscope (Olympus CH40, Japan). The optical density of the culture was evaluated by using a spectrophotometer (Ultrospec 1100 pro, Amersham Bioscience), at $\lambda = 600$ nm. The specific growth rate (μ) of the cells was calculated from the exponential (straight line) phase, as $\mu = (lnN_1 - lnN_1)/d(t_2 - t_1)$, where N_2 is the final cell concentration, N_1 is the initial cell concentration and dt is the time required for the increase in concentration from N_1 to N_2. Doubling time (DT) was also calculated as DT = $ln2\ \mu^{-1}$, according to Wood et al., 2005.

Morphological characterization of the strain was performed by light and florescence microscopy (Olympus BX53, Japan).

Diatoms were harvested by centrifugation (Pro-Research by Centrurion Scientific Ltd) at 5,000 rpm for 5 min. Cells were washed twice with distilled water to remove sea salt. The pellets were then lyophilized with a Christ (Alpha 1–2 LD plus, Germany) freeze dryer, to estimate the cell dry weight. The dried biomass obtained after freeze-drying was stored in air-tight containers at -20 °C. Biomass productivity was expressed as dry weight from 1 L of culture per days of algal growth.

Lipid was extracted from lyophilized diatom biomass using extraction solvent mixture of methanol/chloroform, described by Demirel et al. 2015.

The data were analyzed using one-way analysis of variance (ANOVA). A probability value of $p \leq 0.05$ was considered to denote a statistically significant difference, and $p \leq 0.01$ was also used to show the power of the significance. Results were reported as mean values with standard deviations ($n = 3$) unless otherwise indicated.

RESULTS AND DISCUSSION

Me_2SO was introduced into cryobiology as a very effective, rapidly penetrating, and universal the cryoprotective additive (Hubalek, 2003). 10% Me_2SO were useful cryoprotectant and 1%, 2% and 3% salt concentrations were the better medium in the majority of the combinations tested. The staining method of FDA is rapid and convenient for viability assay, as well as commonly used for microalgae (Mori et al., 2002). In this study, diatom cells appeared in six months after subculturing of the thawed strains. The dead cells had surface damage or ruptured membranes. The results showed that among the salt concentrations of cell viability was found the highest in 1% salinity. In other words, the cell viability was increased with decreasing the salinity concentration for the cryopreservation of marine diatoms. Osmotic alters in cells throughout ice formation was a primary factor negatively affecting viability (Canavate & Lubian, 1994). The effect of reducing the salinity of the external medium on diatom cells viability is shown in the data in Fig. 1.

In generally, penetrating cryoprotectant was used for marine microalgae such as methanol (MeOH), dimethylsulfoxide (Me_2SO) and glycerol (Gly). The three most used CPAs for the viability observed in frozen cells with dimethyl sulfoxide originates during the freezing period and the function of cryoprotectants is related to a decrease in risk of physical and chemical damage during the ice formation process (Grima et al., 1994).

Though Canavate & Lubian (1994) and Joseph et al. (2000) studied tolerance of *Chaetoceros gracilis* and *C. calciltrans* to Me_2SO, Methanol and showed that it completely lost viability when exposed to 20% concentration of Me_2SO was so much lethal. But safer concentrations for Me_2SO were at 5% and lower. Methanol was described as an affectless CPA for diatoms. Some marine microalgae are more effectively cryopreserved with Me_2SO compared to MeOH, whereas glycerol is effective for members of the genus *Tetraselmis* (Reed, 2007).

There are many reports for the growth rate of cultivated marine phytoplankton species isolated from coastal and oceanic habits (Scholz & Liebezeit 2012; Scholz, 2014). Non-cryopreserved and cryopreserved marine diatom species were grown in standard F/2 medium (Table 1).

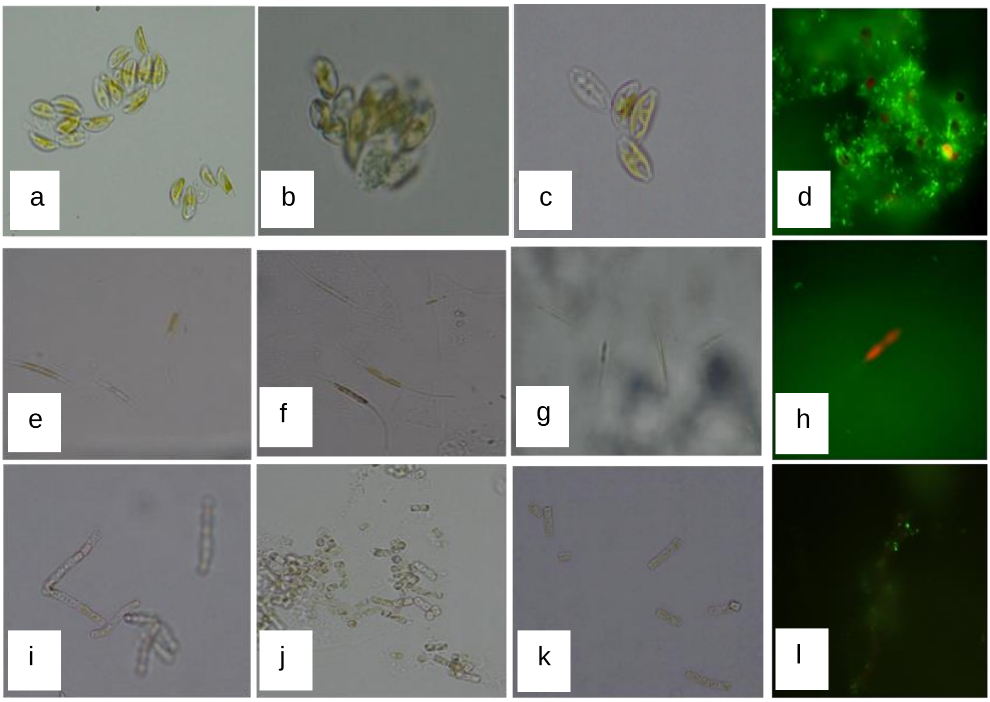


Figure 1. Diatom cells treated with 10% Me_2SO cryoprotectant. Figs a, b, c − *A. capitellata* with 1%, 2%, 3% salt concentrations, respectively, d − staining with 1% FDA 10% Me_2SO cryoprotectant; Figs e, f, g, *C. closterium* with 1%, 2%, 3% salt concentrations, respectively, h − staining with 1% FDA 10% Me_2SO cryoprotectant; Figs i, j, k, *N. shiloi* with 1%, 2%, 3% salt concentrations, respectively, l − staining with 1% FDA 10% Me_2SO cryoprotectant using light and florescence microscopy (63X magnification).

Table 1. Non-cryopreserved and cryopreserved diatom species were grown in F/2 medium

	Specific growth rate (μ; day^{-1})	Doubling time (day)	Dry weight (mg L^{-1})	Biomass Productivity (mg $L^{-}1day^{-1}$)	Percentage of lipids (%)
Amphora cf. capitellata	0.1072 ± 0.005	6.466	124.5	8.300 ± 0.001	**33.719 ± 0.244**
Amphora cf. capitellata-cryopreserved	0.2015 ± 0.015	3.441	212.8	14.187 ± 0.001	15.576 ± 0.208
Cylindrotheca closterium	0.1800 ± 0.012	3.851	312.8	20.853 ± 0.001	18.771 ± 0.083
Cylindrotheca closterium-cryopreserved	0.1750 ± 0.007	3.961	326.8	21.786 ± 0.003	25.150 ± 0.175
Nanofrustulum shiloi	0.2957 ± 0.018	**2.345**	366	**24.400 ± 0.001**	24.295 ± 0.163
Nanofrustulum shiloi-cryopreserved	0.2647 ± 0.023	2.619	259.1	17.273 ± 0.001	23.641 ± 0.346

Each diatom strains showed specific slope during the cultivation period (Fig. 2).

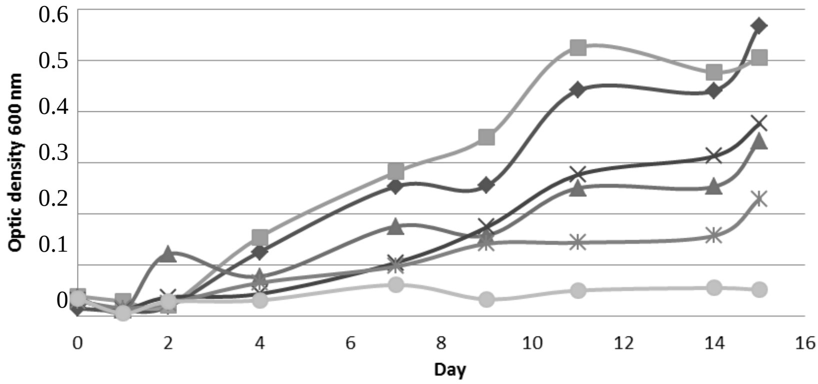


Figure 2. Growth profiles of cryopreserved diatom species. *C. closterium*; *C.closterium*-cryopreservation; *N. shiloi*; *N. shiloi*-cryopreservation; *A. capitellata;* *A. capitellata*.

In this study, the specific growth rate of *Amphora cf. capitellata* was determined with the lowest value of 0.1072 ± 0.005 day^{-1} and doubling time of 6.466 day^{-1} whereas the specific growth rate of cryopreserved *A. capitellata* was obtained with the value of 0.2015 ± 0.015 day^{-1}. Dry weights for cryopreserved *Cylindrotheca closterium* and *A. capitellata* were higher than non-cryopreserved cells. Cryopreserved *C. closterium* showed higher lipid productivity than non-cryoreserved *C. closterium* cells. On the other hand, the doubling time and lipid productivity of non-cryopreserved *A. capitella* was two times higher than the cryopreserved *A. capitella* cells. Therefore, cryopreserved *A. capitellata* could not accumulated into fatty acids. In addition, lipid content of *A. capitellata* was obtained at the highest concentration compared to that of the other diatoms. The results were indicated that cryopreserved diatom had higher lipid productivity. The reason is that lipid accumulation has been reported to protect cells from injury during freezing. *Isochrysis galbana* accumulate lipid droplets, which coalesce during cooling and till the cell. During thawing, droplets again become discrete. Hence, the high lipid content of cells could survive under freezing (Grima et al., 1994).

CONCLUSIONS

Cryopreserved diatoms *Amphora cf. capitellata*, *Cylindrotheca closterium*and *Nanofrustulum shiloi* could allow reduction of time consuming and area needed for the maintenance of their live cultures. In the present study, the salt concentration of 1% gave the highest viability for *A. capitellata, C. closterium* and *N. shiloi* with 10% Me_2SO for six months in the liquid nitrogen preserved. This could be explained that the low salinity content caused to decrease the penetration of osmotic injury. Therefore, knowledge of the capacity of the cell membrane to lose or gain water osmotically would be useful for more complete understanding of the physical processes affecting cryopreservation of the phytoplanktonic species. Using cryopreservation of marine diatoms to produce fatty acids has several advantages, such as controlled culture conditions, lack of contamination, and the presence of fatty acids in the polar lipid fraction, and carotenoids as fucoxanthin. Conservation of marine diatoms at sub-zero temperature limiting factors must also be taken into account, such as light, temperature, nutrients, pH, etc. for efficient industrial production of lipids.

ACKNOWLEDGEMENTS. The authors would like to thank the Scientific and Technological Research Council of Turkey (TUBITAK) with the project number of 113Z202 for the financial support.

REFERENCES

Brand, J.J. & Diller, K.R. 2004. Principles and applications of algal cryopreservation. *Nova Hedwigi*a **79**, 175−190.

Bui, T.V.L., Ross, I.L., Jakob, G. & Hankamer, B. 2013. Impact of Procedural Steps and Cryopreservation Agents in the Cryopreservation of Chlorophyte Microalgae. *Plos One* **8**(11) e78668, | www.plosone.org.

Canavate, J.P. & Lubian, L.M. 1994. Tolerance of six marine microalgae to the cryoprotectant dimethyl sulfoxide and Methanol. *Phycol.* **30**(3), 559−565.

Day, J.G. & Brand, J.J. 2005. Cryopreservation Methods for Maintaining Cultures. In: Andersen RA (ed.), *Algal Culturing Techniques*. Academic Press, New York, pp. 165−187.

Day, J.G. & DeVille, M.M. Cryopreservation of algae. *Methods in Molecular Biology* **38**, 81−89.

Day, J.G., Watanabe, M.M., Morris, G.J., Fleck, R.A. & McLellan, M.R. 1997. Long-term viability of preserved eukaryotic algae. *Journal of Applied Phycology* **9**, 121−127.

Day, J.G. & Stacey, G.N. 2007. Cryopreservation and freeze-drying protocols Second edition. *Methods in Molecular Biology* 368, Humana press, Totowa, New Jersey. 141−151.

Demirel, Z., Imamoglu, E. & Conk Dalay, M. 2015. Fatty acid profile and lipid content of *Cylindrotheca closterium* cultivated in air-lift photobioreactor. *J. Chem. Technol. Biotechnol.* **90**(12), 2290−2296.

D'Ippolito, G., Sardo, A., Paris, D., Vella, F.M., Adelfi, M.G., Botte, P., Gallo, C. & Fontana A. 2015. Potential of lipid metabolism in marine diatoms for biofuel production. *Biotechnology for Biofuels*. DOI 10.1186/s13068, 212−224.

Fuller, B.J. 2004. Cryoprotectants: The essential antifreezes to protect life in frozen state. *CryoLetters*. **25**(6), 375−388.

Grima, E.M., Perez, U.J.A., Camacho, F.G., FernBndez, F.G.A., Alonso, D.L. & Segura de Castillo, C.I. 1994. Preservation of the marine microalga, *Isochrysis galbana*: influence on the fatty acid profile. *Aquaculture* **123**, 377−385.

Hedoin, H., Pearson, J., Day, J.G., Philip, D., Young, A.J. & Hall, T.J. 2006. *Porphyridium cruentum* A-408 and *Planktothrix* A-404 retain their capacity to produce biotechnologically exploitable metabolites after cryopreservation. *Journal of Applied Phycology* **18**, 1–7.

Hubalek, Z. 2003. Protectants used in the cryopreservation of microorganisms, Review. *Cryobiology* **46**, 205−229.

Joseph, I., Panigrahi, A. & Chandra, P.K. 2000. Tolerance of three marine microalgae to cryoprotectants dimethyl sulfoxide, methanol and glycerol, *Indian Journal of Marine Sciences* **29**, 243−247.

Levitan, O., Dinamarca, J., Hochman, G. & Falkowski, P.G. 2014. Diatoms: a fossil fuel of the future. *Trends in Biotechnology* **32**(3), 117−124.

Mori, F., Erata, M. & Watanabe, M.M. 2002. Cryopreservation of cyanobacteria and green algae in the NIES-Collection. *Microbiol. Cult. Coll.* **18**(1), 45−55.

Piasecki, B.P., Diller, K.R. & Brand, J.J. 2008. Cryopreservation of *Chlamydomonas reinhardtii*: A cause of low viability at high cell density. *Cryobiology* **58**, 103−109.

Redekar, P.D. & Wagh, A.B. 2000. Cryopreservation studies on the marine diatom *Navicula subinflata* Grun. *Seaweed Res. Utiln.* **22**(1−2), 183−187.

Reed, B.M. 2007. Plant Cryopreservation: A Practical Guide. Spinger, Corvallis, OR, USA, pp. 93−116.

Saks, N.M. 1978. The Preservation of Salt Marsh Algae by Controlled Liquid Nitrogen Freezing. *Cryobiology* **15**, 563−568.

Scholz, B. 2014. Purification and Culture Characteristics of 36 benthic marine diatoms isolated from the Solthörn Tidal Flat (Southern North Sea). *J. Phycol*. **50**, 685–697.

Scholz, B. & Liebezeit, G. 2012. Growth responses of 25 benthic marine Wadden Sea diatoms isolated from the Solthörn tidal flat (southern North Sea) in relation to varying culture conditions. *Diatom Res*. **27**, 65−73.

Tanniou, A., Turpin, V. & Lebeau, T. 2012. Comparison of cryopreservation methods for the long term storage of the marine diatom *Haslea ostrearia* (simonsen). *Cryobiology* 65, 45−50.

Taylor, R. & Fletcher, R.L. 1999. Cryopreservation of eukaryotic algae – a review of methodologies. *Journal of Applied Phycology* **10**, 481−501.

Wood, A.M., Everroad, R.C. & Wingard, L.M. 2005. Measuring growth rates in microalgal cultures. In: Andersen R.A.(ed). *Algalculturing techniques*. USA: Elsevier Academic Press, pp. 269−285.

Agronomy Research **14**(4), 1274–1284, 2016

Soil microbiological activity depending on tillage system and crop rotation

L. Dubova*, A. Ruža and I. Alsiņa

Institute of Soil and Plant Sciences, Faculty of Agriculture, Latvia University of Agriculture, Liela iela 2, LV-3001 Jelgava, Latvia
*Correspondence: laila.dubova@llu.lv

Abstract. Soil management practices include various tillage systems that influence plant growth and activity of microorganisms. Minimum tillage without soil inversion is increasingly being used because the conventional soil tillage with soil inversion is a more energy-consuming operation and affects the biodiversity of agroecosystems. The present study was aimed to estimate the effect of conventional and minimum tillage systems on soil microbiological activity. The trials were established in the experimental fields of the Latvia University of Agriculture. The intensity of soil respiration and the ratio of microbial biomass between minimum tillage and conventional tillage were calculated from 2011 to 2013, and cellulose degradation intensity – from 2012 to 2014. The conventionally tilled plots were ploughed to the depth of 23 cm, but minimum tillage was done at the depth of 10–12 cm without soil inversion. Soil samples were collected at two depths: 0–10 cm, and 11–20 cm. The crops were cultivated both in a monoculture (winter wheat) and using crop rotation (winter wheat–rape). Soil microbiological activity was characterised by soil respiration, cellulose degradation intensity, and biomass of soil microorganisms. The results suggest that microbial biomass of soil increased in the fields under minimum tillage compared to those under conventional tillage. It was found that crop rotation had no significant effect on the microbial biomass and soil respiration intensity. Although the upper soil layer has a higher potential of microbiological activity, the cellulose degradation intensity showed a tendency to decrease at both soil depths in the experimental plots without crop rotation.

Key words: cellulose degradation, soil minimum tillage, soil respiration.

INTRODUCTION

Soil use influences the quality of soil since it can deteriorate, stabilize, or improve the soil ecosystem. Soil quality affects micro- and macroorganisms that live in the soil, but ecological factors such as water content, temperature, and aeration of soil modify the intensity of soil microbiological processes (Feng et al., 2003; Han et al., 2007). The qualitative and quantitative changes in the population of soil microorganisms reflect the changes in soil quality (Sharma et al., 2010). Soil tillage practices affect the soil microbial community in various ways, with possible consequences for nitrogen (N) losses, plant growth, and soil organic carbon (C) decomposition. At the same time, soil microorganisms are involved in biochemical processes that include the decomposition of plant residues and the transformations of organic matter, affect the mineralization of plant available nutrients, and influence the efficiency of nutrient cycles (Singh et al., 2011; Jackson et al., 2012; Tiemann et al., 2015).

A growing interest in soil management that could prevent decrease in soil quality has been observed throughout the world. Therefore, farmers replace the conventional soil tillage with alternative techniques of crop cultivation and soil management defined as conservation agriculture that include no-tillage (conservation tillage) or reduced tillage. Reduced tillage is increasingly being used to save soil quality and to decrease soil mechanical disturbance, erosion, and agricultural production costs (Andrade et al., 2003; Morris et al., 2010). Investigations of various tillage systems under all climatic conditions have not been carried out equally intensively. Reduced tillage, especially no-tillage, methods are widespread throughout the North and South America but are less used in Europe, where intermediate forms of the non-ploughing or non-inversion tillage have been adopted much more readily than no-till farming system; however, some advantages and disadvantages are being studied more extensively (Soane et al., 2012; Avižienyte et al., 2013; Brennan et al., 2014).

The weather conditions have a significant effect on the crops grown using non-inversion tillage (Brennan et al., 2014), so that plant residues on soil surface influence the soil properties and the efficiency of utilisation of fertilizers, pesticides, and other inputs. As pointed by some authors, soil tillage affects the abundance and diversity of weed species and the survivability of plant pathogens (Gaweda, 2007; Morris et al., 2010; Brennan et al., 2014). The minimum tillage increases the amount of plant residues on the soil surface. Plant residue decomposition is slow due to the partial contact between crop residues and soil. Equally important, the soil microbiological activity is influenced also by other site-specific factors (Andrade et al., 2003). The accumulation of plant debris in soil or on its surface may increase the biodiversity of agroecosystems; at the same time, there is a risk that various pathogens may retain their viability until the succeeding crop is grown. Crop rotations and cover crops are considered to be essential components in the reduction of weeds (Soane et al., 2012).

The conversion from conventional to conservation tillage introduces changes in the distribution of organic matter within soil profile and increases the amount of organic matter and microbial biomass in the soil surface layer (Šimon et al., 2009). Both the soil tillage system and the soil type affect the amount of mineral elements in different soil layers, which, in its turn, influences the development of plants and the number and activity of microorganisms (Feiza et al., 2010).

Mikanova et al. (2009) have found that soil biological activity, particularly the activity of microorganisms, is a significant indicator of the soil quality and fertility. Different agroecosystem management practices differently influence the soil nutrient availability and potential enzyme activity. Research findings about the effect of agroecosystem management on the number of soil bacteria and fungi are contradictory. For example, Bowles et al. (2014) have not detected its major effect on soil microbial community. Their research suggests that the growth rates of saprophytic fungi and bacteria were unaffected by tillage practice. Greonigen et al. (2010) have noted that reduced tillage treatment increased the biomass of both microbial groups in the topsoil layer, whereas Frey et al. (1999) have reported that the fungal and bacterial biomass ratio increased under no-till systems. The observed differences may be explained by a higher degree of soil disruption in reduced tillage systems compared to strict no-till systems.

Plant residues left on the soil surface may increase the fungal population. On the other hand, growth rates are more strongly affected by environmental factors in the short term than the biomass of microbes and their metabolites such as enzymes and biologically active components. Soil tillage may also affect the composition of soil amino sugar pool, which dynamics represents an important component of the carbon (C) and nitrogen (N) cycles (Greonigen et al., 2010). The activity of soil respiration and enzymes can be a sensitive indicator of the changes occurring in the soil biological activity and fertility in response to various soil management practices. Gajda & Martyniuk (2004) have reported a lower microbial biomass C and N content, soil respiration intensity and enzyme activity for the soil of conventional winter wheat monoculture compared to organic management and conventional short-rotation farming system. Assessment of the microbial biomass and activity can reveal changes in the content of soil organic matter before these changes are detected in the total soil organic matter (Andreda et al., 2003).

The aim of the current research was to assess the effect of soil tillage methods and crop rotation on the activity of soil microorganisms.

MATERIALS AND METHODS

The description of experimental site. A stationary field experiment (established in 2009) was carried out at the Study and research farm 'Peterlauki' of the Latvia University of Agriculture. The data were obtained in the experimental period 2011–2014. The soil was *Cambic Calcisol*, pH KCl 6.8, according to WRB 2014. The soil agrochemical properties and the evaluation of the amount of mineral elements are presented in Table 1.

Table 1. Soil agrochemical properties at the depth of 0–20 cm

Index	Values		Evaluation*
	mean	±	
Humus, g kg^{-1}	22.0	2.0	low
P_2O_5, mg kg^{-1}	134.5	25.3	sufficient
K_2O, mg kg^{-1}	245.3	22.5	sufficient
Ca, mg kg^{-1}	1,809.0	92.5	sufficient
Mg, mg kg^{-1}	483.6	43.6	high

* According to Fertiliser Recommendations for Agricultural Crops, 2013.

Agrotechniques of experimental site. Two soil primary tillage treatments were investigated: conventional tillage (CT) – ploughing at the depth of 22–23 cm with a mouldboard plough; and minimum shallow tillage (MT) – at the depth of 10–12 cm with a disc harrow. The crops were cultivated without crop rotation (plots No. 1 and No. 2) and with crop rotation (plots No. 3 and No. 4). The scheme of crop rotation and soil tillage methods used in the experimental plots by years is presented in Table 2. Each plot size was 24×100 m. Each experimental variant was designed in two replications.

Table 2. The scheme of crop rotation and soil tillage in the experimental plots

Year	Minimum tillage (MT)	Conventional tillage (CT)		Minimum tillage (MT)
	Plot 1	Plot 2	Plot 3	Plot 4
2010	winter wheat	winter wheat	winter rape	winter rape
2011	spring wheat	spring wheat	spring wheat	spring wheat
2012	winter wheat	winter wheat	winter wheat	winter wheat
2013	winter wheat	winter wheat	winter rape	winter rape
2014	winter wheat	winter wheat	winter wheat	winter wheat

In 2011, fertilization of all experimental plots was done in August – with complex NPK 7–24–24 kg ha^{-1}. CT and MT were performed in September. In May 2012, all plots were additionally fertilized with ammonium nitrate at the dose of N 50 kg ha^{-1}. In the autumn of 2012, after soil tillage, complex fertilizer NPK 7–20–28 was applied at the dose of 300 kg ha^{-1}. In 2013, ammonium nitrate was additionally applied in April and May: to winter wheat – N 80 kg ha^{-1} and N 70 kg ha^{-1}, respectively; and to winter rape – N 80 kg ha^{-1} and N 80 kg ha^{-1}, respectively.

Weather conditions. In the vegetation period of 2011, the average temperature was 0.2–3.6 degrees higher than the long-term average. Dry weather prevailed from April to November, except May, July, and August, when precipitation was 40.5%, 40.0%, and 60.4% higher, respectively, than the long-term average. In 2012, the average monthly temperature was lower, but the amount of precipitation was higher than in the previous year. In 2013, spring was cooler than the long-term average, but the vegetation period was mostly warm and dry. Meteorological conditions throughout the vegetation period of 2014 were characterized by larger precipitation amounts than the long-term average (123–220% from long-term data) (Figs 1 and 2).

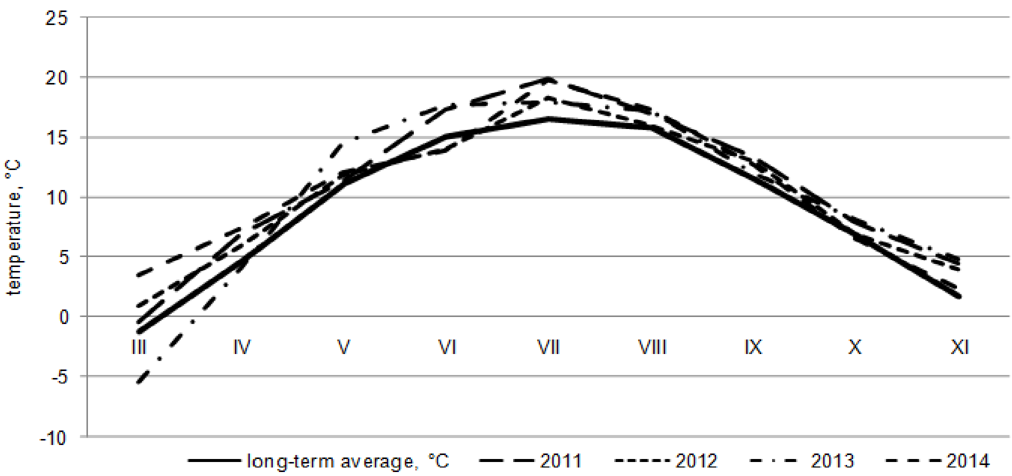


Figure 1. Temperature in the experimental period.

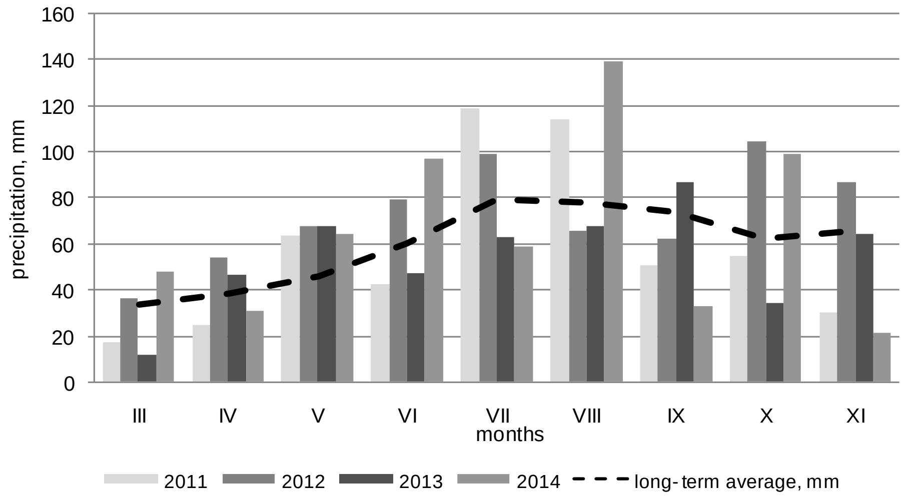


Figure 2. Precipitation in the experimental period.

Soil sampling and assessment of biological activity. The soil was sampled four times from each plot during the vegetation period. Soil samples were taken from two soil layers (at the depths of 0–10 cm and 10–20 cm) using an auger with a 2 cm diameter. A composite sample of 10–15 drillings was taken from each plot. Field-moist samples were stored in plastic bags at 4 °C for soil biological activity analysis.

Soil basal respiration was determined by placing 50 g of field-moist soil and a beaker containing 5 mL of 0.1 M KOH solution into a 500-mL jar; the jar was sealed and placed in the dark at the temperature of 30 °C for 24 hours. Afterwards, the KOH solution was removed and titrated with 0.1 M HCl to determine the amount of CO_2 evolved with the soil microbial respiration (Pell et al., 2005). The soil moisture was determined by drying the sample for 24 hours at 105 °C. Soil microbial biomass carbon (microbial biomass-C) was calculated by substrate-induced respiration results according to LVS ISO 14240-1:1997. For the assessment of substrate-induced respiration, 2 mg of glucose were added to 1 gram of a soil sample.

In May of 2012, 2013 and 2014, cellulose degradation activity was determined using linen pieces. A soil sample from each plot was placed in two containers (volume – 1 L); in each container, three weighed linen pieces were placed. All containers were stored in field conditions. After six weeks, the linen pieces were removed from the sampled soil and weighed. The degree of degradation was expressed as percentage of linen degradation.

The experimental data were analysed by the two-factor analysis of variance. The data were processed using software *ANOVA*. The parameters were considered as significant at $P < 0.05$.

RESULTS AND DISCUSSION

The biomass of soil microorganisms. Soil microorganisms indicate the living and dynamic component of soil organic matter. Despite the fact that microbes are only a few percent of soil organic matter, they can affect crop production and are significant for sustainable agroecosystems. However, the microbial biomass can be affected by the factors that change the water or carbon content of soil and include soil type, climate, and management practices. The soil properties that usually affect the microbial biomass are soil pH, content of clay, and organic matter. To compare the effect of tillage and crop rotation on the biomass of microorganisms, the ratio $C_{MT} : C_{CT}$ was calculated. Changes in the ratio of microbial biomass-C ($C_{MT} : C_{CT}$) at the depth of 0–10 cm and 10–20 cm in conventionally tilled and minimum-tilled soil are shown in Table 3.

Table 3. The ratio of microbial biomass-C between minimum-tilled soil and conventionally tilled soil without crop rotation (plots No. 1 and No. 2) and with crop rotation (plots No. 3 and No. 4)

Year	Plot No.	April	June	August	November	On average
	$C_{MT} : C_{CT}$ at soil depth 0–10 cm					
2011	1 : 2	1.32	1.08	1.47	1.06	1.23
	4 : 3	1.02	1.17	1.06	1.17	1.11
2012	1 : 2	1.08	1.20	0.94	0.91	1.03
	4 : 3	1.19	1.21	0.79	0.97	1.04
2013	1 : 2	1.73	1.66	1.26	0.92	1.39
	4 : 3	1.67	1.62	1.55	0.97	1.45
	$C_{MT} : C_{CT}$ at soil depth 10–20 cm					
2011	1 : 2	1.23	0.86	1.42	0.81	1.08
	4 : 3	0.93	0.92	1.06	0.95	0.97
2012	1 : 2	1.02	0.88	0.96	1.14	1.00
	4 : 3	1.02	0.95	1.11	1.00	1.02
2013	1 : 2	1.34	1.06	1.34	0.65	1.10
	4 : 3	1.12	1.48	0.79	1.27	1.17

The results show that MT, contrary to CT, increased the biomass of microorganisms. Each year during the vegetation period, the value of the biomass of microorganisms fluctuated, and a statistically different (F = 0.74 > F crit = 0.006) value of the ratio $C_{MT} : C_{CT}$ was only in the year 2013 – at the depth of 0–10 cm and 10–20 cm. The results are in accordance with Andrada et al. (2003) and Groenigen et al. (2010) who have noted that reduced tillage or no tillage increased the amount of microorganisms in the upper soil layer, whereas the impact of crop rotation on the biomass of microorganisms was insignificant. The response of soil microbial biomass to tillage varied because of the climatic conditions, sampling depth, and cropping system.

Soil respiration intensity. The obtained data show that weather conditions significantly affected the activity of microorganisms. The average soil respiration intensity during the experiment is shown in Fig. 3. In 2013, the lowest soil respiration intensity was observed in the 0–10 cm soil layer. The year 2013 was characterized by high air temperatures and little precipitation, which may explain the low level of soil respiration intensity observed under both tillage methods. In 2011 and 2012, a significantly higher soil respiration intensity was determined in the upper layer of minimum-tilled soil compared to conventionally tilled soil. Accumulation of plant residues in upper soil layers and sufficient moisture stimulate the activity of microorganisms. Yao et al. (2011) suggest that temperature and moisture are important environmental factors influencing the soil microbial growth and activity. Also heterotrophic organisms are largely dependent on the amount of organic matter presented in the soil. On the other hand, plant residue distribution in the whole plough layer at CT provides an unfluctuating activity of microorganisms throughout the vegetation period. Our results demonstrate that soil respiration intensity when using CT was not so strongly affected by environmental factors, especially at the depth of 10–20 cm. This suggests that under MT system, the upper-soil-layer microorganisms are more exposed to the weather conditions.

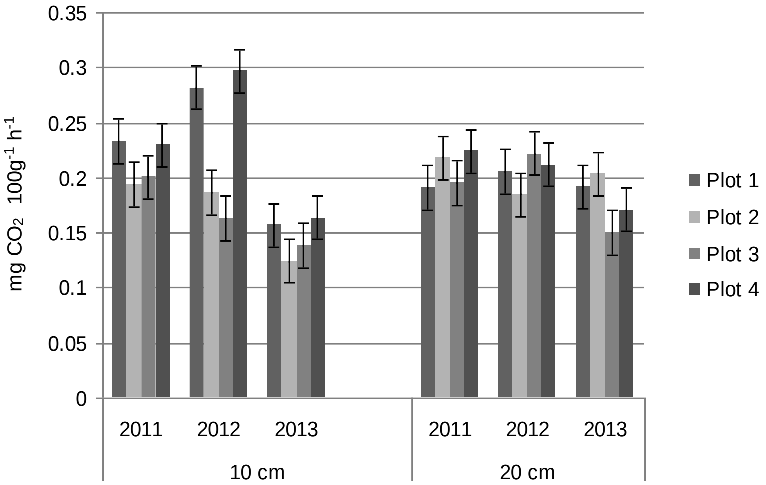


Figure 3. Soil respiration intensity in the experimental period (bars present LSD).

The results of the assessment of microbial activity during the 2011–2013 vegetation period are shown in Fig. 4.

In 2011, the highest soil respiration intensity was observed in April; then it decreased and fluctuated between 0.1 and 0.25 mg CO_2 100 g^{-1} h^{-1}. No statistically significant fluctuations in soil respiration intensity were detected in deeper soil layers. The research suggests that tillage had a significant effect on upper soil layers. This could be explained by the rather warm air temperatures and abundant precipitation, which affected plant residue decomposition in the upper soil layer.

In the second part of the 2012 vegetation period, a significant increase in soil respiration intensity was observed in minimum-tilled plots – on average, two times higher than in conventionally tilled plots. This may be due to the accumulation of plant residues in the upper soil layer and the heavy rainfalls in July, which stimulated the activity of microorganisms.

Large fluctuations in the intensity of soil respiration were observed in August 2013, when soil respiration drastically increased in both soil layers. This might have been influenced by the increase in precipitation after the long dry and warm period in the first part of vegetation. No significant effect of crop rotation on soil respiration intensity was detected.

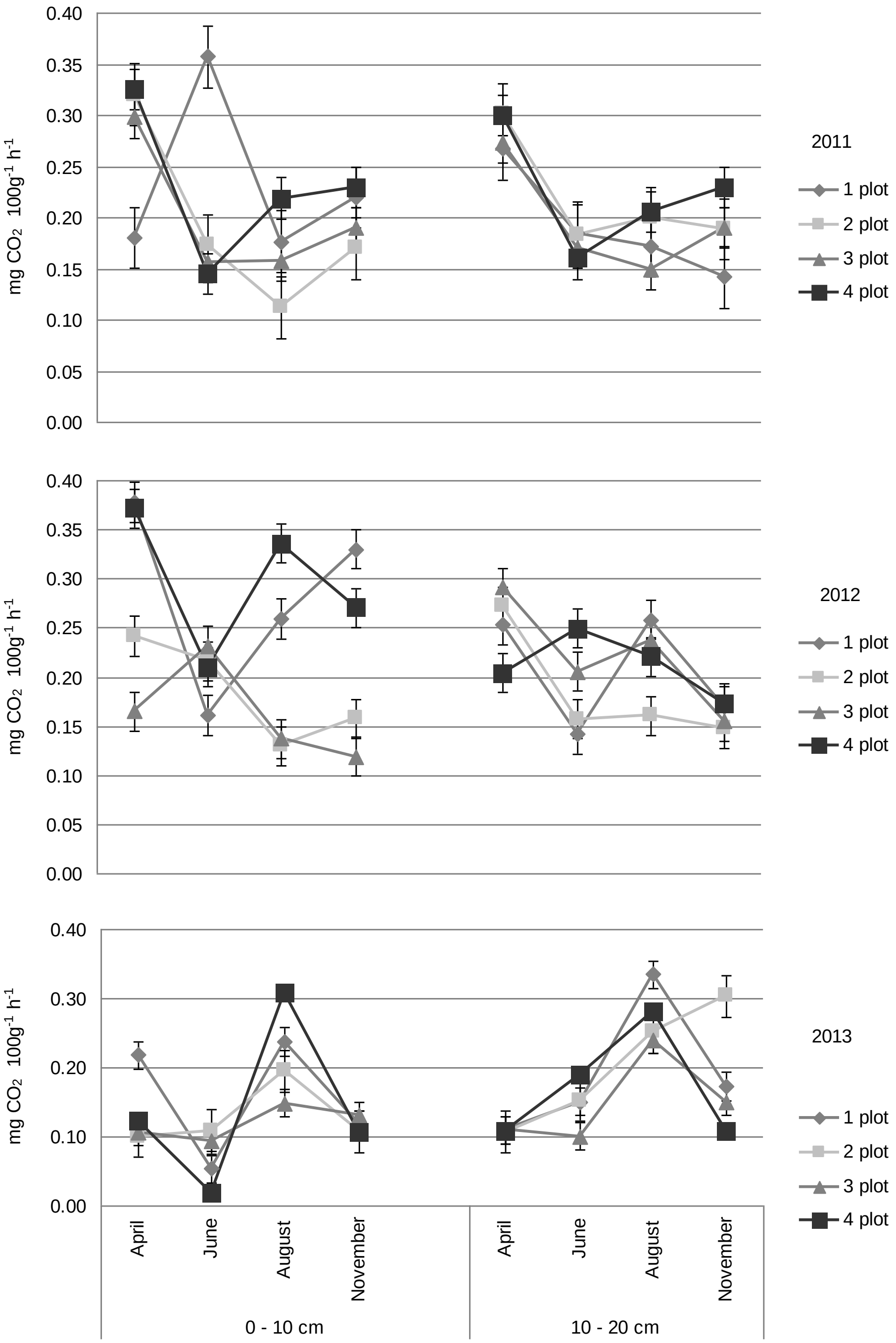


Figure 4. Soil respiration intensity during the vegetation period of 2011, 2012, and 2013.

Cellulose degradation intensity. The data obtained in 2012 revealed significant differences between the soil layers. In the upper soil layer, cellulose degradation intensity was 2–2.5 times higher compared to the 10–20 cm soil depth (Figs 5–7). This corresponds to the data obtained by other researchers (Andrade et al., 2003; Šimon et al., 2009). In 2013, no fluctuations between tillage method and soil sampling depth were observed. In 2014, a difference between the reduced and conventional tillage methods was established. In all experimental period, except the year 2012, it was detected that in conventionally tilled plots, the activity of cellulose degrading bacteria was similar at both soil depths.

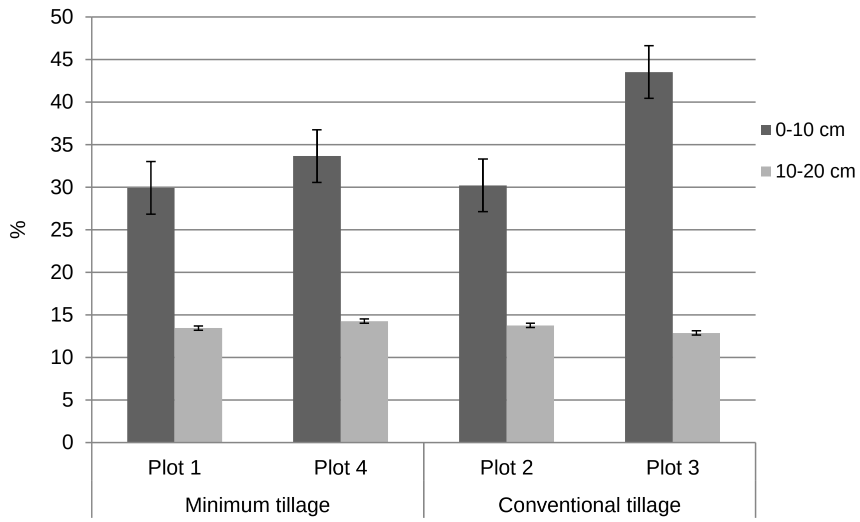


Figure 5. Cellulose degradation intensity in 2012.

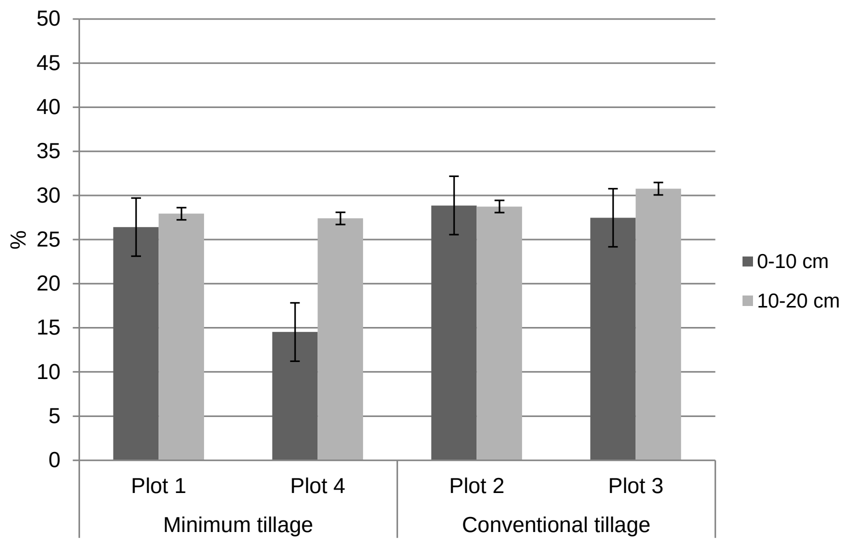


Figure 6. Cellulose degradation intensity in 2013.

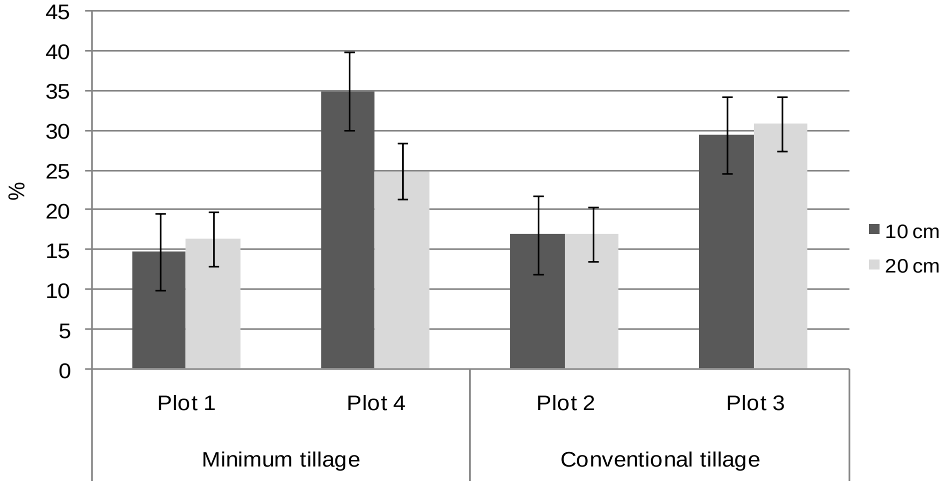


Figure 7. Cellulose degradation intensity in 2014.

Cellulose degradation intensity had a tendency to decrease at both soil depths in the experimental plots without crop rotation. Although the upper soil layer has a higher potential for microbiological activity because it accumulates more plant debris, it is more exposed to the influence of weather conditions.

CONCLUSIONS

Minimum tillage (MT), contrary to conventional tillage (CT), increased the biomass of microorganisms. A statistically significant difference was detected between soil sampling depths, whereas crop rotation showed no significant effect on soil respiration intensity. Although the 0–10 cm soil layer has a higher potential of microbiological activity, the minimum soil tillage does not provide an even decomposition of plant residues because the upper layers are more influenced by the weather conditions.

ACKNOWLEDGEMENT. The research was supported by the State research program ‘Agricultural Resources for Sustainable Production of Qualitative and Healthy Foods in Latvia’, Project No. 1 ‘Sustainable use of soil resources and abatement of fertilization risks (SOIL)’.

REFERENCES

Andrade, D.S., Colozzi-Filho, A. & Giller, K.E. 2003. The soil microbial community and soil tillage. In: El Titi A. (ed.). *Soil Tillage in Agroecosystems*, pp. 51–82.

Avižienytė, D., Romaneckas, K., Palyškytė, R., Bogužas, V., Pilipavičius, V., Šarauskis, E., Adamavičienė, A. & Vaiciukevičius, E. 2013. The impact of long-term reduced primary soil tillage on maize (*Zea mays* L.) productivity. *Zemdirbyste-Agriculture* **100**(4), 377–382.

Brennan, J., Hackett, R., McCabe, T., Grant, J., Fourtune, R.A. & Forristal, A.C. 2014. The effect of tillage system and residues management on grain yield and nitrogen use efficiency in winter wheat in cool Atlantic climate. *European Journal of Agronomy* **54**, 61–69.

Bowles, T.M., Acosta-Martinez, V., Calderon, F. & Jackson, L.E. 2014. Soil enzyme activities, microbial communities, and carbon and nitrogen availability in organic agroecosystems across

an intensively-managed agricultural landscape. *Soil Biology and Biochemistry* **68**, 252–262.
Feiza, V., Feizienė, D., Auškalnis, A. & Kadžienė, G. 2010. Sustainable tillage: results from long-term field experiments on *Cambisol*. *Zemdirbyste-Agriculture* **97**(2), 3–14.
Feng, Z., Motta, A.C., Reeves, D.W., Burmester, C.H., Van Santen, E. & Osborne, J.A. 2003. Soil microbial communities under conventional-till and no-till continuous cotton systems. *Soil Biology and Biochemistry* **35**, 1693–1703.
Fertiliser Recommendations for Agricultural Crops. 2013. Ed. by A. Karklins and A. Ruza. Jelgava, LLU, 55 pp.
Frey, S.D., Elliot, E.T. & Paustian, K. 1999. Bacterial and fungal abundance and biomass in conventional and no-tillage agroecosystems along two climatic gradients. *Soil Biology and Biochemistry* **31**, 573–585.
Gajda, A. & Martyniuk, S. 2005. Microbial biomass C and N and activity of enzymes in soil under winter wheat grown in different crop management systems. *Polish Journal of Environmental Studies* **14**(2), 159–163.
Gaweda, D. 2007. Winter wheat weeds infestation under conditions of various tillage systems. *Acta Agrophysica* **10**, 317–325.
Greonigen, K.J., Bloem, J., Baath, E., Boeck, P., Rousk, J., Bode, S., Forristal, D. & Jones, M. 2010. Abundance, production and stabilization of microbial biomass under conventional and reduced tillage. *Soil Biology and Biochemistry* **42**(1), 48–55.
Han, G., Zhou, G., Xu, Z., Yang, Y., Liu, J. & Shi, K. 2007. Biotic and abiotic factors controlling the spatial and temporal variation of soil respiration in an agricultural ecosystem. *Soil Biology and Biochemistry* **39**(2), 418–425.
Jackson, L.E., Bowles, T.M., Hodson, A.K. & Lazcano, C. 2012. Soil microbial-root and microbial-rhizosphere processes to increase nitrogen availability and retention in groecosystems. *Current Opinion in Environmental Sustainability* **4**, 517–522.
LVS ISO 14240-1:1997. Soil quality – determination of soil microbial biomass. Part 1: Substrate-induced respiration method.
Mikanova, O., Javurek, M., Šimon, T., Friedlova, M. & Vach, M. 2009. The effect of tillage systems on some microbial characteristics. *Soil and Tillage Research* **105**, 72–76.
Morris, N.L., Miller, P.C.H., Orson, J.H. & Fround-Williams, R.J. 2010. The adoptation of non-inversion tillage systems in the United Kingdom and the agronomic impact on soil, crops and the environment – a review. *Soil and Tillage Research* **108**, 1–15.
Pell, M., Stenström, J. & Granhall, U. 2005. Soil respiration. In: Bloem J. *et al*. (eds). Microbiological methods for assessing soil quality, pp. 117–126.
Sharma, S.K., Ramesh, A., Sharma, P., Joshi, O., Govaerts, B., Steenwerth, K.L. & Karlen, D.L. 2010. Microbial community structure and diversity as indicator for evaluating soil quality. In: E. Lichtfouse (ed.). *Biodiversity, Biofuels, Agroforestery and Conservation Agriculture, Sustainable Agriculture Reviews*, 5, Springer Science+Business Media, pp. 317–347.
Singh, J.S., Pandey, V.C.. & Singh, D.P. 2011. Efficient soil microorganisms: A new dimension for sustainable agriculture and environmental development. *Agriculture, Ecosystems and Environment* **140**, 339–353.
Soane, B.D., Ball, B.C., Arvidsson, J., Basch, G., Moreno, F. & Roger-Estrade, J. 2012. No-till in northern, western and south-western Europe: A review of problems and opportunities for crop production and the environment. *Soil and Tillage Reaserch* **118**, 66–87.
Šimon, T., Javurek, M., Mikanova, O. & Vach, M. 2009. The influence of tillage systems on soil organic matter and soil hydrophobicity. *Soil and Tillage Research* **105**, 44–48.
Tiemann, L.K., Grandy, A.S., Atkinson, E.E., Marin-Spiotta, E. & McDaniel, M.D. 2015. Crop rotational diversity enhances belowground communities and functions in an agroecosystem. *Ecology Letters*, doi: 10.1111/ele.12453.
Yao, H., Bowman, D. & Shi, W. 2011. Seasonal variations of microbial biomass and activity in warm- and cool-season turfgrass systems. *Soil Biology and Biochemistry* **43**, 1536–1543.

Agronomy Research **14**(4), 1285–1292, 2016

Method to monitor sand level changes in free-stall lying area for dairy cows

M. Gaworski[1,*] and Á. Garreth Ferraz Rocha[2]

[1]Warsaw University of Life Sciences, Department of Production Management and Engineering, Nowoursynowska street 164, PL 02-787 Warsaw, Poland
[2]University Federal of Uberlândia, Faculty of Veterinary Medicine and Zootechnology, #1720, Pará Avenue – Campus Umuarama – Uberlândia, MG – ZIP 38400–902, Brazil
[*]Correspondence: marek_gaworski@sggw.pl

Abstract. Understanding sand properties and proper sand management is critical to the selection and successful use of sand as a dairy bedding material. Use of sand as a bedding material is an alternative solution at many dairy farms instead of straw and other organic materials. In order to successfully use and manage sand as a bedding material for cows, it is necessary to consider monitoring of the sand amount in order to create the highest possible level of lying comfort for animals. The objective of the study was to investigate a modified approach to sand level measurements to find changes in the amount of sand covering the lying area in a barn with the free-stall keeping system. The method to measure sand level changes included use of a timber board (put on the neighbouring partitions at each lying stall) to determine the distance to the bedding surface in two zones of lying stalls. Results of the investigated method of monitoring sand level changes were discussed against the background of other results presented in the specialist literature. The discussion included the problem of measurement accuracy as well as simplicity of the proposed measuring method for practical use by farmers.

Key words: bedding, cow, dairy farm, free-stall, keeping system, management, sand.

INTRODUCTION

Effective management and an appropriate environment are essential for dairy cattle health and welfare (Vasseur et al., 2015). Proper practices and guidance provide dairy farmers with best results concerning care and handling of their cattle.

Cows' comfort is part of animal welfare and may determine efficiency of farm dairy production (von Keyserlingk et al., 2009). Comfort of the cow herd is created in many areas of the barn. The daily time budget for lactating dairy cows indicates that the most important role in the field of comfort is that of the lying area (Gomez & Cook, 2010). Adequate rest has been positively associated with productivity, health and welfare of dairy cattle (Solano et al., 2016).

The percentage of time spent lying by cows shows that it is necessary to create excellent comfort conditions in the lying area to ensure improved cow herd handling. As a result of many experiments, Nordlund & Cook (2003) suggest that the lying surface is a particularly important component of the free-stall design. Such observations were already found in the early eighties, when cow preferences for certain free-stall surface materials as well as hygiene and lying down behaviour was compared (Natzke et al., 1982).

Certain investigations regarding the lying area for dairy cows emphasize the significance of bedding quality (Fregonesi et al., 2007), amount of bedding (Norring et al., 2010) as well as bedding management resulting in a longer time spent lying down in well bedded stalls in comparison with poorly bedded places (Tucker et al., 2003; Wagner-Storch et al., 2003). Sand and straw beddings influence the lying behaviour, cleanliness, as well as hoof and hock injuries of dairy cows (Norring et al., 2008). Bedding types can be associated with management practices and constitute indicators of milk quality (Rowbotham & Ruegg, 2015). One of the management effects is the amount of bedding used on the stall surface and affecting the cow's response. Drissler et al. (2005) documented how declines in deep-bedded and not maintained stalls with sand as the bedding material can have a dramatic effect on stall usage; lying time declined by about 10 min/d for every 1 cm of reduction in sand bedding. Sand is a popular bedding material used in barns for dairy cows and heifers at the west coast of Canada.

The response of cows to the abovementioned quality of lying surface and quantity of bedding material can be an inspiration for development of methods aimed at assessing changes in the lying conditions of dairy cows. The lying conditions can be identified not only by the stall design (Gaworski et al., 2003) but also by the amount of bedding material. The aim of the paper was to present the research approach (method) for measuring changes in the level of bedding material covering the lying surface for dairy cows kept in the barn with the free-stall system.

It is possible to enumerate certain reasons underlying development of a method for assessing changes in the amount of bedding material consumption. A modified approach to assessment of bedding material for dairy cows can be a source of comparisons with certain known methods for measurement of bedding material changes. Moreover, it can be a source of suggestions to improve management of bedding material in the lying area for dairy cattle and, at the same time, a practical proposition regarding implementation by farmers of a method of bedding material assessment including some simple measurements.

MATERIALS AND METHODS

The measurements concerning changes in the amount of bedding material covering the lying surface for dairy cows were conducted in a free-stall barn located at the University of British Columbia's Dairy Education and Research Centre in Agassiz (British Columbia, Canada) in October 2015. The investigated, naturally ventilated (with curtained sidewalls) wooden frame barn consisted of 288 free stalls divided into smaller units, i.e. pens with 12 stalls each. The lying stalls in each individual pen were configured in 3 rows, 2 rows facing one another and the back row facing a cement wall (Fig. 1). The pens were equipped with stalls divided by Dutch-style partitions (Fig. 2). One stall at each row was bounded by a cement wall.

The laying stalls in the investigated barn were filled with sand.

The laying stalls in the investigated part of barn were refilled with new sand each 18th day. To spread sand on the lying stalls in barn, a spreader attached to the tractor's three point linkage was used.

In order to spread sand in the stalls located in three rows, the tractor with the attached machine (spreader) had to move along two scraper alleys (Fig. 1). During sand spreading, the scrapers were stopped at such a position as to enable the tractor to move along the scraper alleys without any hindrance. At the time of refilling sand at the stalls, the cows were separated in each pen using the chains closing a part of the pen.

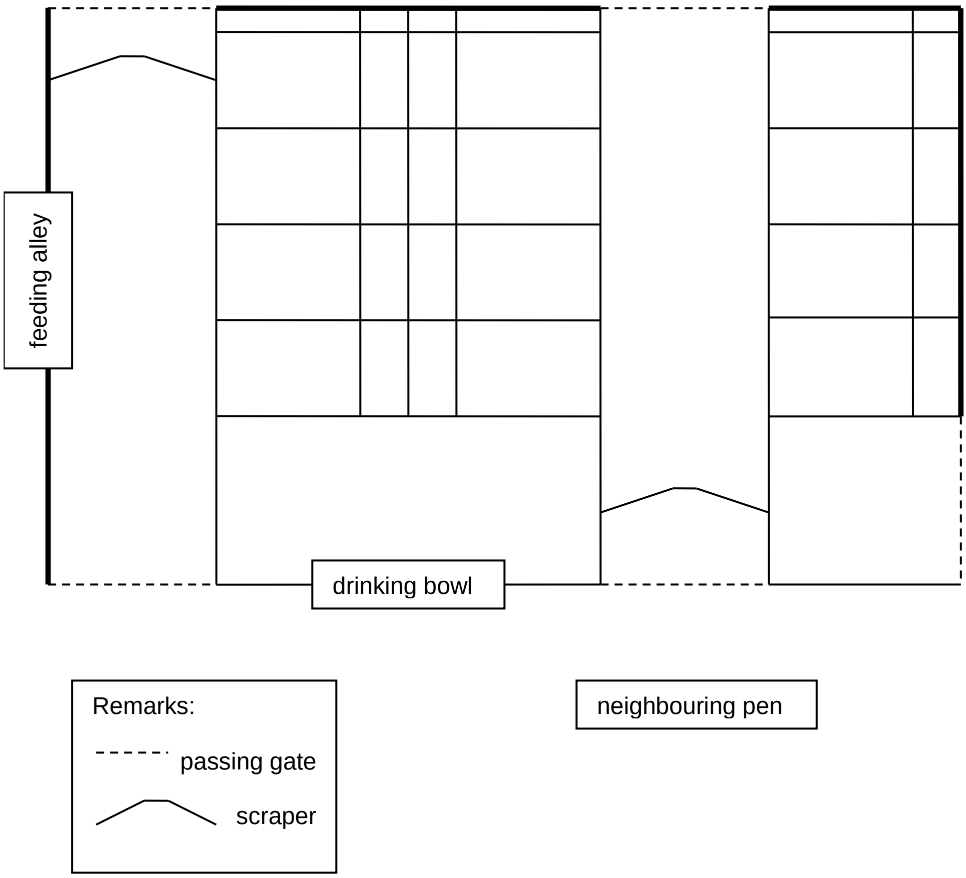


Figure 1. Schema of the pen with lying stalls where measurements of sand level were conducted.

For detailed measurements of sand amount changes, only one pen with twelve lying stalls was chosen. The pen was equipped with typical partitions and, additionally, partitions in the stalls bounded by a cement wall.

Changes in the amount of sand covering the lying surface for dairy cows were identified based on the measured sand level. In order to determine changes in sand level, the distance between the timber board and the bedding surface with sand was measured. The timber board was fixed on the neighbouring partitions in the same places (marked for precise location of the board during each measurement). Measurements with the use of the timber board were taken in two zones (parts) of each lying stall. The front zone was the place where the cow had her front legs during standing and lying activity, whereas the rear zone is the place where the cow kept her rear legs during stall occupation (Fig. 2). The bottom edge of the board had 12 reference points, marked each

10 cm along the board. The distance between each reference point and sand (including vertical direction of the measurement) was measured. Including 12 reference points, the working length of the removable timber board was 110 cm, but real length of the board was greater to enable fixing of the board on the partitions. Its size was smaller than width of each lying stall amounting to about 120 cm.

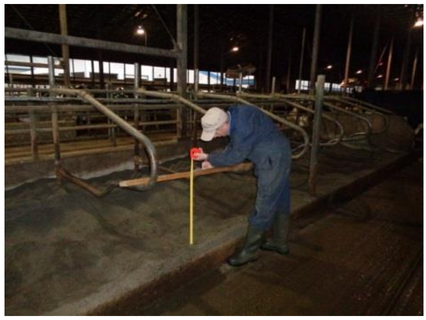
a)  b) 

Figure 2. Measurements of distance between the sand bedding surface and the timber board put on the front part of partitions (a) and rear part of partitions (b).

Measurements of the distance between 12 reference points and the sand level were carried out for each stall. Including two lines of measurements (timber board put in the front and rear part of the partitions), a set of 24 data items was collected for each lying stall. A measuring tape was used to measure the distance between reference points and the sand level on the wall. A typical flexible measuring tape with the function of stiffening to carry out measurements more easily was used. Measurement accuracy was 0.5 cm. A printed version of a respective sheet was prepared to collect data obtained from the measurements at the barn. During the next stage, the data were transferred into an Excel file for further analyses.

Measurements concerning the level of sand covering the lying stalls were conducted within the period of 17 days, one time per day, during evening milking. The pen was occupied by 12 dairy cows taken to the milking parlour two times per day. A group of cows was out of the pen (in the milking parlour) for about half of hour (per milking), which was enough time to carry out necessary measurements in the lying area. Because the typical procedure of stall management includes levelling of the bedding material surface whenever cows are taken to the milking parlour, the same activity (levelling of the bedding material) was conducted after sand level measurements.

Statistical analysis of collected data was conducted using the Statistica v.12 software. Analysis of variance (ANOVA) for changes in the sand level was conducted. The significance level was $\alpha = 0.05$. Results of the experiment on sand level changes were included as a set of independent measurements. Each day, the sand was levelled after measurements, according to general rules concerning sand bedding management. Inter-observer reliability wasn't checked. The experiment was carried out as a pilot study and will be repeated for more stalls and new measuring equipment (measuring laser) to collect data in a more effective way and include inter-observer reliability.

To find the regression function, nonlinear regression with the backward stepwise analysis was used.

RESULTS AND DISCUSSION

To analyse changes in the amount of sand at the lying area, the following days were included: starting day (day one) and research days (16 days). The period of research days was divided into four stages (I–IV). Each stage consisted of 4 days. For each stage, the mean value of sand level was calculated based on data from all stalls, and included as data for comparisons. In order to find changes in the sand level during the investigation period, differences between level of sand on day one and level of sand for each stage were calculated. The calculations were conducted for data concerning the front and rear line of measurements in the stalls. Thanks to this schema of measurements, the differences in sand level for front and rear part of the stalls are presented in Fig. 3 and Fig. 4, respectively.

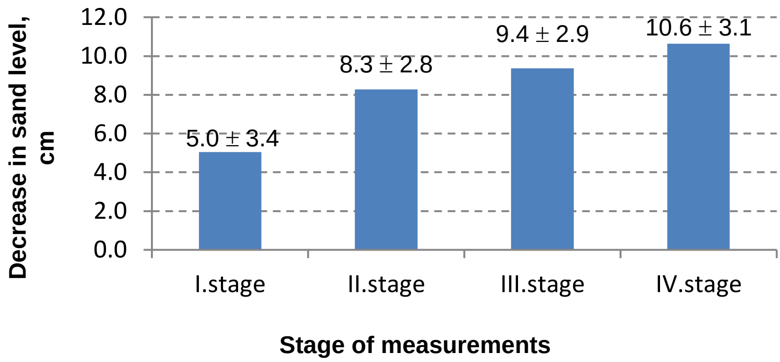


Figure 3. Decrease in level of sand as a bedding material in the front part of measured lying stalls (mean ± SD).

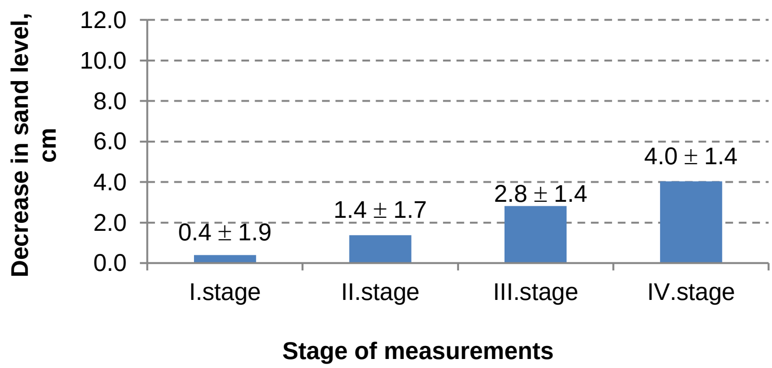


Figure 4. Decrease in level of sand as a bedding material in the rear part of measured lying stalls (mean ± SD).

More details concerning changes in the sand level for the front and rear part of the stalls, i.e. formula of curve and R^2, are given in Table 1.

Table 1. Curve – equation and R^2 concerning decrease in sand level

Part of measured stalls	Curve – equation	R^2
Front	$y = 3.9699\ln(x) + 5.1742$	0.9901
Rear	$y = 0.0602x^2 + 0.9331x - 0.6265$	0.9971

Results of the measurements showed gradual decrease in the level of sand as a bedding material during the research period. Generally, it is possible to observe a difference in dynamics of sand level decrease for two places of measurements, i.e. front and rear part of the stall. The front zone of lying stalls was characterized by a lower level of sand than the rear part of stall during the period of measurements. On the other hand, when data for the first and last stage (I vs. IV) of the measurements are compared, a greater difference (ten times greater) is observed for the rear zone of the stalls than for the front one (the difference: about two times). Of course, one may ask why the decrease in sand level in the front zone of stall is about 2.5 times higher (including comparison of data for the fourth stage of measurements) than the decrease in sand level in the rear zone of the stall. Development of more detailed observations to measure space use by dairy cows when lying down (Ceballos et al., 2004) may be suggested. Moreover, according to own observations during the experiment, persons responsible for taking cows to the milking parlour and levelling the sand bedding showed a tendency to level mainly the rear part of the stalls. To receive the effect of levelling, sand was taken by rake from the middle part of the stall to level the rear zone of the lying stall. Sand in the front part of each stall was also levelled, but without transfer of sand from the middle part of the stall.

Analysing the measurement results, it can be interesting to compare the decrease in sand level observed in the first stage of the experiment. The data concerning the front part of the lying stalls show a considerable decrease in the level of sand (5.0 cm) during the first stage of the measurements. The same trend was noted by Drissler et al. (2005), i.e. loss of bedding depth was greatest on the day after new sand was added. Yet, such trend was confirmed only for the front part of the stall in our experiment, while the rear part of the stall was characterized by only 0.4 cm decrease in sand level during the first stage of the investigation.

The following parameters were included in the analysis of variance: day, stall, row and place of measurements (front and rear part of the stall). The dependent variable in the analysis was the level of sand.

Results of the variance analysis are presented in Table 2.

Table 2. Variance analysis of variance of selected parameters included in the investigation

Effect	SS	df	MS	F	p
Day	1,232.33	15	82.16	5.1236	0.000000
Stall	759.78	11	69.07	4.0316	0.000014
Row	222.85	2	111.43	6.1436	0.002366
Place of measurement	3,655.40	1	3,655.40	401.524	0.000000

Results of the variance analysis showed a significant ($p < 0.05$) difference between the levels of sand for the parameters considered in the investigation. Some results of the statistical analysis are confirmed by observations coming from other experiments. Drissler et al. (2005) indicated that some stalls showed far greater declines than others;

the maximum depths observed on any given days tended to be three times the average depth.

Sand may be removed by the cows digging or by dragging sand out when they exit the stalls, but further research is required to understand how sand leaves the stall (Drissler et al., 2005). Losses of sand used as a bedding material for dairy cows depend on management practices and free-stall construction (Gaworski & Garreth Ferraz Rocha, 2015), but it seems to be important to include other factors to assess quantitative and qualitative changes in the bedding material covering the lying area for cows. These include shape of the bedding surface. Distribution of sand gives the stall surface a concave shape with the maximum depths at the centre and minimum depths near the edges of the free-stall (Drissler et al., 2005).

Management of sand used for bedding in the lying area should ensure the cow's comfort. Thus, it is recommended that at least 4 inches of "workable" sand should be in the stalls at all times (Stowell & Inglis, 2000). The depth of four inches is suggested because cows' legs may tend to sink into fresh sand about 2 to 3 inches. In a typical situation, stalls can be maintained in a good condition by adding fresh bedding every 7–10 days (Stowell & Inglis, 2000). Sand usage rates can range from less than 1 to more than 10 cubic yards per stall per year, with an average of 4.6 cubic yards/stall/year (Stowell & Bickert, 1995). According to own observations, lying stalls with sand as the bedding material are levelled one or two times per day. Most often, sand is levelled each time when cows are taken from the pen to the milking parlour.

The proposed method to monitor sand amount changes in the free-stall lying area for dairy cows includes only two lines of measurements. It seems to be more simple in comparison with the experiment carried out by Drissler et al. (2005), where a grid (120×180 cm) was used to measure the distance between the grid and surface of sand covering the lying stall. The aim of the next step can be an investigation to compare the proposed approach to measurements and measurement accuracy with the method where changes in the bedding material level are measured on the basis of more points included in the stall space.

CONCLUSIONS

In order to successfully use and manage sand as a bedding material for cows, it is necessary to consider monitoring of the sand amount in order to create the highest possible level of lying comfort for animals.

Results of the measurements show an expected gradual loss of bedding depth during the research period. Generally, it was possible to observe a difference in the dynamics of decrease in sand level for two places of measurement, i.e. front and rear part of the stall. Loss of bedding depth was greatest on the day after new sand was added in the front part of the stalls.

The proposed method with two lines of sand level measurements can be one step to improve the approach concerning assessment of the lying conditions for dairy cows kept in the free-stall system.

This work was conducted during a scholarship of Águida Garreth Ferraz Rocha supported by CAPES – Brazilian Federal Agency for Support and Evaluation of Graduate Education within the Ministry of Education of Brazil – Process No. BEX 3220/15-0.

REFERENCES

Ceballos, A., Sanderson, D., Rushen, J. & Weary, D.M. 2004. Improving stall design: Use of 3-D kinematics to measure space use by dairy cows when lying down. *Journal of Dairy Science* **87**(7), 2042–2050.

Drissler, M., Gaworski, M., Tucker, C.B. & Weary D.M. 2005. Freestall maintenance: Effects on lying behavior of dairy cattle. *Journal of Dairy Science* **88**(7), 2381–2387.

Fregonesi, J.A., Veira, D.M., von Keyserlingk, M.A.G. & Weary, D.M. 2007. Effects of bedding quality on lying behavior of dairy cows. *Journal of Dairy Science* **90**(12), 5468–5472.

Gaworski, M. & Garreth Ferraz Rocha, Á. 2015. Effect of management practices and free-stall construction on losses of sand used as a bedding material for dairy cows – pilot study. *Annals of Warsaw University of Life Sciences – SGGW, Agriculture (Agricultural and Forest Engineering)* **66**, 111–118.

Gaworski, M., Tucker, C.B., Weary, D.M. & Swift, M.L. 2003. Effects of stall design on dairy cattle behaviour. [In:] Proc. Fifth International Dairy Housing Conference. Fort Worth, Texas. Am. Soc. Agric. Eng, St. Joseph, MI, pp. 139–146.

Gomez, A. & Cook, N.B. 2010. Time budgets of lactating dairy cattle in commercial freestall herds. *Journal of Dairy Science* **93**(12), 5772–5781.

Natzke, R.P., Bray, D.R. & Everett, R.W. 1982. Cow preference for free stall surface material. *Journal of Dairy Science* **65**(1), 146–153.

Nordlund, K. & Cook, N.B. 2003. A flowchart for evaluating dairy cow freestalls. *Bovine Practitioner* **37**(2), 89–96.

Norring, M., Manninen, E., de Passillé, A.M., Rushen, J., Munksgaard, L. & Saloniemi, H. 2008. Effects of sand and straw bedding on the lying behavior, cleanliness, and hoof and hock injuries of dairy cows. *Journal of Dairy Science* **91**(2), 570–576.

Norring, M., Manninen, E., de Passillé, A.M., Rushen, J. & Saloniemi, H. 2010. Preferences of dairy cows for three stall surface materials with small amounts of bedding. *Journal of Dairy Science* **93**(1), 70–74.

Rowbotham, R.F. & Ruegg, P.L. 2015. Association of bedding types with management practices and indicators of milk quality on larger Wisconsin dairy farms. *Journal of Dairy Science* **98**(11), 7865–7885.

Solano, L., Barkema, H.W., Pajor, E.A., Mason, S., LeBlanc, S.J., Nash, C.G.R., Haley, D.B., Pellerin, D., Rushen, J., de Passillé, A.M., Vasseur, E. & Orsel, K. 2016. Associations between lying behavior and lameness in Canadian Holstein-Friesian cows housed in freestall barns. *Journal of Dairy Science* **99**(3), 2086–2101.

Stowell, R.R. & Bickert, W.G. 1995. Storing and handling sand-laden dairy manure. Extension Bulletin E-2561. Michigan State University, East Lansing, MI.

Stowell, R.R. & Inglis, S. 2000. Sand for bedding. [In:] Proc. Conference on Dairy housing and equipment systems: managing and planning for profitability. Camp Hill, Pennsylvania, USA, pp. 226–234.

Tucker, C.B., Weary, D.M. & Fraser, D. 2003. Effects of three types of free-stall surfaces on preferences and stall usage by dairy cows. *Journal of Dairy Science* **86**(2), 521–529.

Vasseur, E., Gibbons, J., Rushen, J., Pellerin, D., Pajor, E., Lefebvre, D. & de Passillé, A.M. 2015. An assessment tool to help producers improve cow comfort on their farms. *Journal of Dairy Science* **98**(1), 698–708.

von Keyserlingk, M.A.G., Rushen, J., de Passillè, A.M.B. & Weary, D.M. 2009. The welfare of dairy cattle – Key concepts and the role of science. *Journal of Dairy Science* **92**(9), 4101–4111.

Wagner-Storch, A.M., Palmer, R.W. & Kammel D.W. 2003. Factors affecting stall use for different freestall bases. *Journal of Dairy Science* **86**(6), 2253–2266.

Agronomy Research **14**(4), 1293–1299, 2016

Modification of the rheological properties of the honey in the honeycombs prior to its extraction in the production conditions

T. Jehlička[1,*] and J. Sander[2]

[1]Czech University of Life Sciences Prague, Faculty of Engineering, Department of Technological Equipment of Buildings, Kamýcká 129, CZ 16521 Prague 6 – Suchdol, Czech Republic
[2]Czech University of Life Sciences Prague, Faculty of Engineering, Department of Technological Equipment of Buildings, Kamýcká 129, CZ 16521 Prague 6 – Suchdol, Czech Republic
[*]Correspondence: jehlickat@tf.czu.cz

Abstract. This paper addresses the issue of honey extraction in difficult conditions (prevailing cold weather) and the extraction of highly viscous honey from the honeycombs. The objective was to design and validate a technology that will reduce the viscosity of honey in the honeycombs by warming up by infrared radiation and shorten the total time of honey extraction. To verify the proposed procedure three groups of samples of the capped honeycombs were selected that contained honey of different botanical origin and rheological properties. The honeycombs were warmed up to the targeted temperature (from 15 °C to 40 °C). Warming was carried out by two low-temperature emitters of the infrared radiation. The time dependence of honey extraction on the temperature of the pre-heated honeycombs was monitored. The measured values indicate that the dependence of the rheological properties of honey on temperature is technologically significant. Operational monitoring shown that the optimal rheological properties for the processing of the honeycombs are at a temperature above 30 °C as the time necessary for the honeycombs extraction reaches its minimum value. The optimal temperature for the honeycomb extraction can be considered the temperature above 30 °C which corresponds to the extraction time for about 4 minutes. The evaluation of the obtained results demonstrates the operational reliability of the proposed technology. Measurements proved that the infrared radiation is suitable for warming up of the honeycombs, warming up is quick and results in time reduction of honey extraction from honeycombs is dependent on temperature.

Key words: honey, honey extraction, infrared radiation heating, viscosity.

INTRODUCTION

This paper addresses the issue of honey extraction from the capped honeycombs during adverse climatic conditions, obtaining highly viscous or partly crystallized honey. The objective was to verify the possibility of changing the rheological properties of honey in the honeycombs in the production conditions by infrared radiation heating and thus achieve higher productivity and yield of honey during its separation from the honeycombs.

Honey is a sweet substance produced by honey bees from the nectar or honeydew which the bees transform by the secretion of their pharyngeal glands and store in honeycombs. Honey is a liquid which is difficult to process from the technological point of view. It is influenced by the chemical composition and physical properties (Fischer & Windhab, 2011). Technologically significant are the rheological properties of honey. They influence 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 the viscosity of honey. The degree of crystallization is dependent on several factors of which the most important is the glucose / fructose ratio 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 the botanical origin of honey 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 and is regularly used in practice.

The temperature dependence of honey viscosity is described by the Arrhenius model, this model is also used for sugar syrups or fruit juices (Smanalieva & Senge, 2009). 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 10–40 °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 form 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 firmness of the wax comb (the risk of damage and contamination of honey by wax). Therefore in the production conditions for honey extraction a change in honey's rheological properties is sometimes used before the uncapping of the honeycombs. It's about the increase of temperature by the conventional warming and thus reducing viscosity, which affects the efficiency and speed of honey extraction (Oroian et al., 2013). This procedure is time consuming and laborious.

The proposed technology solves the problem of reduction in the viscosity of honey by warming up the capped honeycombs by infrared radiation. It is based on the assumption that the infrared radiation warms the honeycombs evenly to a depth of a few millimetres; is faster compared to the conventional heating and is friendly for the honey quality (Hebbar et al., 2003). The goal is to propose and validate a technology that will reduce in adverse climatic conditions the viscosity of honey in honeycombs by heating by infrared radiation, shorten the total time of honey extraction from the honeycombs and increase efficiency, i.e. the total amount of honey extracted. A chamber with infrared radiators was assembled for warming up the honeycombs. For the measurement several samples of the filled honeycombs were selected which contained honey of different rheological properties. It was measured how the temperature of the pre-hated honeycombs impacts the time 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 infrared radiation in the operating conditions.

Three groups of samples of the capped honeycombs that contained honey of different botanical origin and came from different periods of honey brood were selected. Thus the requirement of different rheological properties of honey was fulfilled. The honeycombs were warmed up to the targeted temperature (from 15 °C to 40 °C, always by 3 °C). Warming up was carried out always for four honeycombs by two low-temperature emitters of the infrared radiation. Once the target temperature was reached, honey was extracted from the honeycombs on honey extractors with automatic control. The overall time required to extract all the honey from the honeycombs was measured. Honeycombs were extracted to reach the complete extraction of honey (level of such honey extraction from honeycombs was assessed subjectively.) The foregoing measurement was carried out at a bee farm during the summer honey brood.

Honeycombs samples

In order to verify the assumption, three samples of the capped honeycombs were selected. (As used herein, sample means a few tens of capped honeycombs coming from the beehives which were in immediate proximity in the period of honey brood and contained honey of the same chemical composition and the same physical properties). Each sample of the honeycombs came from a different period of honey brood and contained honey of different botanical origin. Thus the assumption that each sample contained honey of different rheological properties was met.

Sample 1: nectar honey, brood period – June.

Sample 2: honeydew honey, brood period – June.

Sample 3: honeydew honey, brood period – July.

Warming up of the honeycombs

A device was created to warm up the honeycombs which consisted of a holder of honeycombs, two low-temperature infrared panels, thermometers and switching regulator controller with a thermostat to adjust the temperature.

Two low-temperature emitters IT AG–600 (Termowell) were used to warm up the honeycombs. Base panel consists of carbon thermocouple equipped on their surface with silicon grains with a white surface finish. Input 600 W, voltage 230 V, frequency 50 Hz, size 1,200 x 600 x 50 mm. The efficiency of electrical energy transformation into heat radiation energy is 92%.

Four honeycombs were always attached to the honeycombs' holder (two and two superimposed). The holder with the fixed honeycombs was placed between two heating surfaces of the infra-panels facing each other. The warming up from both sides was opted in order to achieve a homogeneous temperature field. The distance from the infrared radiation heating to the surface of the honeycomb was set at 0.5 m. Thermometers were inserted to a depth of honeycomb so that the temperature was measured inside of the honeycomb. The targeted temperature was set on the thermostat of the control unit. Once reached, the regulatory control unit switched off both infra-panels and the heating was interrupted.

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 the honey from the honeycomb.

RESULTS AND DISCUSSION

To verify the assumption that the infrared heat radiation can be utilized to change the rheological properties of honey in the operating conditions, the time dependence of honey extraction on the temperature of the pre-heated honeycombs was monitored. Table 1 shows the values measured, i.e. the targeted temperature of the honeycombs and the time required for their complete extraction at the preset temperature.

Table 1. The temperature of the honeycombs and the extraction time

Sample 1 time, min	Sample 2 time, min	Sample 3 time, min	Temperature, °C
10	12	10	15
8	8	10	18
8	8	10	21
6	6	8	24
4	6	6	27
2	4	4	30
2	4	4	33
2	2	4	36
2	2	2	40

Dependence of the measured factors shows Fig. 1. In Fig. 1 the values from Table 1 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.

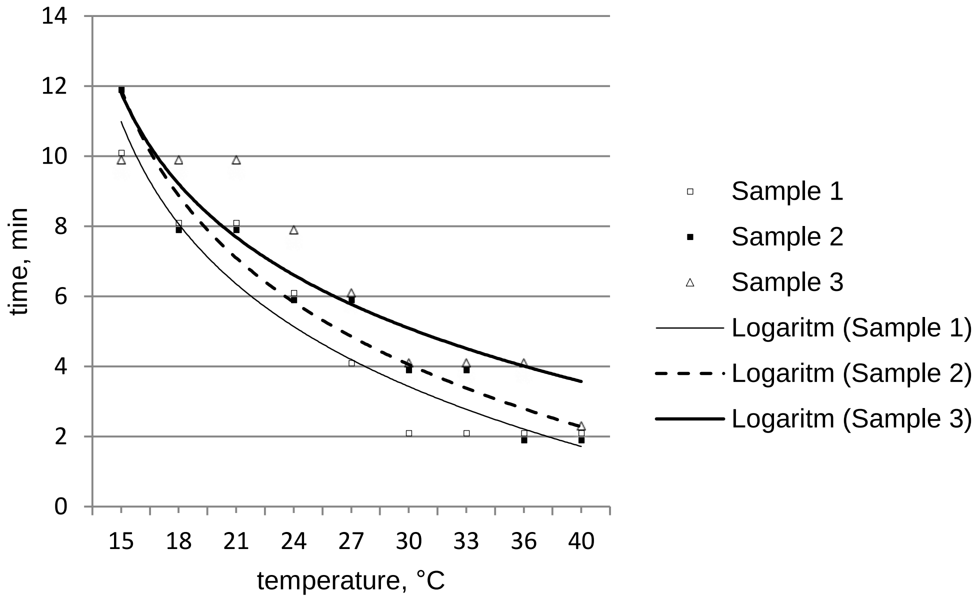


Figure 1. Time dependence of honey extraction on the temperature of honeycombs.

For plotted dependencies of all three samples of the honeycombs was used logarithmic trendline. This one most closely represents the actual time reduction of the extraction depending on the rising temperature. The coefficient of reliability correlation was in all samples around 0.95.

Summing up the above analysis, it is possible to demonstrate that the time required to extract the honeycombs in all samples is directly dependent on the temperature. For all samples, i.e. for nectar and both honeydew honeys, the trendlines of extraction time and temperature are very similar. This demonstrates that the course of dependency is only minimally influenced by the botanical origin of honey, but depends mainly on temperature. Botanical origin of honey, respectively rheological properties of honey defined by its chemical composition impact in all samples only mutual shift of the plotted dependencies, but the course remains the same. As follows from Table 1, and then from Fig. 1, this shift of the set temperature causes the difference of maximum of two minutes to achieve complete honey extraction. The plotted curves indicate that the rheological properties dominantly depend 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. This is important in terms of process performance, but also in terms of the extent of the honeycombs wax damage. The extraction time is affected by the construction of the honey extractor (radius and speed of the drum) and by rheological properties of honey. The design and setting of the honey extractor was constant during the measurement. Then, the plotted dependencies on Fig. 1 imply that extraction time depends mainly on honey temperature. It reaches its minimum at all observed samples after reaching a temperature of about 30 °C. The optimal temperature for the honeycombs extraction can be considered a temperature above 30 °C, which corresponds to the extraction time of 4 minutes.

Besides an objective assessment of the impact of the honeycombs' warming by infrared radiation on the rheological properties of honey during processing, secondary technological factors were observed. The average time of the warming up to reach the targeted temperature and the extent of damage to the honeycombs wax during the extraction on the honey extractor were observed in indicative terms. Both factors were not monitored objectively, but for reference purposes only. The specific values are not provided because the measurement methodology did not allow the precise detection (due to the thermostatic temperature control of the heating).

The extent of damage of the honeycombs can be indirectly estimated by the amount of wax in the extracted honey. Subjectively, it was observed that at the time of extraction over 6 minutes its presence in the extracted honey increases. Wax pollutes extracted honey. The second interesting operating figure is the warming time by infrared radiation. Infrared radiation penetrates the honeycombs to a depth of a few millimetres. According to the methodology used the warming up was both-sided (honeycombs were placed between two heating surfaces of two infra-panels facing each other). This allowed even and rapid heating of the honeycomb. Warming time from 15 °C to 30 °C was an average of 5 minutes, warming to 40 °C about 8 minutes. When comparing the extraction time and the warming time of the honeycombs it is clear that the warming period of the honeycombs corresponds approximately to the time of their extraction. This is technologically advantageous. The honeycombs can gradually warm up and then extract without unnecessary loss of time. In comparison with the convectional heating at the warming chambers the infrared radiation heating allows to work operatively i.e. to eliminate the long-term warming and work with less honeycombs during the honey extraction procedure.

CONCLUSIONS

Based on the measured values it can be determined that infrared radiation can change the rheological properties of honey and such change can be utilized to increase efficiency and probably also effectiveness of honey extraction technology.

The proposed technology utilizes for warming up two low-temperature emitters of infrared radiation. The honeycombs were placed between two heating surfaces facing each other and warmed up by infrared radiation to the targeted temperature. Warming up from both sides was opted in order to achieve a homogeneous temperature field. Warming time from 15 °C to 30 °C was an average of 5 minutes.

The measured values indicate that regardless of the botanical origin of honey (nectar and both honeydew honey), the dependence of the extraction time on the temperature is very similar in all observed samples. This means that the dependence of the rheological properties of honey on the temperature is technologically significant. The technological significance of the botanical origin of honey affects its rheological properties only minimally. Operational monitoring has shown that the optimal rheological properties for the processing of the honeycombs are at the temperature above 30 °C as the time necessary for the honeycombs extraction reaches its minimum value. The optimal temperature for the honeycomb extraction can be considered the temperature above 30 °C which corresponds to the extraction time for about 4 minutes.

According to the proven results, the possibility of heating the honeycombs by infrared radiation can be assessed as operationally efficient technology. In comparison with the convectional way of heating at the tempering chambers, the use of infrared heating is faster, not space consuming, does not require investment to acquire the tempering chamber and further it can be assumed that it is less energy-intensive.

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.

Hebbar, H.U., Nandini, K.E., Lakshmi, M.C. & Subramanian, R. 2003. Microwave and infrared heat processing of honey and its quality. *Food Science and Technology Research* **9**(1), 49–53.

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

Smanalieva, J. & Senge, B. 2009. Analytical and rheological investigations into selected unifloral German honey. *European Food Research and Technology* **229**(1), 107–113.

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.

Agronomy Research **14**(4), 1300–1306, 2016

Comparative study of the noise levels: impact of renovation

S. Kalle[1,*] and J. Paju[1,2]

[1]Tallinn University of Technology, Tallinn School of Economics and Business Administration, Department of Business Administration, Academia road 3, EE12618, Tallinn, Estonia
[2]Tallinn University, School of Natural Sciences and Health, Narva road 25, EE10120, Tallinn, Estonia
[*]Correspondence: sigrid.kalle@ttu.ee

Abstract. Health effects from different noise exposures have been studied by many researchers. According to the frequency of the noise, the complaints induced differ. Some studies have shown that low frequency noise may have serious health effects from annoyance to sleeping disturbances. Using a sound analyser with 1/3 octave band sound spectrum analysis capability, measurements were conducted on a scientific research vessel. Measurements were carried out in cabins, mess hall and engine room. The results were then compared to the Estonian and International Maritime Organization's recommendations on noise as well as results from a previous study on the same vessel (previous study was conducted before the renovations to modernise both the engine and the cabins was conducted). The renovations did not have the desired effect on the overall noise levels of the vessel as a working environment; the noise values obtained after the renovations do not agree with the normative values during sailing. The situation has improved in several cabins on the vessel but the improvement is rather insignificant.

Key words: Noise, noise reduction, frequency analysis, vessel, occupational hazards.

INTRODUCTION

Health effects from noise exposure are well known – loss of hearing, sleep disturbances (Tamura et al., 1997; Alves-Pereira & Castelo Branco, 2007) and annoyance. Tamura et al. (1997) have suggested that exposure to ship noise of 65 dB(A) can have unfavourable effects on night sleep. Consequently noise measurements, risk assessment and both compliance to national norms as well as reduction of noise is important. The noise exposure of crewmembers on board of older vessels is a subject that still needs attention. Goujard et al. (2005) did a survey where respondents had to rank different comfort criteria that are relevant to sailing on board of a vessel. The results showed that 39% of respondents considered the importance of acoustics significant and 44% found improvements necessary. Borelli et al. (2015) have done a profound literature overview on the subject. Their results show that there are not too many articles on the topic of health and safety of the workers on vessels. Therefore, to contribute to the field, more research is necessary on the topic to obtain more data in order to give scientific solutions to an engineering problem.

On the other hand, a unique EU project on the topic of exposure to vibration and noise in maritime domain was SILENV (2012a). During the project new noise exposure values were recommended. For example the new cabin noise limit was suggested to be less than 50 dB(A). Estonian legislation for the limit of cabin's noise is 60 dB(A), whereas the limit for mess hall is 65 dB(A). Agreement with latter values has to be guaranteed to the crew at all times, regardless of whether the ship is sailing or anchored (EG, 2007).

The vessel under investigation is registered in Estonia; therefore it has to comply with Estonian norms. The value of 60 dB(A) is also given in The International Maritime Organization's (IMO) Resolution A.468(XII), which covers noise control issues on commercial ships. As the studied ship that was previously a fishing ship and was redesigned to serve as a research vessel, the IMO values are suitable for recommendation purposes.

Working environment noise norms do not have any specific exposure limits according to octave band spectrum. Nevertheless, research (Tamura et al., 1997) has shown that typically the frequencies of a diesel engine ship lay in the range of 100 to 1,000 Hz, which is below the threshold of the most sensitive range of perception – which is 1,000 to 4,000 Hz, as Salvendy (2012) suggests. Evaluation of acoustics should also include spectral composition as the effectiveness of personal protective equipment (PPE) at different frequencies varies. The octave band analysis helps to predict the attenuation of PPE (Salvendy, 2012) and thus select adequate PPE.

To understand the current study more thoroughly an overview of the investigated vessel is required. The vessel was built in 1974 as a fishing ship. In the year 2009 the ship was repurposed as a research vessel and therefore parts of it were renovated – the hold, galley and the main deck. Also, its engine had few minor fixes but the auxiliary device (the diesel generator) was not modernized. During 2015 additional renovations were carried out in the cabins to lower the noise. For soundproofing and insulation purposes several materials were used. Panels of 5 cm thick compressed wool were attached to the walls of cabins. Then 5 cm of soft wool was added, which was then covered with additional thin wall panels (which were made from compressed wool covered with foil). The ceilings were covered with 5 cm thick compressed wool and metal ceiling panels that, unfortunately, produce additional noise during sailing. The vessel's floors were also insulated with 5 cm of compressed wool.

The purpose of the study: (1) analyse whether the noise values have reduced after the renovations; (2) analyse whether the renovations have influenced the spectrum of the noise; (3) ascertain whether the materials that were used during the renovations were suitable; (4) to contribute to the research field in order to complement the overall amount of scientific data on the topic.

MATERIALS AND METHODS

The data was collected during three working regimes: (1) while vessel's auxiliary device (48 kW diesel generator) worked, (2) anchored while the engine still worked, (3) and during sailing. TES 1358 sound analyser with sound spectrum analysis capability in 1/3 octave bands was used for measurements (class I device): (1) the equivalent sound pressure level; (2) the peak sound pressure level; (3) the sound frequency spectrum. The analyser was held at a 1.55 m height from the floor (measured with a measuring tape), in the centre of a cabin or 10 cm from a working machine (in case of vessels engine, in the engine room). The centre of the rooms was selected to generalize the obtained noise values in the cabins. A measurement with both an A and a C frequency weighting was recorded during the period of 30…60 seconds at each location. The exposure levels were normalized to a nominal 8 h working day. All the results were compared to Estonian and International legislations.

Statistics were done with Excel, 2010. All measuring results have standard deviation of 1.0 to 1.5 dB and measurement uncertainty of 2.2 to 2.6 dB.

RESULTS AND DISCUSSION

Analysis of noise levels before (2013) and after (2015) renovations show that during sailing norms are exceeded (see Table 1) in both datasets. In some parts of the vessel the overall noise levels have aggravated – e.g. in the engine room. Both in the mess hall and in the cabin next to the engine room (Cabin E) the noise levels of being anchored regime increased after the renovations. Do note, noise spectrum of auxiliary device in cabin E is not available due to device error during measurements.

Table 1. Comparison of noise levels before and after renovations. Noise measurements were done in three occasions: (1) while only vessel's auxiliary device (diesel generator) worked, (2) when vessel was anchored while the engine still worked, (3) and during sailing. Cabin C – the chief officer's room; Cabin E – cabin next to the engine room

Measuring place		Noise level L_{EX} 8h dB(A)		Noise level L_{EX} 8h dB(C)		Norms dB(A)	Reference to norms
		2013	**2015**	**2013**	**2015**		
Mess hall	diesel generator	42.0	50.0	58.1	69.5	65	EG, 2014
	anchored	65.3	67.8	86.9	87.1		
	sailing	70.9	69.9	93.3	99.0		
Cabin E	diesel generator	52.8	48.7	74.2	71.1	60	EG, 2007
	anchored	72.1	74.2	86.5	97.5		
	sailing	81.0	79.4	97.0	98.5		
Engine room	diesel generator	-	-	-	-	85; 110	EG, 2014; IMO, 1981
	anchored	99.8	101.4	116.1	111.1		
	sailing	101.4	104.0	109.8	111.4		
Cabin C	diesel generator	-	44.7	-	71.7	60	EG, 2007
	anchored	73.5	68.5	89.9	102.3		
	sailing	-	75.2	-	100.5		

In the chief officer's room (Cabin C) the noise levels have gone down by 5.0 dB(A) and 13.4 dB(C) while the vessel is anchored. Unfortunately other comparative results considering the Cabin C from the year 2013 are not available, as the measurements were not conducted during a) sailing and b) while only the auxiliary device was working.

Comparing the results of lower frequency ranges before and after renovations, dB(C) has increased in most of the measuring places.

The noise frequency analysis in the research from theyear 2013 showed that most of the peaks, meaning the maximum sound pressure level values of the graphs, of different measuring conditions and measured areas appeared in range of 50 to 1,250 Hz while sailing (Reinhold et al., 2014). Two years later the range was a bit narrower – 63 to 1,000 Hz (see Table 2).

Table 2. Comparison of peak sound pressure level (dB(A)) before and after renovations and the peak frequencies in concurrence with the occurring peak values (Hz) in engine room and Cabin E (the cabin next to the engine room)

Measuring place		Peak sound pressure level dB(A)		Peak frequencies in concurrence with the occurring peak values, Hz	
		2013	**2015**	**2013**	**2015**
Cabin E	Diesel generator	46.6	56.3	100	100
	Anchored	65.8	67.9	250	100
	Sailing	73.5	72.9	400	160
Engine room	Anchored	84.1	84.8	315	1,000
	Sailing	87.6	87.5	1,250	630

In the engine room the peak frequency of 1,250 Hz has shifted to 630 Hz, while sailing (Fig. 1). In cabin E peaks have shifted from 400 Hz to 160 Hz (Figs 2, 3). The overall change of the noise frequency is not significant.

Goujard et al. (2005) analysed their questionnaire and found that 31% considered the cabins of ships to be acoustically uncomfortable and in need of improvement. The SILENV research (2012a) suggests a new stringent cabin norm of 50 dB(A). That value is very hard to maintain, as Borelli et al. (2015) have shown by indicating that just by using ventilation the cabin's noise levels exceed 50 dB(A).

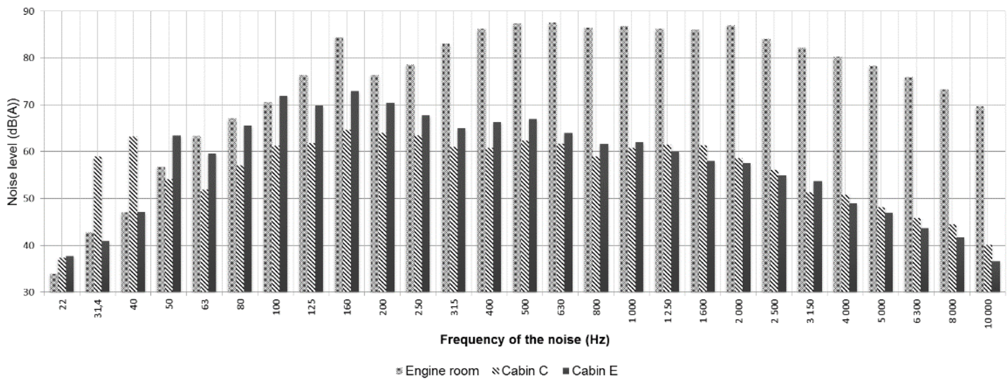


Figure 1. Ship, while sailing, noise frequency analysis 2015. Cabin C – the chief officer's room; Cabin E – cabin next to the engine room and both are situated in the stern.

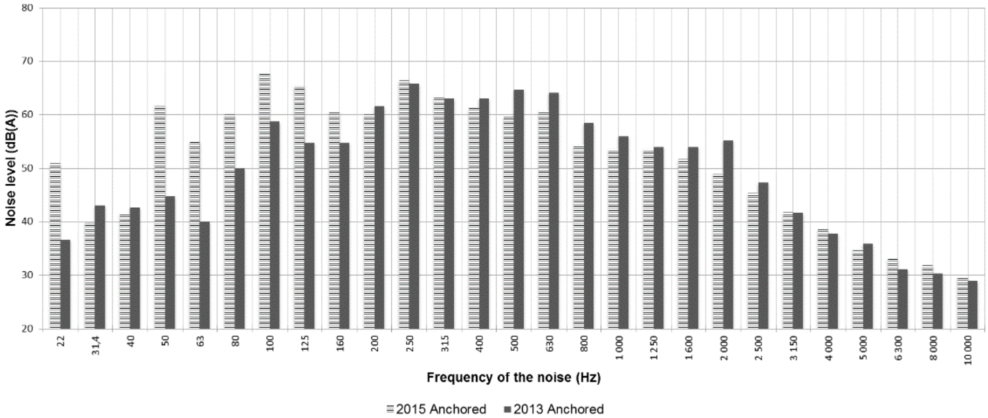


Figure 2. Noise frequency comparison of the results of measurements in Cabin E (in the stern, next to the engine room) in when the ship was anchored.

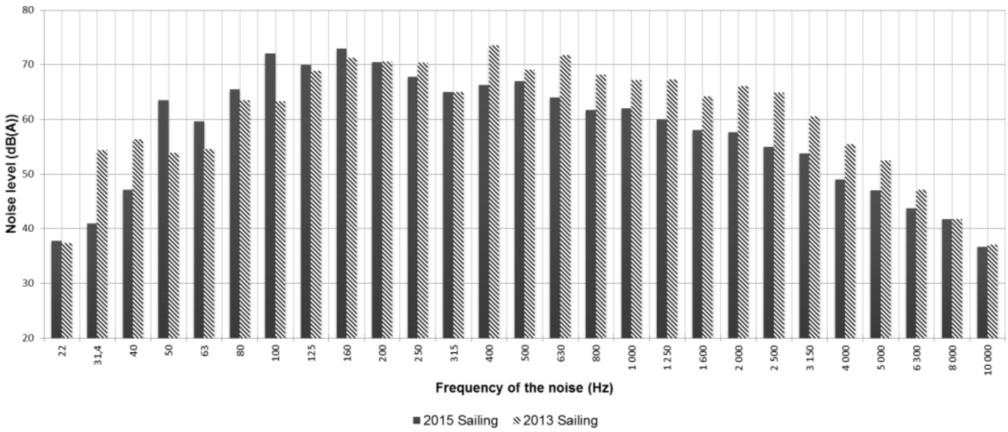


Figure 3. Noise frequency comparison of the results of measurements in Cabin E (in the stern, next to the engine room) while sailing.

Now, regarding the effectiveness of the renovations, it must be considered, that the main objective of the renovations was to lower the noise in cabins. In lower cabins the noise travels mainly through walls and floors. The floating room concept (SILENV, 2012b) was used during the renovations, but unfortunately desired effect was not obtained. Presumably the problem lies in a stiff connection between the ship's structure and either the cabin's inner wall, floor or ceiling. Although there is no information considering the direction of the fibre of wool that was used during the renovations, the SILENV (2012b) suggests orienting the mineral wool fibre in horizontal direction instead of vertical, to achieve an additional 7dB noise reduction. Another deficiency to explore is the possibility that the wool used had insufficient density for the environment and noise in question. By increasing the density of mineral wool by 100 kg m^{-3} up to 9 dB noise reduction can be achieved. To improve the cabins' (C and E) acoustic environment where the ceiling panels were creating additional noise, the metal ceiling panels ought to be replaced with more suitable material or reattached using some additional sealant to reduce the vibration induced noise.

Tamura et al. (1997) have suggested that exposure to ship noise of 65 dB(A) during sleep can have unfavourable effects on the quality of night sleep. Fortunately, during the night when only the generator works, the cabin's noise remains below 50 dB(A) and therefore no disturbing effects on the crews' sleep should occur.

CONCLUSIONS

Although the main purpose of the latest renovation was to reduce the noise levels in cabins, the best result obtained was 5 dB(A), while anchored. Even though cabin noise norms are exceeded during sailing, the 60 dB(A) norm is not surpassed during the night while only the diesel generator works. The renovations did not influence remarkably neither the noise frequency spectra nor the noise levels measured in the A weighting scale. Comparing the results of low frequency ranges before and after renovations, dB(C) values have mostly increased.

Probably the results would have improved more if the floating room concept was used correctly and mineral wool that was used on the walls as insulation was denser. To reduce the noise from metal ceiling panels, the panels ought to be replaced with more suitable material or reattached using some additional sealant to reduce the vibration induced noise.

Our research indicates that on the vessel the normative values of Estonian legislation were not achieved everywhere and at all occasions, which makes reaching the SILENV values even more impossible. Therefore further research, both from the scientific aspect as well as from the development of the suitable engineering solutions, is needed on the topic, to improve the conditions of workers on the vessels.

ACKNOWLEDGEMENTS. We would like to thank the vessel's crew for allowing and helping us with the measurements.

REFERENCES

Alves-Pereira, M. & Castelo Branco, N.A.A. 2007. Vibroacoustic disease: Biological effects of infrasound and low-frequency noise explained by mechanotransduction cellular signaling. *Prog. Biophys. and Mol. Biol.* **93**, 256–279.

Borelli, D., Gaggero, T., Rizzuto, E. & Schenone, C. 2015. Analysis of noise on board a ship during navigation and manoeuvres. *Ocean Eng*. **105**, 256–269.

Goujard, B., Sakout, A. & Valeau, V. 2005. Acoustic comfort on board ships: An evaluation based on a questionnaire. *Appl. Acoust*. **66**(9), 1063–1073.

EG (Estonian Government). 2007. Resolution No. 108 of 12 April 2007 on the occupational health and safety requirements for noisy work environment, the occupational exposure limits for noise and measurement of noise level. State Gazette in Estonia, RTL 2007, 34, 214 (In Estonian).

EG (Estonian Government). 2014. Resolution No. 112 of 10 July 2014 on the accommodation requirements of ship crew. State Gazette in Estonia, RT I 12.07. 2014, 174 (In Estonian).

IMO (International Maritime Organization). 1981. Resolution A.468 (XII) of 19 November 1981 on Code on Noise Levels on Board Ships. Cited: http://www.imo.org/blast/blastDataHelper.asp?data_id=22286&filename=A468(12).pdf Accessed 25. 1. 2016

Reinhold, K., Kalle, S. & Paju, J. 2014. Exposure to high/low frequency noise at workplaces: differences between assessment, health complaints and implementation of adequate personal protective equipment. *Agronomy Research* **12**, 895−906.

Salvendy, G. 2012. Handbook of Human Factors and Ergonomics. John Wiley & Sons, New Jersey, pp. 1752.

SILENV, 2012a. Ships oriented innovative solutions to reduce noise and vibrations, FP7. Cited: http://www.silenv.eu/ Accessed 25. 1. 2016.

SILENV, 2012b. WP5 Green Label Proposal – Subtask 5.2: Noise and Vibration label proposal, SILENV Project, EU. Cited: http://www.silenv.eu/green_label/D5.2_green_label_rev_2.pdf Accessed 25.1.2016.

Tamura, Y., Kawada, T. & Sasasawa, Y. 1997. Effect of ship noise on sleep. *J. Sound Vib.* **205**(4), 417–425.

Agronomy Research **14**(4), 1307–1320, 2016

Awareness and adoption of precision agriculture in the Cukurova region of Turkey

M. Keskin* and Y.E. Sekerli

[1]Department of Biosystems Engineering, Faculty of Agriculture, Mustafa Kemal University, TR 31040 Antakya, Hatay, Turkey
*Correspondence: keskin@mku.edu.tr, mkeskinhatay@gmail.com

Abstract. Adoption of precision agriculture (PA) technologies has an increasing trend in developed countries. However, it is not well known in developing countries including Turkey. No study was reported on the awareness of PA in Turkey before. The objectives of this study were to assess the awareness of PA in the Cukurova region of Turkey using an interview survey study and also to briefly inform each survey participant about these technologies. The study was conducted with 164 participants that were agricultural engineers, farm equipment dealers and farmers. 90.2% of all participants reported that they followed new trends in agriculture. However, 51.8% of all participants indicated that they did not hear the term 'PA' before. Only 29.3% of the participants who heard the term 'PA' knew its concept. Internet was the most important means to gather information on new technologies. Most three well-known technologies by all participants were satellite positioning (GPS) (81.7%), geographical information systems (GIS) (69.5%) and remote sensing (61.0%) as the least known two ones were variable rate application (33.5%) and soil sampling and mapping (34.8%). In addition, a training brochure was handed out to each participant and the PA technologies were explained. 97.6% of the participants expressed that these technologies would be somehow beneficial for agriculture in Turkey. 88.4% of the participants wanted to get more detailed training on these technologies. Also, information on recent developments in the adoption of PA technologies is included in the paper.

Key words: Precision agriculture (PA), awareness, adoption, survey, Cukurova Region, Turkey.

INTRODUCTION

Agriculture is a crucial sector in Turkey producing a wide range of agricultural products including grains, pulses, fruits, vegetables and livestock and providing employment to nearly 23% of the total in 2012 (Berk, 2013). The cultivated area is very large (24.5 million ha); however, the average farm size is only 5.9 ha which is well below than EU and US averages (174 and 180 da respectively) (Berk, 2013). Farms in Turkey are mostly specialized in field crop production (25.7%), mixed crop and livestock production (21.8%) and fruit and vineyards (19.8%) (Berk, 2013).

Technological developments in agricultural sector yield better management practices resulting in more precision in agricultural operations from planting to harvesting to reduce inputs, increase profits and protect environment (Ess & Morgan, 2003; Rains & Thomas, 2009; Keskin & Görücü Keskin, 2012). The term precision agriculture (PA) or precision farming comprise these improved management technologies such as soil sensing and mapping, yield mapping, satellite-based positioning, remote sensing, geographical information systems (GIS), variable rate application and automatic steering (Ess & Morgan, 2003; Rains & Thomas, 2009).

Awareness and adoption rate of PA technologies are affected by many factors including personality and family structure of the farmer, education level, characteristics of the farms, farm size, affordability and profitability of equipment, characteristics of the technologies such as complexity and compatibility, legal affairs, social interaction (fairs, exhibition and field days) and properties of the institutions offering support on these technologies (Daberkow & McBride, 2003; Pawlak, 2003; Edwards-Jones, 2006; Kutter et al., 2011; Paudel et al., 2011; Robertson et al. 2012; Keskin, 2013).

The adoption of PA is in an increasing trend in developed countries particularly in the US. Isgin et al. (2008) reported that 36% of farmers surveyed in Ohio reported that they use at least one PA technology. Norwood & Fulton (2009) stated that 54% of the farmers adopted one or more technologies and most common ones were yield monitoring and automatic steering (32%) in the US. Whipker & Akridge (2009) reported that 85% of agricultural dealers in the US use at least one PA technology in their operations. Paudel et al. (2011) reported that about one-third of the cotton farmers (34%) in twelve states in the US adopted PA technologies. Schimmelpfennig & Ebel (2011) indicated that yield monitoring was used on over 40% of US grain crop acres as GPS maps and variable-rate technologies were used on 24% and 16% of corn acres, respectively in 2005 and on 17% and 12% of soybean acres in 2006 in US Corn Belt region, but nationally the adoption rates for variable-rate technologies were 12% for corn and 8% for soybeans. Erickson & Widmar (2015) carried out a survey study with 261 crop input dealers across the US and reported that the most popular three technologies were GPS guidance with auto control/autosteer (83%), GPS-enabled sprayer section control (74%) and GPS guidance with manual control (63%) and stated that 82% of the dealers offered PA services to their customers. According to a report by the USDA (2015a), about 25% of peanut farms adopted GPS soil map technology and over 40% used auto steering systems while variable rate fertilizer application had a higher adoption rate in peanut production at over 20% of farms than for many other crops in the US in 2013 (USDA, 2015a). In another report by the USDA (2015b), about 60% of rice farms adopted yield monitoring technology and about 55% used auto guidance systems in the US in 2013 (USDA, 2015b).

Similar trends can be seen in other developed or developing countries. Bongiovanni & Lowenberg-DeBoer (2005) indicated that yield monitors, positioning systems (GPS), auto guidance and satellite images are increasingly used in Argentina which was reported to be the second country after the US with number of yield monitors (1200) and fifth country with yield monitor density of 51 monitors per million hectares (after the US, Denmark, Sweden and Great Britain). It was reported that, in South Africa, in the year of 2005, the number of yield monitors was increased to more than 600, the number of variable rate controlled lime application to 244, the number of manual guidance systems to 200 and the number of auto guidance systems to 60 (Helm, 2005). Reichardt et al. (2009) interviewed with farmers at agricultural exhibitions in Germany and reported that a large number of farmers did not know what PA meant and stated that between 6.6% and 11.0% of them used PA, mainly data collection techniques such as GPS based area measurement and soil sampling rather than variable rate application. In Germany, Finland and Denmark, 36% of the survey respondent farmers had previous experiences in PA but 28% of them had difficulties due to ‘language problems’ between different equipment and software (Bligaard, 2013). Robertson et al. (2012) indicated that the variable rate technology adoption in 2008–2009 has increased significantly to 20% nationally in Australia. Leonard (2014) reported that 80% of the grain growers in Australia use automatic guidance. In China, tractor auto guidance was the most accepted technology and about 25% of the farmland was managed using PA in Heilongjiang Province (Verma, 2015). In Sweden, nitrogen sensors are used in about 20% of wheat fields primarily for nitrogen fertilizer application (Söderström, 2013). Silva et al. (2011) carried out a survey study on sugar and ethanol companies in the Sao Paulo state of Brasil reporting that 58% of the domestic companies and 38% of the foreign capital companies adopt PA stating the most preferred technologies as satellite imaging (76%), auto pilot guidance (39%), geo-referenced soil sampling (31%) and variable rate fertilizing and liming (29%).

PA is not recognized well in most of the developing countries including Turkey. No study was reported on the awareness level of PA in Turkey before. Therefore, the two objectives of this study were to:

– assess the awareness level of PA technologies in Cukurova region of Turkey using a face-to-face survey;
– briefly inform each survey participant about PA technologies at the end of the survey questionnaire.

MATERIALS AND METHODS

Study area

The study was conducted in the Cukurova region of Turkey including four provinces (Hatay, Osmaniye, Adana and Mersin) based on interview questionnaire. Cukurova region is located on the mid-south of Turkey (Fig. 1) and is one of the important agricultural areas in Turkey. The total area of the region is 38,509 km^2 as the area of cropping land is 1,091,000 ha with 421,000 ha irrigated and it accounts for 5% of the total cultivation area of Turkey (Akcaoz & Ozkan, 2005). Most important crops include cereals, cotton, corn, soybean, peanut, sunflower, olives, citrus, vegetables, fruits and medicinal and aromatic plants. The region has a typical Mediterranean climate having warm and rainy winters and hot, humid and dry summers. Farmers in this region tend to use new agricultural practices and cultivars in their production as the use of agricultural inputs has risen very rapidly and yields of crops such as wheat, cotton and maize are in an increasing trend (Akcaoz & Ozkan, 2005).

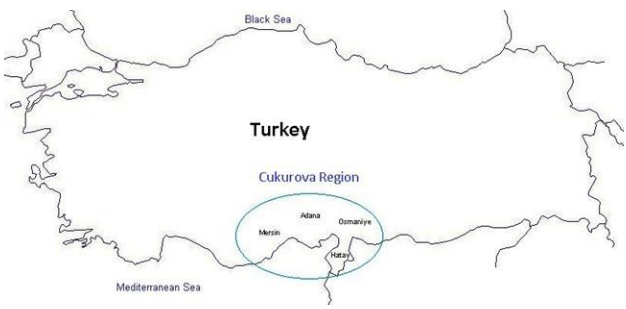


Figure 1. The study area, Cukurova region, is located on the mid-south of Turkey.

Survey questionnaire and training brochure

The survey questionnaire consisted of five pages and included questions in five categories:

1) Personal information (age, gender, education level, work experience, etc),
2) General information (job related questions),
3) General questions on PA (basic concepts),
4) Detailed questions on PA (technologies),
5) Questions after short training (possible adaption of PA).

In addition, a four-page training brochure was prepared along with the questionnaire (Fig. 2). A copy of the brochure was given to each participant after the survey and PA technologies were explained in a short face-to-face training session (about 5 to 10 minutes for each participant).

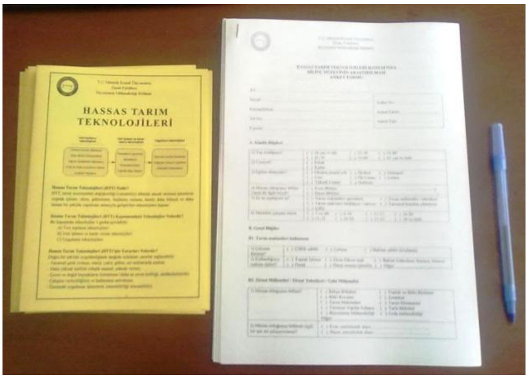


Figure 2. Training brochure (left) and questionnaire (right) used in the study.

Target people

Questionnaire study was conducted with 164 participants. The participants were agricultural engineers, farm equipment dealers and farmers. Majority of the participants were agricultural engineers working for the government institutions. In the study, the graduates from the departments of agricultural machinery, irrigation and agricultural structures, biosystems engineering, field crops, horticulture, soil science, crop protection, animal science and agricultural economics were considered as agricultural engineers in compliance with the technical terminology in Turkey even if it is not same in some developed countries.

Statistical analysis

Statistical data were analyzed in SPSS statistics software (v 17.0).

RESULTS AND DISCUSSION

Characteristics of the participants

The study was conducted with 164 participants using interview survey method. The participants were agricultural engineers, farm equipment dealers and farmers. The number of participants in each group is presented in Table 1. Personal characteristics of the participants including age, gender, education level and work experience were also studied (Table 2). Majority of the participants were in the age group of 31–40 (33.5%) followed by 41–50 (26.2%). 80.5% of the participants were male while 19.5% were female. It was observed that majority of the participants had a bachelor's degree (51.8%). Regarding the work experience, 18.9% of the participants had an experience of less than five years as 18.3% of them had an experience of 16–20 years (Table 2).

Table 1. Number of participants in each group

Participant group	Number	Ratio
Agricultural engineers	103	62.8%
Farm equipment dealers	22	13.4%
Farmers	39	23.8%
Total	164	100%

Table 2. Personal characteristics of all participants

Property	Value	Number	Ratio
Age	< 20	0	0%
	21–30	34	20.7%
	31–40	55	33.5%
	41–50	43	26.2%
	51–60	26	15.9%
	> 61	6	3.7%
Gender	Male	132	80.5%
	Female	32	19.5%
Education level	Elementary school	20	12.2%
	Middle school	7	4.3%
	High school	14	8.5%
	Associate's degree	16	9.8%
	Bachelor's degree	85	51.8%
	Master's degree	15	9.1%
	Doctorate degree	7	4.3%
Work experience (years)	< 5	31	18.9%
	6–10	22	13.4%
	11–15	21	12.8%
	16–20	30	18.3%
	21–25	11	6.7%
	26–30	23	14.0%
	31–35	11	6.7%
	> 36	15	9.1%

Agricultural engineers constituted the biggest group (62.8%). They play a crucial role as a consultant to inform and promote new agricultural technologies including PA (Kutter et al., 2011). Therefore, we included them as one of the participant groups in the study. Most of the agricultural engineers were employed by government institutions mainly the Ministry of Food, Agriculture and Livestock. In the study, the graduates from the departments of agricultural machinery, irrigation and agricultural structures, biosystems engineering, field crops, horticulture, soil science, crop protection, animal science and agricultural economics were considered as agricultural engineers in compliance with the technical terminology in Turkey even if it is not same in some developed countries. The majority of the agricultural engineers participated were the graduate of the field crops major (22.3%) followed by the horticulture major (17.5%) and the crop protection major (14.6%) (Table 3).

Table 3. Majors of the agricultural engineers participated in the study

Graduation by Major	Number	Ratio
Agricultural machinery	9	8.7%
Agricultural structures and irrigation	9	8.7%
Biosystems engineering	2	1.9%
Field crops	23	22.3%
Horticulture	18	17.5%
Soil science	8	7.8%
Crop protection	15	14.6%
Animal science	6	5.8%
Agricultural economics	5	4.9%
Other	8	7.8%
Total	103	100%

In the subsequent sections of the interview, three general questions about PA were asked to each participant (Table 4).

Firstly, the participants were asked if they follow new trends in agriculture. Overall, 90.2% of them gave a positive answer. When we look at the participant groups, 87.4% of the agricultural engineers, all of the farm machinery dealers (100%) and 92.3% of the farmers told that they followed the new trends in agriculture. It was observed that agricultural engineers followed new trends in agriculture with a lower percentage compared to the farm machinery dealers and the farmers. Most of the remaining participants that answered 'no' to this question told that they are not able to follow the innovations in agriculture due to very busy work tasks.

Secondly, overall, only 51.8% of the participants reported that they heard the term 'PA' before (Table 4). Regarding the participant groups, 52.4% of the agricultural engineers, 77.3% of the farm machinery dealers and 35.9% of the farmers told that they heard the term 'PA' before. This showed that dealers and agricultural engineers have a significantly higher awareness compared to the farmers.

Table 4. Percentage of the positive answers to the general questions

	All Participants	Agricultural Engineers	Machinery Dealers	Farmers
Question	Yes	Yes	Yes	Yes
1) Do you follow new trends in agriculture?	90.2%	87.4%	100.0%	92.3%
2) Have you heard the term 'PA' before?	51.8%	52.4%	77.3%	35.9%
3) Do you know what 'precision agriculture' is?	29.3%;	25.2%	59.1%	23.1%

Finally, 29.3% of all participants who heard the term 'PA' before replied that they knew the meaning and concept of the PA (Table 4). Concerning the participant groups, 25.2% of the agricultural engineers, 59.1% of the farm machinery dealers and 23.1% of the farmers told that they knew the meaning and concept of the PA. Again, farm machinery dealers and agricultural engineers have a significantly higher knowledge level compared to the farmers. It could be stipulated that dealers and agricultural engineers were not able to transfer their knowledge of PA to the farmers well. Also, it was observed that dealers were the most aware of PA compared to the other two participant groups (agricultural engineers and farmers).

In the further sections of the questionnaire, two more questions related to the source of information on PA were directed to the participants that are aware of PA (Table 5). Firstly, most two common information sources were internet (25.6%) and TV (17.7%) for the participants who heard the term 'PA' before. Secondly, 17.1% and 12.8% of the participants who know what 'PA' is replied that they got the information from the training activities and the internet, respectively (Table 5). This revealed that internet was the most important means to gather information about new agricultural technologies. Also, training is crucial to increase the awareness on PA. In general, agricultural engineers and farm machinery dealers had the opportunity to get training on new technologies including PA.

Table 5. Answers to the questions on the source of information on PA

Question	Source	Ratio
1) If you have heard the term 'PA' before, what was the source of information?	Radio	0.6%
	TV	**17.7%**
	Newspaper	1.8%
	Magazine	9.8%
	Internet	**25.6%**
	Fair	14.6%
	Congress	5.5%
	Colleague	12.2%
	Training/Other	14.6%
2) If you know what 'PA' is, what was the source of information?	Radio	0.6%
	TV	6.1%
	Newspaper	1.8%
	Magazine	5.5%
	Internet	**12.8%**
	Fair	6.7%
	Congress	4.9%
	Colleague	7.3%
	Training/Other	**17.1%**

Further sections covered seven PA technologies including yield monitoring and mapping, soil sampling and mapping, satellite-based positioning (GPS), remote sensing, geographical information systems (GIS), assisted and automatic steering and variable rate application (Table 6). For all participants, the most three well-known PA technologies were satellite-based positioning (GPS) (81.7%), remote sensing (69.5%) and geographical information systems (GIS) (61.0%). In reference to the participant groups, the most three well-known PA technologies by the agricultural engineers were positioning (GPS) (87.4%), geographical information systems (GIS) (77.7%) and remote sensing (75.7%). Farm machinery dealers were mostly aware of automatic steering (95.5%), positioning (GPS) (90.9%) and remote sensing (72.7%) while the most three known technologies by the farmers were positioning (GPS) (61.5%), remote sensing (51.3%) and automatic steering (38.5%).

Overall, the least known technologies were variable rate application (33.5%) and soil sampling and mapping (34.8%) for all participants (Table 6). On the other hand, regarding the participants groups, the least known technologies were automatic steering (28.2%) by the agricultural engineers, geographical information systems (GIS) (40.9%) by the dealers and yield monitoring and mapping (20.5%) by the farmers.

Table 6. Percentage of the positive answers to the questions on PA technologies

	All Participants	Agricultural Engineers	Machinery Dealers	Farmers
Question	Yes	Yes	Yes	Yes
Do you have knowledge on:				
1) yield monitoring and mapping technologies?	40.9%	44.7%	59.1%	20.5%
2) soil mapping technologies?	34.8%	36.9%	45.5%	23.1%
3) satellite positioning technologies (GPS)?	**81.7%**	**87.4%**	90.9%	**61.5%**
4) remote sensing technologies?	69.5%	75.7%	72.7%	51.3%
5) geographical info systems (GIS)?	61.0%	77.7%	40.9%	28.2%
6) assisted and automatic steering technologies?	39.6%	28.2%	**95.5%**	38.5%
7) variable rate application technologies?	33.5%	29.1%	63.6%	28.2%

It was observed that most of the agricultural engineers in both private and public sectors use GPS receivers and satellite remote sensing primarily to identify fields and calculate area. Farmers are also aware of GPS receivers since it is intensively used in field area calculation. They are also aware of remote sensing since agricultural government agencies determine the total and average yield of a farmer's field and arrange agricultural price support payments based on the yield data from satellite remote sensing technologies.

Another question directed to the farmers in the interview was 'Do you currently use any of the seven PA technologies?'. 23.0% of them answered that they use satellite-based positioning technologies (GPS) and only 5% use automatic steering (Table 7). None of the farmers use soil mapping, remote sensing and variable rate application technologies.

In the last section of the survey, a four-page training brochure (Fig. 2) was handed out to each participant and the PA concept and seven PA technologies were explained. This brief training process took about five to ten minutes.

Table 7. Percentage of the positive answers by farmers (n = 39) to the question 'Do you currently use PA technologies?'

Precision agriculture (PA) technologies	Yes
Do you currently use:	
1) yield monitoring and mapping technologies?	2.5%
2) soil mapping technologies?	0.0%
3) satellite-based positioning technologies (GPS)?	**23.0%**
4) remote sensing technologies?	0.0%
5) geographical information systems (GIS)?	2.5%
6) assisted and automatic steering technologies?	5.0%
7) variable rate application technologies?	0.0%

Five more questions were directed to each participant after the short training, (Table 8). First, 97.6% of all participants told that the information given in the short training was valuable for them. Secondly, 97.6% of all participants expressed that these technologies would somehow be beneficial for agricultural sector in Turkey. When asked 'Which technology will be more beneficial', 68.4% of participants answered that all technologies could be useful as 15.8% of them answered that variable rate application could be most beneficial. Thirdly, concerning the question 'does the Ministry of Food, Agriculture and Livestock offers grants and/or subsidy for these technologies?', 89.0% of all participants gave a negative answer or they did not have any information on this matter. In fact, the Ministry of Food, Agriculture and Livestock offered 50% grant for only yield monitoring systems in the year of 2014. This information was shared with each participant at the end of the survey. It was determined that unfortunately the Ministry would not continue to support these technologies in the near future including the year of 2015. In the fourth question the participants were asked 'Would you want to acquire more detailed training on PA?' and 88.4% of all participants were willing to get more detailed training. Finally, the farmers were asked if they want to use these technologies and 89.7% of them were positive (Table 8). Farmers who answered 'no' for this question told that high investment cost and small field size would be an important barrier to adopt PA technologies. On the other hand, 2.6% of them replied that they wanted to test the equipment first before using. When asked 'Which technology will be more beneficial?' to the farmers, 62.9% of participants answered that all technologies will be useful as 22.9% and 8.6% favored variable rate application and automatic steering as most beneficial, respectively. Farmers wanted to use the variable rate application due to the high cost of the agricultural inputs particularly chemical fertilizers.

Table 8. Answers to the questions after short training on PA (n = 164)

Question	Yes	No
1) Is the information given in the short training valuable for you?	97.6%	2.4%
2) Would these technologies be beneficial for agriculture in Turkey?	97.6%	2.4%
3) Does the Ministry of Food, Agriculture and Livestockoffers grants and/or subsidy for these technologies?	11.0%	89.0%
4) Would you want to acquire more detailed trainingon PA technologies?	88.4%	11.6%
5) Would you want to use these technologies?	89.7%	10.3%

Statistical data analysis

Statistical analysis was conducted using *Chi-square test* for the awareness level of all participants and participant groups (agricultural engineers, farm equipment dealers and farmers). The awareness level was based on the answers to two general questions on PA 'Have you heard the term PA before?' and 'Do you know what PA is?'.

For all participants, no statistically significant relationship were found between the awareness level of PA and age, gender, education level and work experience ($p > 0.05$). However, a significant relation was found between the awareness level of the three participant groups, agricultural engineers, farm equipment dealers and farmers ($p < 0.05$). Farm equipment dealers had higher awareness percentage (77.3%) than the agricultural engineers (52.4%) and farmers (35.9%) (Table 4).

Regarding the agricultural engineers, no significant relationship was found between the awareness level and age, gender and work experience ($p > 0.05$). On the other hand, a significant relation was found between the awareness level and education level (BS, MS, PhD) and major graduated ($p < 0.05$).

In reference to the dealers, no significant relationship was found between the awareness level and age, gender, major graduated (related to agriculture or not) and work experience ($p > 0.05$). Conversely, significant relations existed between the awareness level and employing an engineer, education level and training ($p < 0.05$).

Concerning the farmers, no relationship was found between the awareness level and age, gender, education level, experience and training ($p > 0.05$). On the other hand, a significant difference was found between the awareness level and farm field size and participation in agricultural fairs ($p < 0.05$). It was found out that participation in exhibitions has an importance to increase the awareness of PA. Some other researchers also indicated that social aspects including communication, co-operation, professional literature, exhibitions, fairs and field days have major importance to increase the awareness of new technologies including PA (Kutter et al., 2011).

Barriers in the adoption of PA technologies

In the study, farmers were also asked if they want to use PA technologies and 89.7% of them were positive (Table 8). We found a significant relationship between the willingness to use PA technologies and two factors being farm field size and high investment cost ($p < 0.05$).

Firstly, a significant relationship existed between field size and the willingness to use 'PA' such that the farmers with bigger field size want to use these technologies (Fig. 3). In Turkey, the average farm size is only 5.9 ha and is well below than EU and the US averages (17.4 and 18.0 ha, respectively) (Berk, 2013). Projects are carried out by state agencies in Turkey for land consolidation to increase average field size. Also, small farms (< 2 ha) are being replaced by large farms as a result of globalization and multinational corporations gaining control over markets (Berk, 2013). Farmers with small field area do not have sufficient incomes to invest in expensive technologies. Small farm size is also reported by other researchers to be a significant barrier (Gandonou et al., 2001; Pawlak, 2003; Bongiovanni & Lowenberg-DeBoer, 2005; Whipker & Akridge, 2009; Paudel at al., 2011). Lending of PA equipment to other farmers through multi-farm machinery use programs (Pawlak, 2003) may be a cure for this problem. We observed that some farmers having automatic steering use it to serve other farmers mainly in ridge tillage in cotton and corn cultivation in the study area.

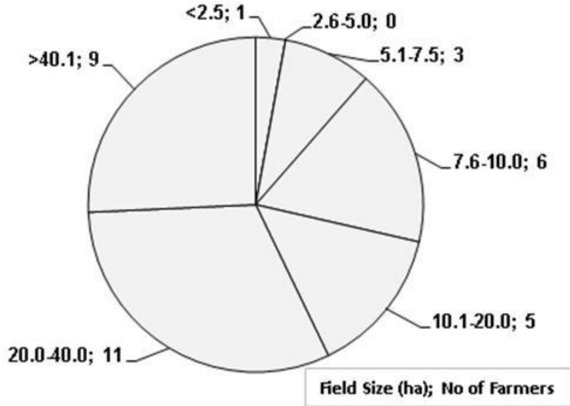


Figure 3. Relation of farm field size and willingness to use 'PA'.

Secondly, another barrier that prevents the adoption of PA was reported by the farmers to be the high investment cost. When asked 'Would you want to use these technologies?', 10.3% of the farmers answered 'no' (Table 8) telling that high investment requirement (as well as small field size) would be an important barrier to prevent the adoption. High cost of equipment was also reported by other researchers to be significant constraint preventing farmers to adopt PA (Gandonou et al., 2001; Pawlak, 2003; Bongiovanni & Lowenberg-DeBoer, 2005; Whipker & Akridge, 2009; Paudel et al., 2011). A solution would be to utilize farm equipment grant programs for PA equipment. The Ministry of Food, Agriculture and Livestock in Turkey offered 50% grant for yield monitoring systems in the year of 2014; however, it was learned that the Ministry will not continue to utilize such supports for the year of 2015.

Current status in precision agriculture adoption

Current status and recent developments in the adoption of PA technologies in the study area and nationwide are explained below:

<u>Yield monitoring and mapping</u>: This technology is not utilized well in the Cukurova region. However, it was found out that an international company (New Holland) planned to install yield monitors on about 500 combine harvesters countrywide in recent years. The Ministry of Food, Agriculture and Livestock offered 50% grant for only yield monitoring systems in the year of 2014. However, we learned that the Ministry will not continue to utilize such supports for the year of 2015.

<u>Soil sampling and mapping</u>: Precision soil sampling and mapping based on soil type or grid is not utilized well in the study area as well. Classical soil sampling is applied based on a condition for a farmer to receive agricultural price support from the state agencies. On the other hand, soil type or grid soil sampling and mapping is used for research purposes.

<u>Satellite-based positioning (GPS)</u>: It was observed that most of the agricultural engineers in both private and public sectors use GPS receivers primarily to identify fields and calculate area. Also, most of the farmers are aware of GPS receivers since it is intensely used in field area calculation.

Satellite remote sensing: It is used primarily to identify the fields, calculate area and predict yield by the agricultural engineers employed by the Ministry of Food, Agriculture and Livestock. Farmers are also aware of remote sensing since government agencies determines the total and average yield on a farmer's field and arranges agricultural price support payments based on the yield data from this technology. However, it is common to see conflict between the farmer and the state agencies in determining the precise average yield. In this manner, a combine harvester with a yield monitor will be more accurate to determine the average and total yield and also generate a yield map to study the variability. The Ministry along with a state university and some government agencies develop an integrated decision support system for good agricultural practices and PA under the acronym of TARBIL by combining satellite remote sensing data and meteorological data from 1,200 countrywide ground stations (Altilar, 2014). The system is used for such purposes including prediction of seasonal and early harvest crop yield, reduction of chemical usage, early warning for possible crop damage and field based mobile data to subscribers (Altilar, 2014).

Geographical information systems (GIS): It was observed that most of the agricultural engineers particularly in public sectors know and use GIS primarily to calculate field area and predict yield. Also, it is used for land consolidation applications governed by the state agencies.

Assisted and automatic steering: The utilization of this technology is in an increasing trend in the study area in recent years. It was found out that an international company (mainly Topcon) sold about 60 auto steering systems in recent years in the study area. Auto steering service providers establish their own reference station networks for positioning correction. Some farmers who have automatic steering use them to serve other farmers mainly in ridge tillage in cotton and corn cultivation.

Variable rate application: This technology is not utilized well in the study area. Most farmers are aware of variability in their field and some of them manage field variability manually rather than sophisticated variable rate technology. Also, it is used for research and demonstration purposes.

CONCLUSIONS

The conclusions of the study were as follow:

- 90.2% of all participants reported that they followed new trends in agriculture. Only 51.8% of all participants reported that they did not hear the term 'PA' before. Only 29.3% of the participants who heard the term 'PA' before replied that they knew the meaning and concept of the PA. Internet was the most important means to gather information about new agricultural technologies including PA.
- The most three known PA technologies by all participants were satellite positioning (GPS) (81.7%), geographical information systems (GIS) (69.5%) and remote sensing (61.0%). Most of the agricultural engineers in both private and public sectors use GPS receivers and satellite remote sensing primarily to identify fields and calculate area. The least known technologies by all participants were variable rate application (33.5%) and soil sampling and mapping (34.8%).
- 97.6% of all participants told that the information given in short training was valuable for them. Also, 97.6% of the participants expressed that these technologies

would be somehow beneficial for agricultural sector in Turkey. 88.4% of the participants were willing to get more detailed training on these technologies.

– 89.7% of the farmers told that they could use PA technologies. However two important barriers preventing the adoption were reported being farm field size and high investment cost.
– It was found out that the adoption of yield monitoring and auto guidance systems is in an increasing trend.

ACKNOWLEDGEMENTS. The authors thank the Scientific Research Project Office (BAP) of Mustafa Kemal University for their financial support for the study (Project No: 12240). Also, they acknowledge the survey participants, related government agencies and agricultural organizations for their cooperation during the study.

REFERENCES

Akcaoz, H. & Ozkan, B. 2005. Determining risk sources and strategies among farmers of contrasting risk awareness: A case study for Cukurova region of Turkey. *Journal of Arid Environments* **62**, 661–675.

Altilar, D.T. 2014. Integrated Agricultural Monitoring and Information System (AGRIMONIS - TARBiL). Workshop on Agricultural Trade and Food Security in the Euro-Med Area. 26 September 2014. Antalya, 35 pp. (In Turkey)

Berk, A. 2013. Processor driven integration of small-scale farmers into value chains in Turkey. Agrarian Structures Initiative. Food and Agriculture Organization (FAO).

Bligaard, J. 2013. Identified user requirements for precision farming in Germany, Finland and Denmark. Project Report, 12 pp.

Bongiovanni, R. & Lowenberg-DeBoer, J. 2005. Precision agriculture in Argentina. *3 Simposio Internacional de Agricultura de Precisao*. 16–18 August 2005. Sete Lagoas, MG (In Brasil).

Daberkow, S. & McBride, W. 2003. Farm and operator characteristics affecting the awareness and adoption of precision agriculture technologies in the US. *Precision Agriculture* **4**, 163–177.

Edwards-Jones, G. 2006. Modelling farmer decision-making: Concepts, progress and challenges. *Animal Science* **82**, 783–790.

Erickson, B. & Widmar, D.A. 2015. Precision agricultural services dealership survey results. Purdue University. West Lafayette, Indiana, USA, 37 pp.

Ess, D. & Morgan, M. 2003. *The Precision-Farming Guide for Agriculturists*. Deere & Company, Moline, Illinois, 138 pp.

Gandonou, J.M., Stombaugh, T.S., Dillon, C.R. & Shearer, S.A. 2001. Precision Agriculture: A Break-Even Acreage Analysis. *2001 ASAE Annual International Meeting*. Paper No. 01-1029. ASAE, St. Joseph, Michigan (In USA).

Helm, C. 2005. Precision Farming in South Africa. FarmTech 2006 Proceedings. pp 76-80.

Isgin, T., Bilgic, A., Forster, L. & Batte, M.T. 2008. Using count data models to determine the factors affecting farmers' quantity decisions of precision farming technology adoption. *Computers and Electronics in Agriculture* **6**, 231–242.

Keskin, M. 2013. Factors Affecting the Adoption of Precision Agriculture Technologies and the Usage Rate of These Technologies in the World. *Journal of Agricultural Machinery Science (Tarim Makinalari Bilimi Dergisi)* **9**, 263–272. (in Turkish).

Keskin, M. & Görücü Keskin, S. 2012. *Precision Agriculture Technologies*. Mustafa Kemal University. Publication No: 35. Antakya, Hatay, Turkey, 212 pp. (in Turkish).

Kutter, T., Tiemann, S., Siebert, R. & Fountas, S. 2011. The role of communication and co-operation in the adoption of precision farming. *Precision Agriculture* **12**, 2–17.

Leonard, E. 2014. Precision Ag Down Under. www.precisionag.com/guidance/precision-ag-down-under.

Norwood, S. & Fulton, J. 2009. GPS/GIS Applications for Farming Systems. *Alabama Farmers Federation Commodity Organizational Meeting*. 5 February 2009 (In USA).

Paudel, K., Pandit, M., Mishra, A. & Segarra, E. 2011. Why Don't Farmers Adopt Precision Farming Technologies in Cotton Production? *2011 AAEA & NAREA Joint Annual Meeting*. 24-26 July 2011, Pittsburgh, PA (In USA).

Pawlak, J. 2003. Precision agriculture - economic aspects. In J.V.Stafford & A.Werner (eds): *Precision Agriculture*. pp. 527–531. Wageningen Academic Publishers.

Rains, C.R. & Thomas, D.L. 2009. Precision Farming: An Introduction. The University of Georgia. Bulletin 1186. Rev. March 2009, 12 pp.

Reichardt, M., Jurgens, C., Kloble, U., Huter, J. & Moser, K. 2009. Dissemination of precision farming in Germany: acceptance, adoption, obstacles, knowledge transfer and training activities. *Precision Agriculture* **10**, 525–545.

Robertson, M.J., Llewellyn, R.S., Mandel, R., Lawes, R., Bramley, R.G.V., Swift, L., Metz, N. & O'Callaghan, C. 2012. Adoption of variable rate fertiliser application in the Australian grains industry: Status, issues and prospects. *Precision Agriculture* **13**, 181–199.

Schimmelpfennig, D. & Ebel, R. 2011. On the Doorstep of the Information Age Recent Adoption of Precision Agriculture. *Economic Information Bulletin No 80*. Economic Research Service, United States Department of Agriculture (USDA), 31 pp.

Silva, C.B., Moraes, M.A.F. & Molin, J.P. 2011. Adoption and use of precision agriculture technologies in the sugarcane industry of Sao Paulo state, Brazil. *Precision Agriculture* **12**, 67–81.

Söderström, M. 2013. Country Report - Sweden. The International Society of Precision Agriculture (ISPA) Report. May 2013, pp 4–5.

USDA. 2015a. Agricultural Resource Management Survey: US Peanut Industry. United States Department of Agriculture (USDA) National Agricultural Statistics Service (NASS) Highlights. No 2015-1, 4 pp.

USDA. 2015b. Agricultural Resource Management Survey: US Rice Industry. United States Department of Agriculture (USDA) National Agricultural Statistics Service (NASS) Highlights. No 2015-2, 4 pp.

Verma, L. 2015. China Pursues Precision Agriculture on a Grand Scale. *Resource Magazine*. July/August 2015 **22**, 18–19.

Whipker, L.D. & Akridge, J.T. 2009. Precision Agriculture Services Dealership Survey Results. Purdue University. West Lafayette, Indiana, USA, 64 pp.

Agronomy Research **14**(4), 1321–1331, 2016

Biomass gasification thermodynamic model including tar and char

V. Kirsanovs*, A. Žandeckis and C. Rochas

Institute of Energy Systems and Environment, Riga Technical University, Azenes iela 12/1, LV-1048 Riga, Latvia
*Correspondence: vladimirs.kirsanovs@rtu.lv

Abstract. Biomass gasification is a thermochemical process in which feedstock is heated to high temperatures in a condition of absence of oxygen. As a result, biomass is converted into the combustible syngas, which typically consists of carbon monoxide (CO), carbon dioxide (CO_2), hydrogen (H_2), methane (CH_4), nitrogen (N_2) and water vapour (H_2O). Biomass gasification process simulation plays an important role in gasification process comprehension and optimization. Typically, gasification models have only one output flow in the process mass balance, which represents the amount of the produced syngas. Tar and char also are significant products of gasification process. This study presents a thermodynamic biomass gasification model. The fundamental distinction of the proposed model, comparing to other available models, is that tar and char also are taken into account in developed model. Gasification process is affected by many factors. Similarly, the amount of produced tar and char can significantly vary depending on gasifier operation conditions. Literature review on the previous studies is done to determinate the most critical factors which affect tar and char formation. Results show that temperature in the gasifier, equivalence ratio and fuel properties have dominant effect on the products yield. Two regression models are elaborated to present the amount of the produced tar and char depending on independent variables. The achieved mathematical equations are added to the developed thermodynamic model of the gasification process. Biomass gasification process is simulated with different values of fuel moisture and equivalence ratio. The results show that produced syngas amount, calorific value and biomass energy conversion efficiency are more realistic after tar and char including in the model.

Key words: biomass gasification, syngas, tar, char, mathematical model.

INTRODUCTION

Gasification is a complex process for conversion of solids into to gaseous fuels. Gasification process consists of drying, pyrolysis, partial combustion and gasification or reduction sub-processes. Produced gas typically contains 70% to 80% of the initial biomass energy, but residual energy is lost. (Blumberga et al., 2011) Efficiency of the gasification process and produced gas properties depend on many mutual factors. Simulation tools are widely used for understanding and optimization gasification process. Nowadays many gasification models exist and describe the effect of operational parameters of the process, as well as fuel properties. Thermodynamic equilibrium and kinetic models are the two most frequently used simulation tools. In the study done by Baruah & Baruah (2014) these simulation approaches are discussed and compared. The influence of gasifier design on the gasification process can be analysed using kinetic models. Produced gas composition at specific place in gasifier and definite time can also be determined. (Gordillo & Belghit, 2011; Saravanakumar et al., 2011) Thermodynamic models are useful to predict chemical composition of the produced gas. The influence of equivalence ratio, temperature in reactor and fuel properties on the gasification process can be successfully simulated using thermodynamic models. (Jarungthammachote & Dutta, 2007; Sharma, 2008; Azzone et al 2012) This is one of the main advantages of the thermodynamic modelling. The global gasification reaction is a base of the thermodynamic model. Fuel chemical composition, moisture content and equivalence ratio are the main input parameters determining composition of produced gas.

Syngas is the main product of the gasification process. Some amount of fuel was converted to the tar and char also. In general, tar is a complex mixture of condensable organic substances, including light aromatics, polyaromatics, heterocycles, etc, that condense in the low-temperature zones of the gasifier and in downstream equipment. Tar is formed in each zone of gasifier, forming the greatest part in pyrolysis zone, where temperature vary from 200 to 500 °C. Tar is undesired substance and can be a reason for many problems such as plugging the equipment because of condensation, formation of tar aerosols, formation of particulates or polymerizing on the surface of solid particles, as well as metal corrosion. (Ahmed et al., 2011). Char is typically produced at the pyrolysis stage and often is the final solid residue left over from gasification process. Char mainly consists of hydrogen and carbon and has high calorific value. Char porosity is relative high and can vary in the range of 40 to 50% (Basu, 2010).

Only in several models include tar and char in the gasification process mass balance, typically as constant value. The aim of this study is get empirical relation of tar and char yield depending from gasifier operation parameters and achieved equation including in the mathematical model. The determination of main factors which have effect on the tar and char yield must be done before. Many studies available about tar and char formation in the gasification process. Sometimes different and even opposite effect of different factors on the tar and char yield can be find. Tar and char formation are depended from many factors. This can be one of the main reason of different results between studies. Only results from studies where one type gasifiers with similar gasification agent used can be compared.

The developed mathematical model describes gasification process in the downdraft gasifier where air was used as gasifying agent. Only studies which analyse tar and char yield from downdraft gasifier with air medium were used for regression model derivation. Tar yield from downdraft gasifiers is lower in comparison with updraft and fluidized bed gasifiers. Biomass gasification with air agent promote higher tar concentration in the syngas than with steam or oxygen gasification.

The temperature increase promotes total tar content decrease in the syngas. Hydrocarbons conversion becomes more active because of heat released by the combustion reactions. (Basu, 2010; Erkiaga et al., 2014). The char yield also reduces due to temperature growth and is converted into gas through Boudouard reactions and thermal cracking reaction (Luo et al., 2012). On the other side, the significant growth of the temperature favours the decrease of the low heating value of the syngas. By increasing temperature, more carbon is oxidized to CO_2, which is incombustible. Syngas heating value goes down in the result. It is important to find optimal temperature range for gasifier operation to produce high syngas yield without significant decrease of the syngas heating value (Sanz & Corella, 2006).

From the other side gasification temperature is affected by many parameters, like equivalence ratio, moisture content of fuel, fuel chemical composition, reactor design, etc. Temperature in the gasifier cannot be changed without changing one or several input parameters and has strong correlation with mentioned parameters. Temperature should be considered as a dependent variable in the result. In the thermochemical models interactive calculation is applied to determine gasification temperature at which energy balance of the global gasification reaction is fulfilled.

Equivalence ratio is one of the most significant parameters affecting gasification process efficiency and syngas composition. Equivalence ratio is the ratio of the actual air/fuel ratio to the stoichiometric air/fuel ratio. Equivalence ratio is 1 for the ideal combustion and typically ranges from 0.2 to 0.4 for biomass gasification. The growth of the air/fuel ratio promotes increase of the activity of the combustion reactions. Temperature in the reaction zone goes up in the result. Many studies' results present that there is a strong correlation between equivalence ratio and temperature (Pellegrini & Oliveira, 2007; Ghassemi & Shahsavan-Markadeh, 2014). Ji et al. (2009) and Guo et al. (2013) determined tar content decreasing, but Fiaschi & Michelini (2001) present char reduction with air/fuel ratio increase.

The similar situation is with fuel moisture. The effect of moisture has influence on tar and char yield and temperature in the gasifier reactor (Pellegrini & Oliveira, 2007; Karamarkovic & Karamarkovic, 2010). The higher the fuel moisture, the higher energy amount is used to evaporate water from the biomass and less energy is available for endothermic reactions. The temperature in the gasifier goes down in the result and promotes growth of the tar and char yield. The tar content growth from 14.4 g m^{-3} to 20.7 g m^{-3} and temperature decrease from 795 °C to 748 °C was found out when the fuel moisture increased from 15% to 34% in the study done by Guo et al. (2013).

There are also some another factors which have influence on the tar and char yield - feedstock particle size (Mohammed et al., 2011), high concentration of volatile matters (Min et al., 2003), lignin content in the fuel (Saw & Pang, 2013; Amirabedin et al., 2014) and fuel chemical composition. Model represent gasification process of wood chips with constant properties. The effect of fuel chemical composition was presented in the previous study (Kirsanovs & Žandeckis, 2015a). It was determined that chemical composition and ash content in the fuel have effect on the gasification temperature. Therefore, the fuel chemical composition influence on the gasification process can be represented due relationships of temperature in the gasifier and tar and char yield.

MATERIAL AND METHODS

Literature review confirm that tar and char formation depends from temperature in gasifier, equivalence ratio and fuel properties. Table 1 summarizes the studies which present effect of gasification operation parameters and fuel properties on the tar and char formation. Table present the ranges of gasification temperature, air/fuel ratio, biomass moisture and ash content in biomass in the studies. Fuel moisture and ash content in some studies are constant in the experiments.

Table 1. Summary of previous studies which present tar and char formation at the biomass gasification process

Gasification temperature	Air/fuel ratio	Biomass moisture, %	Ash content in biomass, w-%, dr	References
930–1,040	1.29–2.88	6.17	5.93	Gai & Dong, 2012
821–1,206	1.37–1.64	12.5	0.77	Dogru et al., 2002a
553–755	1.04–1.63	6.00–11.0	0.50–1.4	Sarket & Nielsen, 2015
705–920	0.87–1.85	4.37–15.2	3.90	Sheth & Babu, 2010
830–1,120	0.96–1.83	4.40–14.9	0.40–21.8	Striūgas et al., 2014
1,009–1,077	2.28–2.69	11.8	23.5	Dogru et al., 2002b
870–1,108	1.11–1.28	8.00	0.55	Lv et al., 2007
773	1.88	18.0	1.3	Atnaw et al., 2013

Data analysis is performed using STATGRAPHICS Centurion 16.1.17 software and shows that there are correlations between tar and char yield and gasification operation parameters and fuel properties. The first mathematical equation below represents gasification temperature, air/fuel ratio and biomass moisture effect on the tar yield. (see Eq. 1) Tar yield was presented as relation of tar mass at the exit of gasifier to total fuel and air mass input. The mass of the fuel and air injected in the gasifier is similar with total product mass output from gasifier. The second equation shows the connection between char yield and gasification temperature, air/fuel ratio, fuel moisture and ash content (see Eq. 2). Char yield was presented as relation of char mass at the exit of gasifier to total fuel mass input.

$$w_{tar} = (6.411 - 0.203 \cdot sqrt(T))^2 + 0.248 \cdot AF - 0.024 \cdot W \quad (1)$$

$$w_{Char} = (6.643 - 0.006 \cdot T)^2 + 2.108 \cdot AF + 0.193 \cdot W + 0.487 \cdot A \quad (2)$$

where: w_{tar} is tar mass concentration, wt%; w_{char} is char mass concentration, wt%; T is temperature in the gasifier, °C; AF is ait/fuel ratio; W is fuel moisture content, wt%; A is ash content in the fuel, wt%, on dry basis.

Analysis of both models is presented in Table 2. Results show that temperature is most influential parameter on the indicator in Model I and II. This is mostly due to significant influence of temperature on the tar and char yield. R-Squared statistic indicates that the model as fitted explains 77.60 and 68.24 variability of tar and char yield. Standard error of the estimate is low and especially for model I, so it can be used to predict limits for new observations. The mean absolute error is the average value of the residuals and also is lower for model I.

Table 2. Data analysis of the regression model

Reg. model	Depended variable	R^2, %	Adjusted. R^2, %	Standard error of estimate	Mean absolute error
I	Tar	77.60	75.81	0.51	0.30
II	Char	68.24	63.67	2.13	1.43

Two achieved equations are integrated in the modified thermodynamic model of the gasification process. Model detailed description can be found in the previous studies (Kirsanovs & Žandeckis, 2015a; Kirsanovs & Žandeckis, 2015b). Global gasification reaction is a base of the created thermodynamic model. CO, CO_2, H_2, CH_4, N_2 and H_2O vapour make syngas composition in the model. The inclusion of tar and char in the model is the main difference from previous models. Air is used as gasification agent in this model. Fuel and ambient temperatures are constant. Fuel properties like chemical composition and ash content are constant in the model for all scenarios and represent typical wood from forest with or without bark. Model validation with others studies also was described in the earlier papers. Model was based on the global gasification reaction, where tar and char were also included (Eq. 3):

$$\begin{aligned} & CH_xO_yN_z + wH_2O + m(O_2 + 3.76N_2) = n_1H_2 + n_2CO + \\ & + n_3CO_2 + n_4CH_4 + n_5HO_2 + (\frac{1}{2}z + 3.76m)N_2 + n_6tar + n_7char \end{aligned} \tag{3}$$

The carbon, hydrogen and oxygen balances in the model were presented as (Eq. 4–6):

$$n_{CO} + n_{CO_2} + n_{CH_4} - 1 = 0 \tag{4}$$

$$n_{H_2} + 2n_{H_2O} + 4n_{CH_4} - x - 2w = 0 \tag{5}$$

$$n_{CO} + 2n_{CO_2} + n_{H_2O} - w - 2m - y = 0 \tag{6}$$

The mass balance consists from two input and for output flows. Fuel and air are input flows, but syngas, tar, char and ash are output flows (Eq. 7). Tar and char mass were calculated using achieved equations 1 and 2.

$$m_f + m_{air} = m_s + m_t + m_c + m_{ash} \tag{7}$$

where: m_f – fuel mass; m_{air} – air mass; m_s – syngas mass; m_t – tar mass; m_c – char mass; m_{ash} – ash mass.

Three input and three output flows form the energy balance in the model (Eq. 8). The main energy was injected with fuel heating value. Some energy goes to gasifier with air and fuel sensible energy. The dominant share of energy leaves gasifier with syngas heating value, but some energy was removed from syngas sensible heat. The remaining energy belong to heat losses. Heat losses from gasifier hot surfaces, heat removed from tar and char are main energy losses ways.

$$E_f + E_{f_s} + E_{a_s} = E_s + E_{s_s} + E_l \tag{8}$$

where: E_f – fuel energy; E_{f_s} – fuel sensible energy; E_{a_s} – air sensible energy; E_s – syngas energy; E_{s_s} – syngas energy; E_l – heat losses.

The cold-gas efficiency of gasification process is relation between produced syngas heat of combustion to input energy with biomass and expressed in model as (9) (Basu, 2010):

$$\eta_{cold} = \frac{LHV_g \cdot V_g}{LHV_f \cdot m_f} \tag{9}$$

where: η_{cold} – the efficiency of the gasification process, %; LHV_g –lower calorific value of the syngas, kJ Nm^{-3}; V_g – volume of the produced syngas, Nm^3; Q_s – sensible heat of syngas, kJ m^{-3}; m_f – the mass of the fuel as fired basis kg.

The hot-gas efficiency take into account produced gas sensible heat also. Sensible heat is depending from syngas temperature after gasifier and after cooling (10) (Basu, 2010):

$$\eta_{hot} = \frac{LHV_g \cdot V_g + Q_s \cdot V_g}{LHV_f \cdot m_f} \tag{10}$$

where: η_{hot} – the efficiency of the gasification process, %; Q_s – sensible heat of syngas.

RESULTS

The effect of gasification operational conditions on the gasification temperature, produced syngas amount, syngas heating value and syngas sensible or latent heat, as well as gasification process efficiencies are analysed. Gasification process is simulated using previous model without tar and char and modified model, which includes gasification process subproducts. It is done to compare models and to represent the difference between the results of modelling. Equivalence ratio and fuel moisture are chosen as independent variables. Equivalence ratio vary in range from 0.2 to 0.4. Three typical values of the amount of water in the biomass – 10%, 20% and 30% – were taken for fuel moisture.

First of all, the yield of the produced tar and char in comparison to total output flow are calculated (see Fig. 1). The results show that tar and char mass concentration is maximal at low equivalence ratio. Tar and char yields decrease from 4.2% and 6.1% respective at equivalence ratio 0.2 to 0.3% and 2.6% at equivalence ratio 0.4 using biomass with 10% moisture content. Fuel moisture growth promotes the increase of tar and char content. Tar and char yields go up from 4.2% and 6.1% respective with fuel moisture content 10% to 5.0% and 8.8% with moisture content 30% at equivalence ratio 0.2. Significant gasification temperature reducing with fuel moisture growth is the main reason of it.

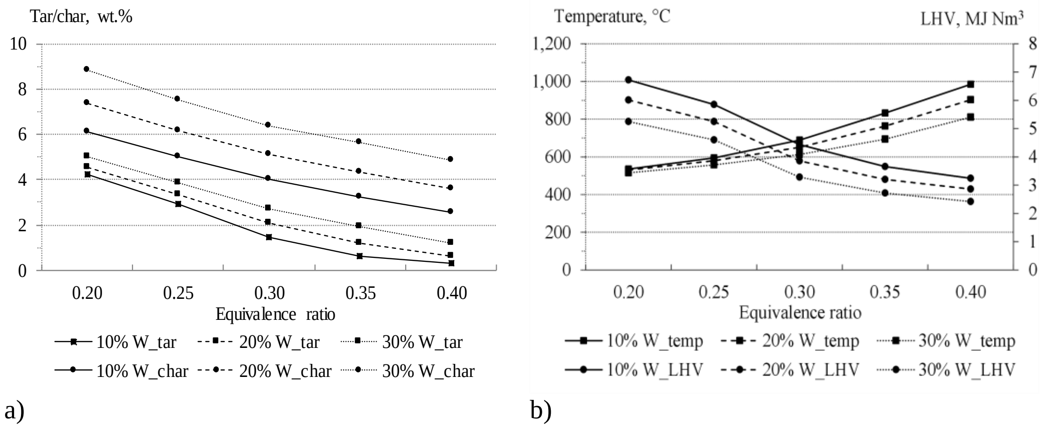


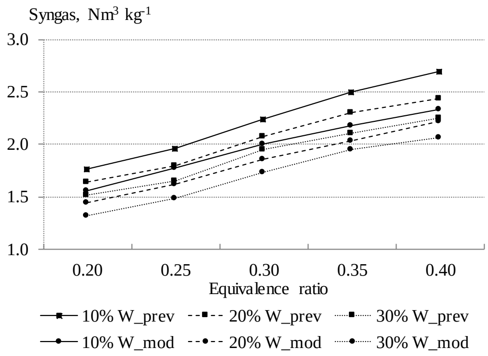
Figure 1. Effect of the equivalence ratio and fuel moisture content on the tar and char yield (a); and temperature and syngas higher calorific value (b), where: 10%W – fuel moisture 10%; 20%W – fuel moisture 20%; 30%W – fuel moisture 30%; temp – temperature in gasifier, °C; LHV – syngas lower calorific value, MJ Nm^3.

Temperature of oxidation zone and temperature in the gasifier in general decrease with biomass moisture growth. More energy from fuel is used to evaporate water. The oxidation reaction activity goes down due fuel moisture increase also. Gasification temperature reduced from 535 °C respective with fuel moisture content 10% to 515 °C with moisture content 30% at equivalence ratio 0.2. At the same time gasification temperature increase from 535 °C at equivalence ratio 0.2 to 985 °C at equivalence ratio using biomass with 10% moisture content.

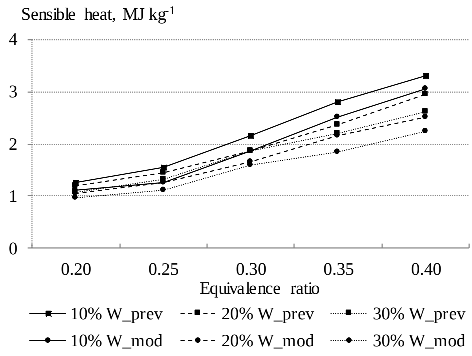
The carbon monoxide and hydrogen content in the produced syngas goes down with fuel moisture increase. Lower heating value of syngas goes down in the result from 6.7 MJ Nm^3 with fuel moisture content 10% to 5.3 MJ Nm^3 with moisture content 30% at equivalence ratio 0.2. The increase of equivalence ratio promotes the growth of the gasification temperature. Methane concentration rapidly goes down and causes the decrease of syngas heating value too.

The volume of the produced gas is lower after tar and char including in the model. Fig. 2 shows difference in the syngas amount between previous model, where tar and char were not included and modified model with tar and char. The results show that the amount of syngas is lower using modified model. Produced syngas flow increases 1.5 times from 1.5 Nm^3 kg^{-1} to 2.5 Nm^3 kg^{-1} and more with equivalence ratio increase from 0.2 to 0.4. Amount of produced incombustible CO_2 and N_2 also increases due ER growth and promote decrease of heating value of syngas. The amount of produced syngas goes down with fuel moisture growth.

Temperature in the gasifier has dominant effect on the sensible heat of syngas. The higher is gasification temperature the higher is sensible heat of produced gas. This is the main reason that sensible heat of syngas is higher for fuel with lower moisture content and at high equilibrium ratios. Sensible heat of syngas is lower for scenarios where tar and char were included in the model, because the total amount of the syngas goes down.



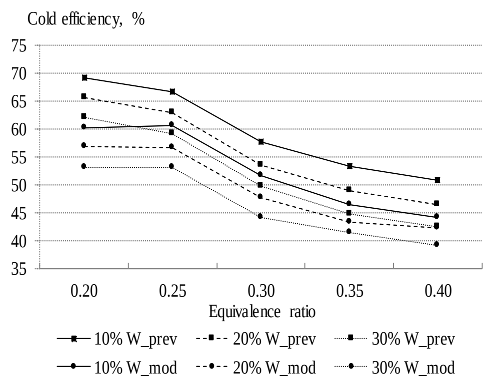
a)



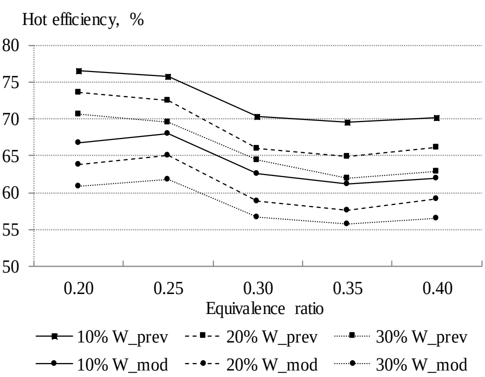
b)

Figure 2. Effect of the equivalence ratio and fuel moisture content(W) on the produced gas volume (a); and syngas sensible heat (b), where: prev – previous model; mod – modified model including tar and char.

The efficiency is one of the main criteria describing performance of the gasification process. Efficiency of the gasification process typically is described using cold gas and hot gas efficiency. Fig. 3 presents calculated cold and hot gas efficiencies of the gasification process for all six scenarios. The syngas calorific value decrease due to equivalence ratio and fuel moisture content growth. Cold gas efficiency of the gasification process goes down in the result. The data from modified model show that cold gas efficiency doesn’t go down or opposite go up with equivalence ratio increase from 0.2 to 0.25. The significant tar and char yield decrease is the main reason of it. The fuel moisture increase on 10% promote decrease of cold gas efficiency on the average by 3.5%. The growth of equivalence ratio from 0.2 to 0.4 promote decrease of cold gas efficiency on the average by 19% and 15% using previous and modified models respectively.



a)



b)

Figure 3. Effect of the equivalence ratio and fuel moisture content(W) on the gasification process cold efficiency (a); and hot efficiency (b).

Data from previous model show that the hot gas efficiency goes down rapidly at lower equivalence ratio too, but after achieving the critical point was more over constant. Significant syngas volume and sensible heat increase at high equivalence ratios are the main reason of it. The achieved data from modified model present some hot gas efficiency growth with equivalence ratio increase from 0.2 to 0.25. The further effect of equivalence ratio decrease was more over similar with results from previous model.

CONCLUSIONS

The effects of temperature, equivalence ratio and fuel properties on the tar and char formation are analysed, using articles available from literature. Tar and char have a strong impact on the produced syngas properties and gasification process efficiency. Tar and char yield should be included in the mass balance of the biomass gasification process to get achieved data from thermodynamic model closer to real data.

Two models are proposed to present the mathematical connection between temperature in gasifier, air/fuel ratio, fuel properties and tar and char yield during gasification process using collected studies. Data analysis shows that the models have a sufficient correlation between the variable. The achieved equations are integrated in the thermodynamic model of gasification process.

The effect of equivalence ratio and fuel moisture is determined using the developed gasification process model. The results show that air/fuel ratio growth promotes decrease of tar and char yield. The increase of temperature in the reactor is the main reason of it. Growth of the temperature has negative effect on the produced syngas calorific value. Fuel moisture increasing has the opposite influence on the tar and char yield. Temperature in the gasifier reduces due to the biomass moisture growth, that favours the increase of the tar and char yield.

The modified model with included tar and char values is compared with previous model. The results show that efficiency of gasification process lowers. Modified model show that equivalence ratio 0.25 can be optimal value for gasification process. Previous model show that the lower is equivalence ratio the higher is gasification process efficiency, because don’t take into account tar and char effect on the process. Data from new model is closer to data from real systems after tar and char including in the model.

ACKNOWLEDGEMENTS. The work has been supported by the National Research Program ‘Energy efficient and low-carbon solutions for a secure, sustainable and climate variability reducing energy supply (LATENERGI)’.

REFERENCES

Ahmed, A., Salmiaton, A., Choong, T. & Wan Azlina, W. 2015. Review of kinetic and equilibrium concepts for biomass tar modelling by usind Aspen Plus. *Renewable and Sustainable Energy Reviews* **52**, 1623–1644.

Amirabedin, E., Pooyanfar, M., Rahim, M.A. & Topal, H. 2014. Techno-environmental assessment of co-gasification of low-grade Turkish lignite with biomass in a trigeneration power plant. *Environmental and Climate Technologies* **13**, 5–11.

Atnaw, S.M., Kueh, S.C. & Sulaiman, S.A. 2014. Study on tar generated from downdraft gasification of oil palm fronds. *The Scientific World Journal* **2014**, 8.

Azzone, E., Morini, M. & Pinelli, M. 2012. Development of an equilibrium model for the simulation of thermochemical gasification and application to agricultural residues. *Renewable Energy* **46**, 248–254.
Baruah, D. & Baruah, D.C. 2014. Modelling of biomass gasification: a review. *Renewable and Sustainable Energy Reviews* **39**, 806–815.
Basu, P. 2010. *Biomass gasification and pyrolysis. Practical design.* Burlington, USA, 355 pp.
Blumberga, D., Veidenbergs, I., Romagnoli, F., Rochas, C. & Žandeckis, A. 2011. Bioenerģijas tehnoloģijas. Riga, 272.
Dogru, M., Howarth, C.R., Akay, G., Keskinler, B. & Malik, A.A. 2002a. Gasification of hazelnut shells in a downdraft gasifier. *Energy* **27**, 415–427.
Dogru, M., Midilli, A. & Howarth, C.R. 2002b. Gasification of sewage sludge using a throated downdraft gasifier and uncertainty analysis. *Fuel Processing Technology* **75**, 55–82.
Erkiaga, A., Lopez, G., Amutio, M., Bilbao, J. & Olazar, M. 2014. Influence of operations on the steam gasification of biomass in a conical spouted bed reactor. *Chemical Engineering Journal* **237**, 259–267.
Fiaschi, D. & Michelini, M. 2001. A two-phase one-dimensional biomass gasification kinetics model. *Biomass and Bioenergy* **21**, 121–132.
Gai, C. & Dong Y. 2012. Experimental study on non-woody biomass gasification in a downdraft gasifier. *International Journal of Hydrogen Energy* **37**, 4935-4944.
Ghassemi, H. & Shahsavan-Markadeh, R. 2014. Effects of various operational parameters on biomass gasification. *Energy Conversion and Management* **79**, 18–24.
Gordillo, E.D. & Belghit, A. 2011. A downdraft high temperature steam-only solar gasifier of biomass char: a modelling study. *Biomass and Bioenergy* **35**, 2034–2043.
Guo, F., Dong, Y., Dong, L. & Jing, Y. 2013. An innovative example of herb residues recycling by gasification in a fluidized bed. *Waste Management* **33**, 825–832.
Jarungthammachote, S. & Dutta, A. 2007. Thermodynamic equilibrium model and second law analysis of a downdraft waste gasifier. *Energy* **32**, 1660–1669.
Ji, P., Feng, W. & Chen, B. 2009. Production of ultrapure hydrogen from biomass gasification with air. *Chemical Engineering Science* **64**, 582–592.
Karamarkovic, R. & Karamarkovic, V. 2010. Energy analysis of biomass gasification at different temperatures. *Energy* **35**, 537–549.
Kirsanovs, V. & Žandeckis, A. 2015a. Investigation of fuel effect on biomass gasification process using equilibrium model. *Agronomy research* **13**(2), 500–510.
Kirsanovs, V. & Žandeckis, A. 2015 b. Investigation of biomass gasification process with torrefaction using equilibrium model. *Energy Procedia* **72**, 329–336.
Luo, S., Zhou, Y. & Yi, C. 2012. Hydrogen-rich gas production from biomass catalytic gasification using hot blast furnace slag as heat carrier and catalyst in moving-bed reactor. *International Journal of Hydrogen Energy* **37**, 15081–15085.
Ly, P., Yuan, Z., Ma, L., Wu, C., Chen, Y. & Zhu, J. 2007. Hydrogen-rich gas production from biomass air and oxygen/steam gasification in a downdraft gasifier. *Renewable Energy* **32**, 2173–2185.
Min, Z., Yimsiri, P., Zhang, S., Wang, Y., Asadullah, M. & Li, C. 2003. Catalytic reforming of tar during gasification. Part III. Effects of feedstock on tar reforming using ilmenite as a catalyst. *Fuel* **103**, 950–955.
Mohammed, M.A.A., Salmiaton, A., Wan Azlina, W.A.K.G., Amran M.S.M. & Fakhru'l-Razi A. 2011. *Energy Conversion and Management* **52**, 1555–1561.
Pellegrini, L. & Oliveira Jr., S. 2007. Exergy analysis of sugarcane bagasse gasification. *Energy* **32**, 314–327.
Sanz, A. & Corella, J. 2006. Modeling circulating fluidized bed biomass gasifiers. Results from a pseudo-rigorous 1-dimensional model for stationary state. *Fuel Processing Technology* **87**, 247–258.

Saravanakumar, A., Hagge, M.J., Haridasan, T.M. & Bryden, K.M. 2011. Numerical modelling of a fixed bed updraft long stick wood gasifier. *Biomass and Energy* **35**, 4248–4260.

Sarker, S. & Nielsen, H.K. 2015. Assessing the gasification potential of five woodchips species by employing a lab-scale fixed-bed downdraft reactor. *Energy Conversion and Management* **103**, 801–813.

Saw, W.L & Pang, S. 2013. Co-gasification of blended lignite and wood pellets in a 100 kW dual fluidised bed steam gasifier: The influence of lignite ratio on producer gas composition and tar content. *Fuel* **112**, 117–124.

Sharma, A.K. 2008. Equilibrium modeling of global reduction reactions for a downdraft (biomass) gasifier. *Energy conversion and management* **49**, 832–842.

Sheth, P.N. & Babu, B.V. 2010. Production of hydrogen energy through biomass (waste wood) gasification. *International Journal of Hydrogen Energy* **35**, 10803–10810.

Sricharoenchaikul, V., Hicks, A.L. & Frederick, W.J. 2001. Carbon and char residue yields from rapid pyrolysis of kraft black liquor. *Bioresource Technology* **77**(8), 131–138.

Striūgas, N., Zakarauskas, K., Džiugys, A. & Navakas, R. 2014. An evaluation of performance of automatically operated multi-fuel downdraft gasifier for energy production. *Applied Thermal Engineering* **73**, 1151–1159.

Agronomy Research **14**(4), 1332–1341, 2016

Speed limits and their impact on emissions production and fuel consumption

M. Kotek, P. Jindra* and J. Mařík

Czech University of Life Science Prague, Faculty of Engineering, Department of Vehicles and Ground Transport, Kamýcká 129, CZ 16521 Prague, Czech republic
*Correspondence: jindrap@tf.czu.cz

Abstract. The article deals with emissions and fuel consumption of road vehicles in real traffic conditions. The aim of this study was to prove or disprove correctness of the decision of Prague city government to change the speed limits from 70 km h^{-1} to 50 km h^{-1} on the parts of one main road leading to/from Prague. For measurements in real traffic conditions was used 2 typical Czech cars Skoda with manual transmission (Fabia 1.2 MPI with petrol engine and Octavia 2.0 TDI with diesel engine). Measurements were performed on both of directions on defined road segment.
At speed 50 km h^{-1} the measurement was repeated 5 times at 3rd and 5 times on 4th gear. Similarly at speed 70 km h^{-1} the measurement was repeated 5 times at the 4th and 5th gear. The aim was to operate the vehicle in the normal engine loads.
The results demonstrate the fundamental assumption that at the higher allowed vehicle speed the engine is more loaded and therefore produces a higher amount of emissions, but according to a higher vehicle speed the emissions are produced on the defined segment for the shorter time. A similar trend is evident even in fuel consumption. The results also indicate the depending on the power reserve of specific vehicle. When the vehicle is more powerful, higher permitted speed is preferable.

Key words: speed limit, emission, fuel consumption, on-road measurement, vehicle.

INTRODUCTION

The increase of road transport (especially the individual transport) is a worldwide problem in the major part of cities. Prague is the capital of the Czech Republic with an area of 496.2 square kilometers and a population of approximately 1.26 millions. The daily traffic volume for year 2014 amounted to 600 thousand vehicles (PTY, 2015).

The increasing traffic intensity brings many negative impacts. The most significant negative impacts of transport include the production of harmful exhaust emissions, noise, vibration, annexation of land for transport infrastructure or traffic accidents (Vojtisek-Lom et al., 2009; Vojtisek-Lom et al., 2015).

Vehicle manufacturers are required to comply with increasingly stringent emission limits for new vehicles, but there is a significant difference between the emissions produced during the homologation and in real traffic. (Vojtisek-Lom et al., 2009; Weiss et al., 2012) Methodology prescribes testing vehicles on a chassis dynamometer under laboratory conditions. The purpose of the chassis dynamometer is mainly reproducibility and comparability of results. According to current methodologies are set limits for the CO, CO_2, HC, NO_X, PM a PN (CD 1999/100/EC).

Another attempt to reduce direct CO_2 emissions is the use of biofuels. They reduce the direct dependence on fossil fuel reserves, increase utilization of agricultural land and support the treatment of bio–waste. Different fuels based on vegetable oils, FAME, fats, HVO and others can be used for diesel engines (Pexa et al., 2015; Vojtisek-Lom et al., 2015). In the case of spark ignition engines are used alcohol fuels on methanol, ethanol or butanol basis (Hromádko et al., 2009; Mařík et al., 2014; Kotek et al., 2015; Sayin & Balki, 2015).

A whole range of other factors are disruptive to vehicle in real traffic, which directly cause the negative effects of vehicles on the environment. Crucial influence has a driver behavior and his driving style, which can lead to fold increase in emissions and fuel consumption during an inefficient aggressive driving (De Vlieger, 1997; T.-Q. Tang et al., 2015). Another influencing factor is the type of road that defines the speed limit, number and arrangement of lanes, crossing with other roads or the occurrence of other road users (cyclists and pedestrians). These impacts can be partially eliminate by the operational management of traffic using intelligence traffic systems (ITS) that can regulate the traffic based on the current traffic situation (Grant-Muller & Usher, 2014).

Often neglected negative impact is traffic noise. It is reported that the noise causes a range of physical and mental diseases. The often solution of this problem is a decrease in a speed limits, the choice of a suitable road surface and structural measures in the form of noise barriers (Foraster et al., 2011).

Named unfavorable noise pollution was the main reason for the design of traffic–engineering solutions on a road that connects the city of Prague and the D1 motorway. After reducing the maximum speed of 70 to 50 km h^{-1} surface treatment road has been a slight reduction in noise pollution (1–2 dB). The aim of this experiment was to evaluate the above traffic measures in terms of emissions and fuel consumption of the representatives of the two most commonly used vehicle (Skoda Octavia 2.0 TDI and the Skoda Fabia 1.2 HTP) on a defined segment in both directions at a constant speed of 50 km h^{-1} and 70 km h^{-1}.

MATERIALS AND METHODS

For the experiment were used two most common vehicles in the Czech Republic. As a representative of a small–volume vehicle with a petrol engine was voted the Skoda Fabia 1.2 HTP and as a medium class car with a turbocharged diesel engine was chosen Škoda Octavia 2.0 TDI. Detailed parameters of both vehicles are shown in Table 1.

For emission measurement was used emission analyzer VMK, specially designed for mobile measurement. It is a 5–components emission analyzer, whose technical data are summarized in Table 2.

During the measurement was recorded vehicle operating data from the engine control unit via the OBD interface (engine speed, load, speed, MAF, IAT, fuel consumption). For communication and record data from the OBD was used car diagnostic system VAG–COM.

Table 1. Technical parameters of measured vehicles

Vehicle	Octavia 2.0 TDI	FABIA 1.2 HTP
	COMBUSTION ENGINE	
Design	compression ignition, turbo charged	spark ignition, atmospheric
Number of cylinders and valves	4, in row, 16 valves	3 in row, 6 valves
Fuel	Diesel	gasoline
Volume of cylinders	1,968 ccm	1,198 ccm
Power	103 kW at 4,000 rpm	40 kW at 4,750 rpm
Torque	320 Nm at 1,750 rpm	106 Nm at 3,000 rpm
EU limit	EU4	EU4
	CAR BODY	
Service weight	1,395 kg	1,055 kg
Total weight	1,995 kg	1,570 kg
	DRIVE PERFORMANCE	
Max. speed	208 km h^{-1}	150 km h^{-1}
Acceleration 0–100 km h^{-1}	9.6 s	18.5 s
Fuel consumption	7.0 / 4.7 / 5.5 (liter per 100 km)	7.8 / 4.8 / 5.9 (liter per 100 km)
Manufacture year	2005	2002
Mileage	45,000 km	80,000 km

Table 2. Technical parameters of mobile emission analyser

Measured values	Measurement range	Resolution	Accuracy
CO	0...10% Vol.	0.001% Vol.	0…0.67%: 0.02% absolute, 0.67%…10%: 3% of measured value
CO_2	0...16% Vol.	0.01% Vol.	0…10%: 0.3% absolute, 10…16%: 3% m.v.
HC	0...20,000 ppm	1 ppm	10 ppm or 5% m.v.
NO_X	0...5,000 ppm	1 ppm	0…1,000 ppm: 25 ppm, 1,000…4,000 ppm: 4% m.v.
O_2	0...22% Vol.	0.1% Vol.	0…3%: 0,1% 3…21%: 3%

The fuel consumption of the car Skoda Fabia was evaluated by a flow meter WF007 fitted to the fuel system of the car. The technical parameters of the flowmeter shown in Table 3.

Table 3. Technical parameters of flow–meter WF007

Parameter	Value
Measuring principle	Oval gear
Sensing principle	Hall Sensor
Flow range	0.005–1.5 l min^{-1}
Pulses output	1,800 pulses l^{-1}
Viscosity	0–2,000 mPas
Accuracy	±0.5%

For check compliance with the prescribed speed and position sensing vehicle was used GPS system DEWETRON VGPS 200C.

General overview of the used measuring devices is illustrated in Fig. 1.

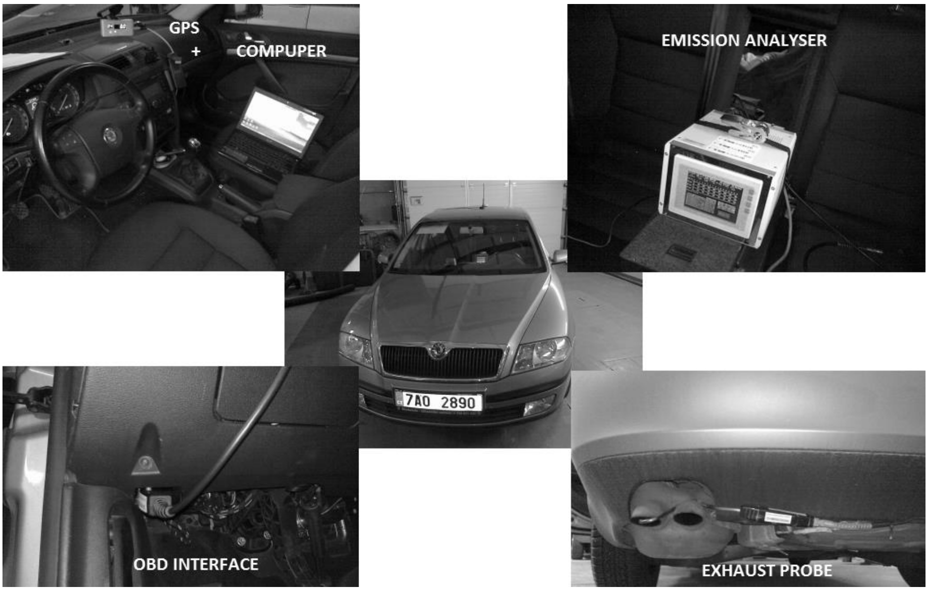


Figure 1. Equipment of measuring vehicle.

The measurement was carried out on the predetermined part of road (see. Fig. 2), which relates to the mentioned speed limits. The road has three traffic lanes in each direction and connects Prague and Brno the second largest city in the Czech Republic.

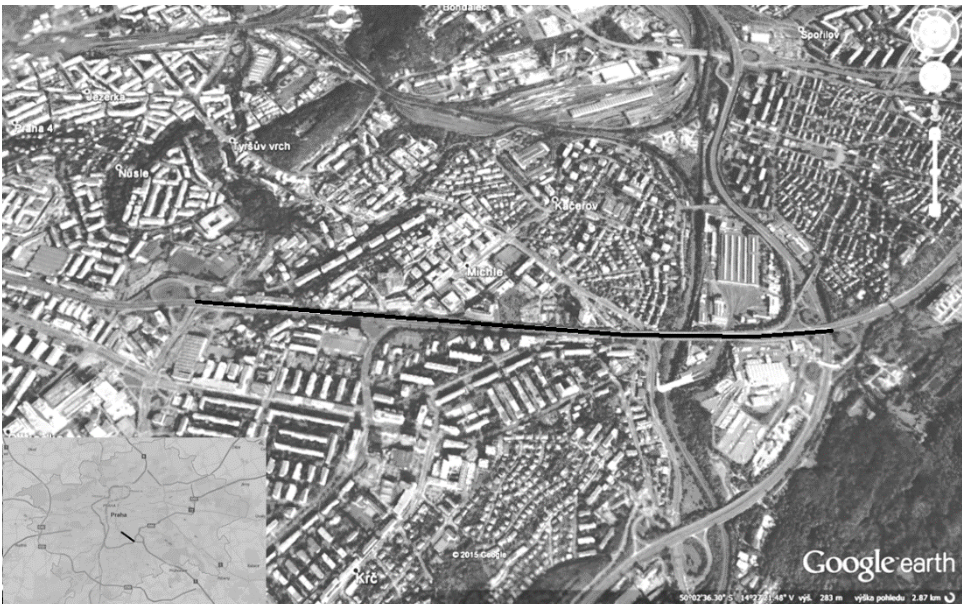


Figure 2. Map of measured track.

Road's horizontal alignment is shown in Fig. 3

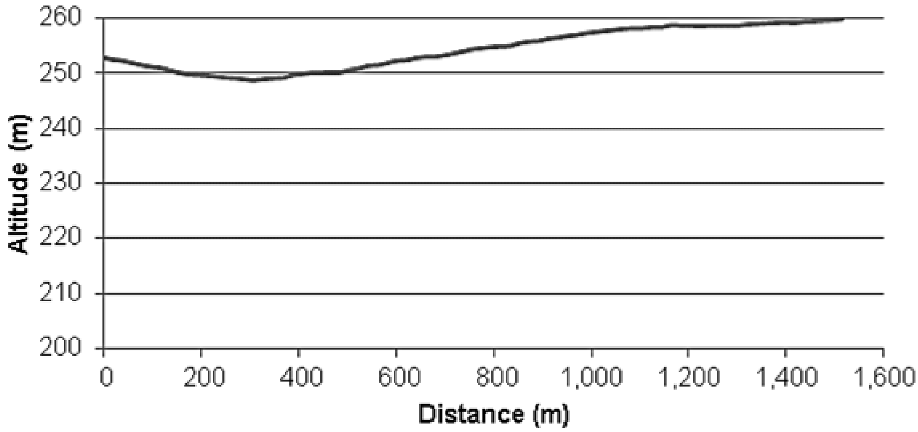


Figure 3. Road's horizontal alignment (direction to the city centre).

There is a direct relation between engine load, engine speed and emissions produced, as is clear from the introduction to this article. Engine load cause overcoming driving resistances. In this case, the driving resistances mainly influenced by a preset vehicle speed, other parameters have remained constant or at most similar. To limit the influence of the engine speed was important to choose the right gear for the specific vehicle speed. Generally, the higher the engine speed, the higher the vehicle will produce emissions. During the experiment was considered a 'reasonable driver behaviour', thus for the mentioned speed limits were selected always 2 different gear grades corresponding to the optimal revolutions range for each engine of the vehicle. For speed of 50 km h^{-1} were chosen gear 3 and 4, for the speed of 70 km h^{-1} were chosen gear 4 and 5. For each speed and direction of travel the measurements were repeated 5 times for each gear grade.

Measurements were performed during the night hours to eliminate the effects of ambient traffic. During the measurement was temperature about 5 °C and constant weather conditions, random wind effect was minimized by repeating the measurement. First was performed all drives at the constant speed of 50 km h^{-1} on 3th gear grade for both direction. Then these drives were repeated on the 4th gear. Next measurement was performed at the constant speed of 70 km h^{-1} on 4th gear grade for both direction and then on 5th gear.

RESULTS AND DISCUSSION

Fig. 4 is an example of instantaneous values of CO, CO_2, NO_x, HC, fuel consumption and engine speed with Skoda Fabia when driving in the direction of the city center at speeds of 50 and 70 km h^{-1}. The figure shows that at a higher speed all monitored values increased. It is further apparent that at higher vehicle speeds the engine is operated at slightly higher revolutions.

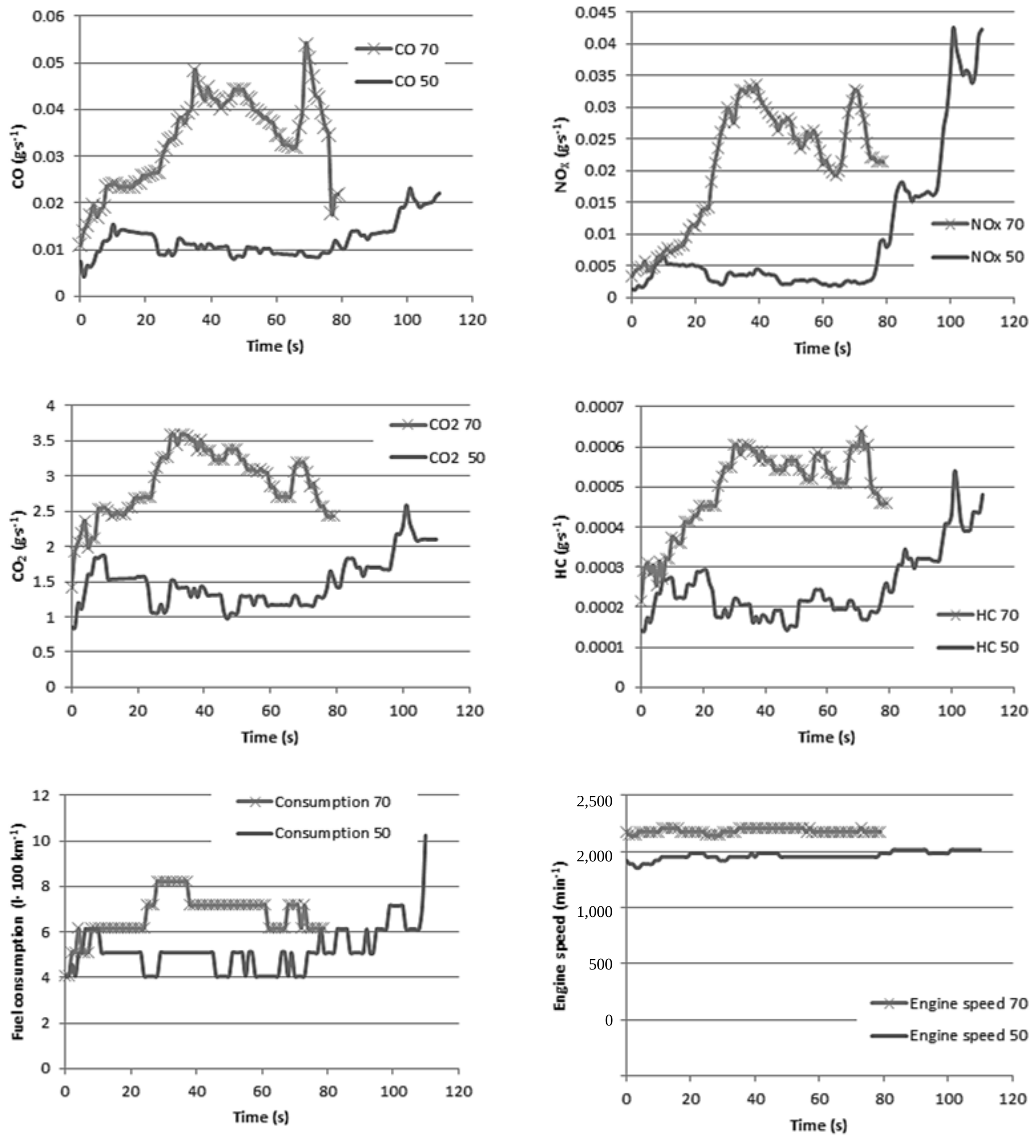


Figure 4. Instantaneous values of emissions, fuel consumption and engine speed with Skoda Fabia, direction from town.

A very similar situation can be seen in Fig. 5 driving Škoda Octavia towards the center at both monitored speeds. There is not shown the concentration of CO, because during operation in both cases was measured zero production. Even here the engine was operated at a slightly higher speed at a speed of 70 km h^{-1}.

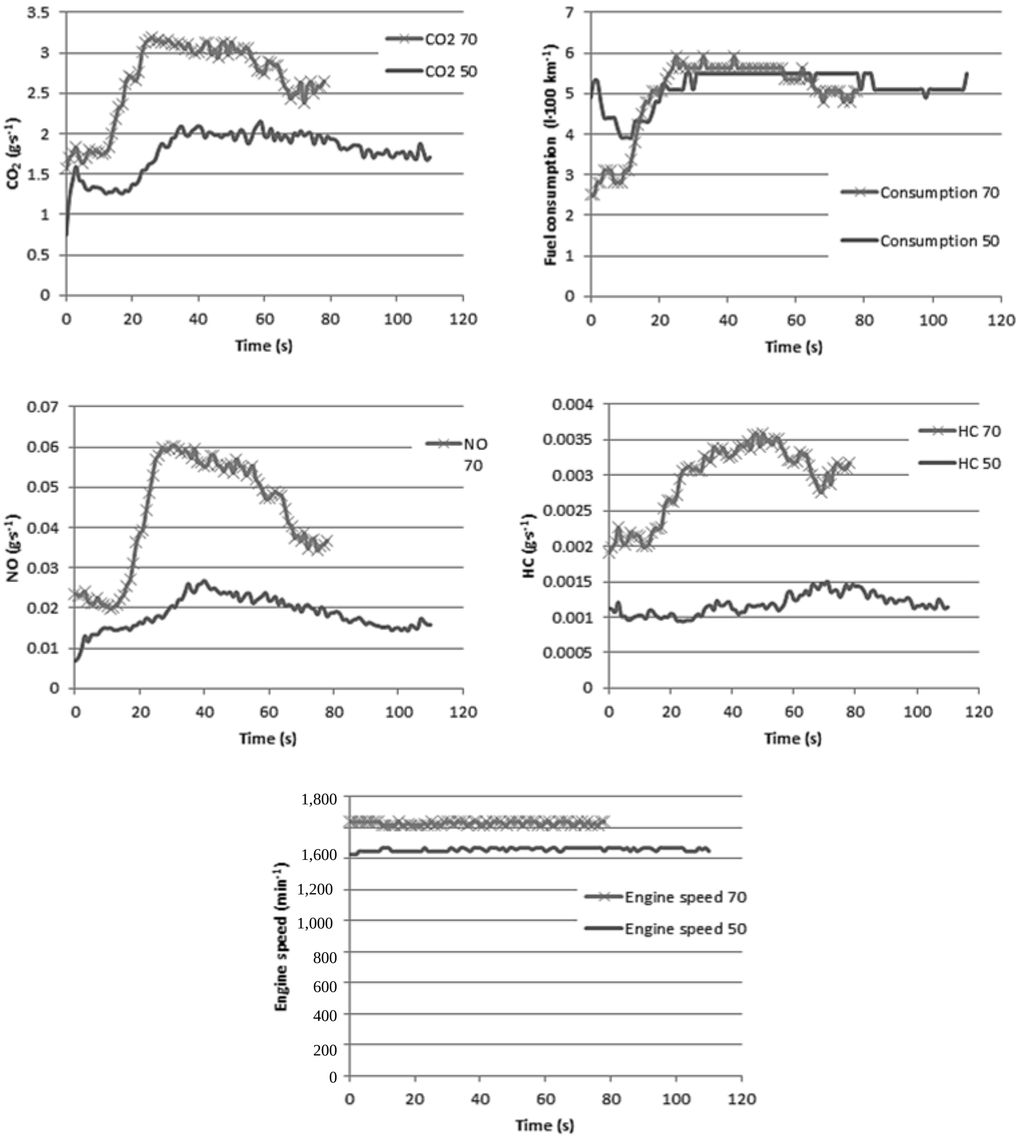


Figure 5. Instantaneous values of emissions, fuel consumption and engine speed with Skoda Octavia, direction to town.

At higher speeds there are always higher instantaneous emissions at higher engine speeds, but for a shorter period, as shown in Figs 4 and 5.

The following Table 4–7 summarizes the average values of the engine operating parameters, the total production of emissions and fuel consumption for each vehicle in both directions. For the more transparency of results data were averaged for both predefined gear grades.

Table 4. Summary results of measured values for Skoda Octavia, direction from centre town

	total time	avg. engine speed	avg. engine load	avg. speed (OBD)	CO	CO_2	NO_X	HC	avg. speed (GPS)	fuel consump-tion
	s	min^{-1}	Nm	$km\ h^{-1}$	g	g	g	g	$km\ h^{-1}$	l
	109	1,739	63	51.3	0.00	183	3.26	0.1900	50.6	0.071
	78	1,850	77	71.4	0.00	181	2.00	0.1857	70.4	0.063
difference	-31	112	13	20.2	0.00	-1	-1.26	-0.0043	19.7	-0.007

Table 5. Summary results of measured values for Skoda Octavia, direction to centre town

	total time	avg. engine speed	avg. engine load	avg. speed (OBD)	CO	CO_2	NO_X	HC	avg. speed (GPS)	fuel consump-tion
	s	min^{-1}	Nm	$km\ h^{-1}$	g	g	g	g	$km\ h^{-1}$	l
	109	1,734	78	51.1	0.00	221	2.52	0.1932	50.4	0.085
	78	1,844	97	71.3	0.00	228	2.90	0.2217	70.1	0.082
difference	-31	110	19	20.1	0.00	7	0.38	0.0285	19.7	-0.003

Table 6. Summary results of measured values for Skoda Fabia, direction from centre town

	total time	avg. engine speed	avg. engine load	avg. speed (OBD)	CO	CO_2	NO_X	HC	avg. speed (GPS)	fuel consump-tion
	s	min^{-1}	%	$km\ h^{-1}$	g	g	g	g	$km\ h^{-1}$	l
	109	2,353	25	49.3	2.11	187	1.57	0.0340	50.8	0.074
	78	2,480	33	69.0	2.48	195	2.38	0.0295	70.7	0.074
difference	-31	127	8	19.6	0.37	8	0.81	-0.0044	19.9	0.000

Table 7. Summary results of measured values for Skoda Fabia, direction to centre town

	total time	avg. engine speed	avg. engine load	avg. speed (OBD)	CO	CO_2	NO_X	HC	avg. speed (GPS)	fuel consump-tion
	s	min^{-1}	%	$km\ h^{-1}$	g	g	g	g	$km\ h^{-1}$	l
	109	2,337	28	49.1	2.22	206.62	1.42	0.0359	50.6	0.082
	78	2,454	39	68.3	2.86	229.14	2.50	0.0346	70.1	0.086
difference	-30	117	11	19.2	0.64	23	1.08	-0.0013	19.5	0.004

Increasing the vehicle speed of both vehicles has resulted in increased engine load, as shown in Table 4–7. A higher engine load was achieved in both cases in the direction of the city center. Yet in the case of Škoda Octavia due to shorter driving time there is a negligible increase in emissions and a decrease in fuel consumption at higher speeds. For Skoda Fabia were worse all mentioned parameters excluding HC emissions.

CONCLUSIONS

Limiting the maximum speed from the perspective of the drivers is very unpopular. On the other hand, it is necessary to carry out such traffic measures that will have a positive impact on the environment.

Reducing the maximum speed in this case had a negligible effect on the noise production. Therefore, measurements were taken other negative impacts of transport on the environment in the form of measuring emissions and fuel consumption of two vehicles on a defined road. Unfortunately, even these results are not substantial argument for maintaining or increasing the maximum permitted speed. Differences in emissions production are too low that more importance will be the driver's behavior and instantaneous traffic situation than adhering to speed limits. It cannot be said that lower speed limit is some major limitations of drivers. Time savings is only 30 seconds, however most drivers are very irritated by this restriction. Perhaps that is why finally maximum speed was increased again to 70 km h^{-1} effect from January 1, 2016.

ACKNOWLEDGEMENTS. Paper was created with the grant support – CZU 2015:31150/1312313109 – Monitoring the impact of transport on the life quality in rural areas

REFERENCES

De Vlieger, I. 1997. On-board emission and fuel consumption measurement campaign on petrol-driven passenger cars. *Atmospheric Environment* **31**, 3753–3761.

COMMISSION DIRECTIVE 1999/100/EC of 15 December 1999 adapting to technicalprogress CouncilDirective 80/1268/EEC relating to the carbon dioxide emissions and the fuelconsumption of motor vehicles

Foraster, M., Deltell, A., Basagaña, X., Medina-Ramón, M., Aguilera, I., Bouso, L., Grau, M., Phuleria, H.C., Rivera, M., Slama, R., Sunyer, J., Targa, J. & Künzli, N. 2011. Local determinants of road traffic noise levels versus determinants of air pollution levels in a Mediterranean city. *Environmental Research* **111**, 177–183.

Grant–Muller, S. & Usher, M. 2014. Intelligent Transport Systems: The propensity for environmental and economic benefits. *Technological Forecasting & Social Change* **82**, 149–166.

Kotek, T., Kotek, M., Jindra, P. & Pexa, M., 2015. Determination of the optimal injection time for adaptation SI engine on E85 fuel using self-designed auxiliary control unit. *Agronomy Research* **13**, 577–583.

Mařík, J., Pexa, M., Kotek, M. & Hönig, V. 2014 Comparison of the effect of gasoline -ethanol E85 - butanol on the performance and emission characteristics of the engine Saab 9–5 2.3 l turbo. *Agronomy Research* **12**, 359–366.

Pexa, M., Čedík, J., Mařík, J., Hönig, V., Horníčková, Š. & Kubín, K. 2015. Comparison of the operating characteristics of the internal combustion engine using rapeseed oil methyl ester and hydrogenated oil. *Agronomy Research* **13**, 613–620.

Prague transportation yearbook [online] [cit. 2016-15-1]. Available at http://www.tsk-praha.cz/wps/portal/root/dopravni-inzenyrstvi/rocenky

Hromádko, J., Hromádko, J., Miler, P., Hönig, V. & Schwarzkopf, M. 2009. Economic analyse of using bioethanol in positive ignition engine. *Listy cukrovar. a řep.* **125**, 101–103 (in Czech).

Sayin, C. & Balki, M.K. 2015. Effect of compression ratio on the emission, performance and combustion characteristics of a gasoline engine fuelled with iso-butanol/gasoline blends. *Energy* **82,** 550–555.

Tang, T.Q., Huang, H.J. & Shang, H.Y. 2015. Influences of the driver's bounded rationality on micro driving behavior, fuel consumption and emissions. *Transportation Research* **Part D 41**, 423–432.

Vojtisek-Lom, M., Pechout, M., Dittrich, L., Beranek, V., Kotek, M., Schwarz, J., Vodicka, P., Milcova, A., Rossnervoa, A., Ambroz, A. & Topinka, J. 2015. Polycyclic aromatic hydrocarbons (PAH) and their genotoxicity in exhaust emissions from a diesel engine during extended low-load operation on diesel and biodiesel fuels. *Atmospheric Environment* **109**, 9–18.

Vojtisek–Lom, M., Fenkl, M., Dufek, M. & Mareš, J. 2009. Off-cycle, real-world emissions of modern light duty diesel vehicles. *SAE International. Technical Papers.* 2009–24–0148.

Weiss, M., Bonnel, P., Kühlwein, J., Provenza, A., Lambrecht, U., Alessandrini, S., Carriero, M., Colombo, R., Forni, F., Lanappe, G., Le Lijour, P., Manfredi, U., Montigny, F. & Sculati, M. 2012. Will Euro 6 reduce the NOx emissions of new diesel cars? – Insights from on-road tests with Portable Emissions Measurement Systems (PEMS), *Atmospheric Environment* **62**, 657–665.

Agronomy Research **14**(4), 1342–1350, 2016

Ventilation and microclimatic conditions in the laboratory of adhesive bonding

A. Krofová[1,*] and P. Kic[2]

[1]Czech University of Life Sciences Prague, Faculty of Engineering, Department Material Science and Manufacturing Technology, Kamýcká 129, CZ 16521 Prague, Czech Republic
[2]Czech University of Life Sciences Prague, Faculty of Engineering, Department of Technological Equipment of Buildings, Kamýcká 129, CZ 16521 Prague, Czech Republic
[*]Correspondence: kofovaa@tf.czu.cz

Abstract. The aim of this paper is to present the results of the research focused on the ventilation and microclimatic conditions in the laboratory of adhesive bonding. This special large underground laboratory is used for the research and teaching purposes during the whole year. The experiments provided in the laboratory require the use of different chemicals, adhesives and glues for the preparation of specimens for the testing various methods of adhesive bonding of metals and wood. There are intensively released chemical pollutants into the indoor environment of the laboratory during those processes. If there are taking place in the lab at the same time the classes with students (maximum 26 persons) there are also produced in that space products of the metabolism. To ensure the hygienic conditions for researchers and students, the laboratory must be adequately ventilated, but it is also necessary to ensure the desired thermal state of the environment. The results of measurements of indoor microclimate in this laboratory during the adhesive bonding processes are also presented in this paper. The experience and new knowledge useful for the future research and practical designs are summarized in the conclusions of this paper.

Key words: chemicals, contamination, dust, temperature.

INTRODUCTION

Adhesive bonding is increasingly used method of dismountable connection of components, parts and elements in various technical fields. New methods and new bonding adhesives under prescribed conditions are tested in the laboratory of adhesive bonding. Chemicals and adhesives containing various chemical components are used for these activities. This creates a very intensive pollution which must be removed. Indoor environmental quality should be kept within the prescribed limits, which are especially air temperature and humidity, concentration of chemical pollutants and dust. Critical period in terms of quality of the indoor environment is winter, because the ventilation is usually minimized (reduction of indoor-air cooling) (Kic et al., 2007; Zajicek & Kic, 2014).

There is no doubt about the harmful effects of the environment on the adhesive bond (Court et al., 2001). The main problem is to define the process and intensity of the changes in mechanical properties (Cidlina et al, 2014).

Adhesive bonds are very often applied in various climatic conditions and environments (Müller & Valášek, 2012; Müller, 2014). Each environment is of specific properties which basically influence entire strength and reliability of an adhesive bond (Müller, 2013; Müller, 2014).

During the transit or the storing the adhesives can meet much higher or lower temperatures than it is recommended by a producer (a sun radiation, a sun radiation through a glass, a transit in a car, a storing in an unheated stock etc.) (Müller, 2014; Müller & Valášek, 2014).

The results of performed experiments proved the essential influence of the storing management in the area of the adhesive bonding technology. The results suggest a necessity to keep the technologic discipline in the area of the storing temperature guaranteed by a producer.

From the results it is obvious that the packing type is essential for a transfer of surroundings temperature into the adhesive. From measurements performed by the contactless infra-thermometer Testo 845 it is evident that there is a huge difference among the surroundings temperature, the temperature of the adhesive and the temperature of mixed adhesive. Optimum storing temperatures were determined in the interval 15 to 30 °C (Müller, 2014).

The results of performed experiments proved the essential influence of the storing management (logistic) in the area of the adhesive bonding technology. The results suggest a necessity to keep the technologic discipline in the area of the storing temperature guaranteed by a producer (Müller & Valášek, 2014).

The adhesive A3T30 can be recommended in cases where the constant temperature (the laboratory one, 22 °C) is not secured owing to the practical application in the logistics area that means transit, storing etc. The adhesive LN7256 is suitable to use till maximum temperature 60 °C. Negative storing values not exceeding tested–20 °C do not decrease utility properties.

Investigated laboratory is used as a research and teaching purposes, therefore sanitary conditions for students and staff must be respected. The requirements of health and safety at work are summarized in Decree no. 361/2007 Coll., (Act No. 262/2006 Coll.). The rules work in the lab ranked according to the total average energy expenditure $M \leq 80$ W m^{-2}, class work I, therefore, the air temperature should be in winter 22 ± 1.5 °C if the expected thermal resistance of a clothing is 1.0 clo, and relative humidity of air from 30 to 70%. Natural ventilation is insufficient in this type of laboratory and therefore must be applied a mechanical ventilation to ensure a year-round health of workers. The fresh air must be filtered and heated in winter.

Chemicals used in the laboratory are: industrial solvent perchlorethylene (tetrachloetylen), acetone, adhesives GLUEPOX rapid F (2-piperazin-1ylethyamin, benzyl alcohol, bisphenol A) contains benzyl alcohol), CHS-EPOXY 324 (contains bisphenol A), ethanol, toluene, and hardener P 11 (diethylene). Exposure limit values for these substances are listed in Table 1.

Table 1. Chemical agents registered in Chemical Abstracts Services (CAS), Occupational Exposure Limits (OEL) and Maximum Exposure Limits (MEL)

Agent	CAS	OEL, mg m^{-3}	MEL, mg m^{-3}
Acetone	67-64-1	800	1,500
Benzyl alcohol	100-51-6	40	80
Bisphenol A	80-05-7	2	5
Diethylene triamin	111-40-0	4	8
Ethanol	64-17-5	1,000	3,000
Tetrachlor ethylene	127-18-4	250	750
Toluene	108-88-3	200	500

Dust that is release into the surrounding air during the preparation of samples corresponds to the material used for the adhesive bonding. Most often it is a metal, plastic or wood. According to the type of material, dust has specific characteristics to which respond the properties. According to the (Act No. 262/2006 Coll.), there can be dust with nonspecific effects (metals) or irritating effects (plastics and wood). For these types of dust there are prescribed OEL permissible exposure limits of total concentration. Occupational exposure limits are listed in the Table 2.

Table 2. Dust and Occupational Exposure Limits (OEL)

Dust	OEL, mg m^{-3}
Iron and iron alloys	10.0
Aluminum and its oxides	10.0
Wood (common species)	5.0
Phenol-formaldehyde resin	5.0
PVC	5.0
Polyethylene	5.0
Polypropylene	5.0
Polymeric materials	5.0
Polystyrene	5.0
Glass laminates	5.0

Referred Exposure Limits OEL and MEL valid for the Czech Republic may be in some cases slightly different (usually higher) from exposure limits valid in the EU or in other countries, however, the principles and solution of this research these small differences do not affect.

MATERIALS AND METHODS

This research work was carried out in the laboratory of the Faculty of Engineering at the Czech University of Life Sciences Prague. The laboratory consists from three connected rooms are situated in the first basement floor. The first room is storage, the main and biggest room is used mainly for the teaching and the third one is used for the experimental work, mainly for adhesive bonding. The rooms have the following dimensions: total volume of room is O = 357 m^3 and inside maximum can be 26 persons. The ground plan of the laboratory is presented on the Fig. 1.

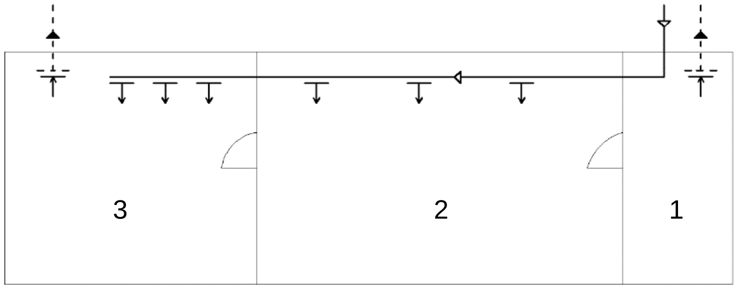


Figure 1. Ground plan of the laboratory, where: 1–storage, 2–teaching area, 3–experimental area.

Air temperatures were measured by thermocouples NiCr-Ni type K installed in the ventilation system (the air flow through the whole system: in the inlet, in different parts of heat recuperation systems, in the outlet etc.). Furthermore, there was measured by data loggers ZTH65 temperature and humidity with registration during the experiments. Parameters of ZTH65 are: temperature operative range -30–80 °C with accuracy ± 0.4 °C and operative range of relative humidity 5–95% with accuracy ± 2.5%.

The thermal comfort in the space was continuously measured by globe temperature (measured by globe thermometer FPA 805 GTS with operative range from -50 to +200 °C with accuracy ± 0.1 K and diameter of 0.15 m) together with temperature and humidity of surrounding air measured by sensor FH A646–21 including temperature sensor NTC type N with operative range from -30 to +100 °C with accuracy ± 0.1 K, and air humidity by capacitive sensor with operative range from 5 to 98% with accuracy ± 2%. All data were measured continuously and stored at intervals of one minute to measuring instrument ALMEMO 2590–9 during the measurement.

The concentration of CO_2 was measured by the sensor FY A600 with operative range 0–0.5% and accuracy ± 0.01%.

The total concentration of air dust was measured by special exact instrument Dust-Track aerosol monitor. After the installation of different impactors the PM_{10}, PM_4, $PM_{2.5}$, PM_1 size fractions of dust were also measured. Measured dust inside the offices is not aggressive, it has properties as house dust, therefore, as a criterion for evaluation of the measured values was selected the limit level of outdoor dust, which is 0.050 mg m^{-3} (50 μg m^{-3}).

RESULTS AND DISCUSSION

Chemical agents or aerosol including dust should be captured and exhausted according to the technical possibilities at the source (Act No. 262/2006 Coll.). This is not possible in this laboratory due to the extent of work and technological activities. Therefore, it must be overall ventilation of the whole room space. There can be used different method for the air flow determination. The first methods are based on the knowledge of quantity of mass flow of the pollutants which are leaking into the ventilated space. The other methods are based on the empirical knowledge and information from standards (prescribed ventilation rates of fresh air per one person or prescribed air exchange of the volume of the room) (Chysky et al., 1993). These methods were used for calculation of the ventilation rate. The real airflows in inlets and outlets were measured as well.

Calculations of the air flow

Assuming steady conditions with a uniform distribution of pollutants in space the required volume air flow for ventilation V_c according to the equation (1).

$$V_c = \frac{M_p}{c_i - c_e} \tag{1}$$

where: V_c – required volume air flow for ventilation, $m^3\ h^{-1}$; M_p – mass flow of produced pollutant, uniformly leaking into the space, $kg\ h^{-1}$; c_e – concentration of pollutant in inlet air, $kg\ m^{-3}$, (usually is $c_e = 0$); c_i – concentration of pollutant in outlet air, $kg\ m^{-3}$, (usually is OEL or MEL).

Due to the fact that the manufacturers do not provide the data on the release of harmful substances into the atmosphere, the mass flow values of produced pollutant M_p of several most important pollutants were measured experimentally in the laboratory. Determined productions M_p of harmful substances presented in the Table 3.

Table 3. Mass flow of produced pollutants

Agent	M_p, mg h^{-1}
Acetone	2,499.2
Toluene	1,005.6

According to (Act No. 262/2006 Coll.) must be 50 $m^3\ h^{-1}$ minimum amount of air entering the workplace for an employee performing a work classified to Class I. In extra load space by odours the minimum amount of air has to be increased. The total amount of the outdoor air flow for ventilation V_{min} supply is determined from the highest number of people simultaneously using the ventilated space and from the ventilation rates of fresh air per one person according to the equation (2).

$$V_{min} = n_1 \cdot d \tag{2}$$

where: V_{min} – minimal capacity of air flow for ventilation, $m^3\ h^{-1}$; n_1 – number of persons in the room, units; d – ventilation rate of fresh inlet air, $m^3\ h^{-1}\ unit^{-1}$.

The air flow calculated according to the prescribed air exchange V_I supply is determined from the prescribed air exchange I of the ventilated room with the volume O according to the equation (3). The results of airflow calculated according to all described methods are summarized in the Table 3. It is obvious that the results of airflow calculation based on the mass flow of produced pollutants inside the rooms are very small in comparison with the results of calculation according to the empirical methods. Therefore the suitable ventilation rate can be determined according the biggest calculated value from the Table 3 which is V_I is 1,607 $m^3\ h^{-1}$.

Calculation of air flow according to the prescribed air exchange V_I:

$$V_I = I \cdot O \tag{3}$$

where: V_I – air flow according to the prescribed air exchange, $m^3\ h^{-1}$; I – prescribed air exchange of the room, h^{-1}; O – volume of ventilated room, m^3.

Table 4. Calculated values of air flows

-	$V_{cAcetone}$, m^3 h^{-1}	$V_{cToluene}$, m^3 h^{-1}	V_{min}, m^3 h^{-1}	V_I, m^3 h^{-1}
According equation	1	1	2	3
Airflow rate	3.12	5.03	1,300.00	1,607.41

The real airflow ventilation rates supplied to and discharged from the ventilated laboratory are the same. During the normal conditions when the pollution inside the room is not so intensive can be used I level of ventilation, approximately 720 m^3 h^{-1}. The ventilation rate 1,440 m^3 h^{-1} (II level) is used if the pollution of air inside the laboratory is maximal, during intensive research work and teaching activity.

Results of measurements

The results of measurement of main microclimatic parameters in the laboratory are presented in the Table 5. The air temperature should be in winter 22 ± 1.5 °C for the normal working conditions, and relative humidity of air from 30 to 70%. The readings of temperature and humidity during the ventilation at I and II levels are within the specified values and meet the requirements of relevant standards and regulations. The globe temperature is higher than the average air temperature which is caused by the radiation form the surrounding walls and mainly the ceiling which contents the heating pipelines of central heating systems. The positive influence of ventilation on the concentration of noxious gases is obvious from the decrease of CO_2 concentration in the Table 5 and Fig. 2.

Table 5. Average values and standard deviation of air external temperature t_e, external relative humidity RH_e, and temperature t_i, globe temperature t_g, relative humidity RH_i and CO_2 in the laboratory during the different levels of ventilation, without ventilation (0 level), standard ventilation (I level) maximal ventilation (II level)

Ventilation	t_e	RH_e	t_i	t_g	RH_i	CO_2
-	°C ± SD	% ± SD	°C ± SD	°C ± SD	% ± SD	% ± SD
0	2.06 ± 1.03	70.44 ± 3.95	20.93 ± 0.03	21.34 ± 0.02	34.18 ± 0.41	0.053 ± 0.003
I level	3.73 ± 0.62	63.30 ± 3.20	20.83 ± 0.14	21.15 ± 0.08	29.68 ± 1.44	0.038 ± 0.006
II level	5.36 ± 0.79	57.03 ± 2.38	21.28 ± 0.06	21.46 ± 0.09	26.60 ± 0.59	0.033 ± 0.000

SD –Standard deviation

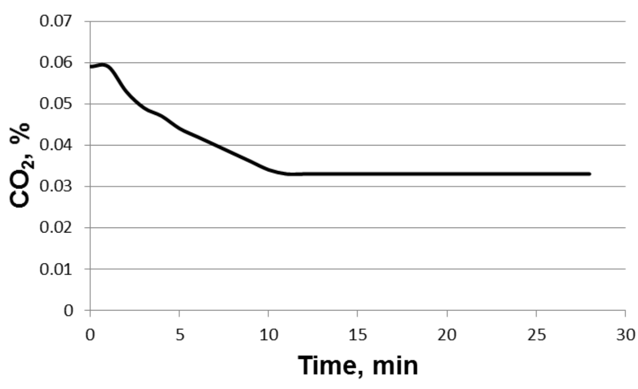


Figure 2. The course of CO_2 concentration in the laboratory with level I of ventilation capacity.

The resulting concentration 0.033% CO_2 corresponds according to our measurement to the concentration of CO_2 in outdoor air. By further or more intensive ventilation therefore cannot be achieved lower concentration of CO_2.

The dust concentration in the laboratory was very high. Principal results of dust measurement are summarized and presented in the Figs 3–5. The Fig. 3 presents results of measurement inside the laboratory without ventilation. The average concentration of total dust pollution was very high, nearly 0.2 mg m^{-3}. Prescribed occupational exposure limits OEL of total concentration for all types of dust according to the Table 2 were not exceeded, but if there is compared as a criterion for evaluation of the measured values the limit level of outdoor dust, the concentration of all fractions was higher than the limit level 0.050 mg m^{-3} (50 µg m^{-3}). The main part of dust particles were small fractions. About 81% of dust was size fraction PM_1 which can penetrate into the alveoli and cause health problems.

Increased ventilation on level I and later on level II reduced strongly the dust concentration (Figs 4 and 5), but the limit level 0.050 mg m^{-3} was exceeded in total concentration of dust and also of all fractions in both cases of ventilation levels.

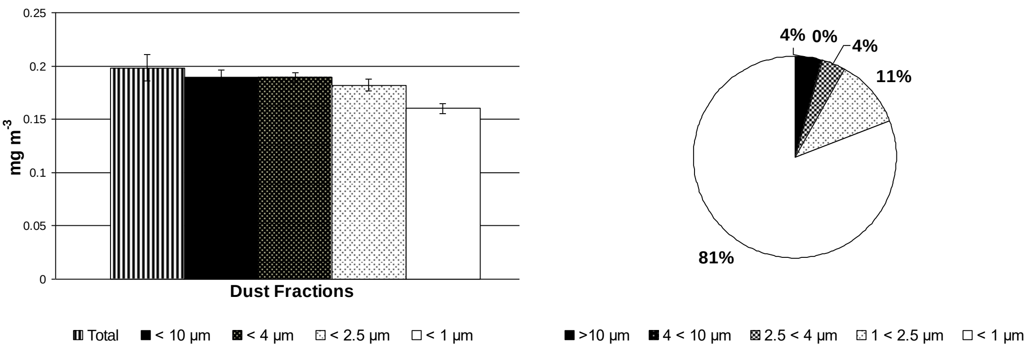


Figure 3. Concentrations and percentage of dust fractions inside the laboratory without ventilation.

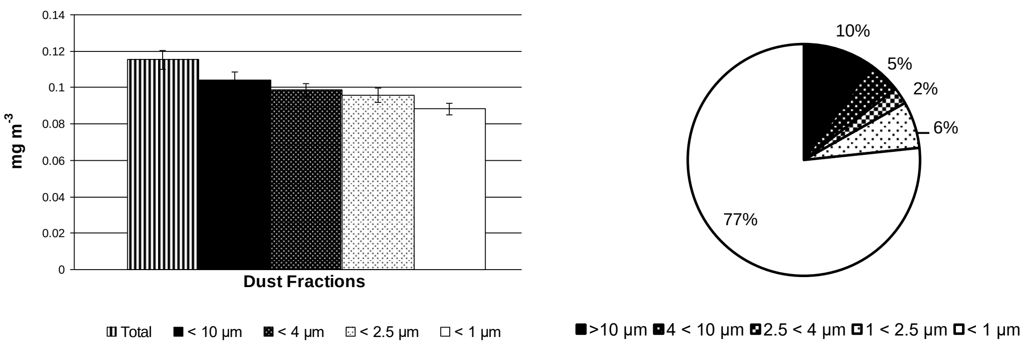


Figure 4. Concentrations and percentage of dust fractions inside the laboratory with ventilation level I.

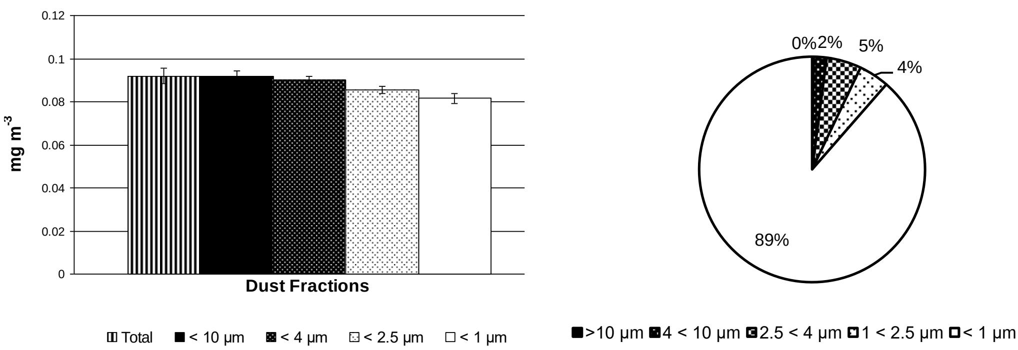


Figure 5. Concentrations and percentage of dust fractions inside the laboratory with ventilation level II.

The dust concentration decreased in all size of dust particles. Due to different particle dimensions and therefore different aerodynamic properties, more intensive ventilation with higher velocity of air streams the percentage of each size particles has been changed in the measured total dust concentrations. A higher percentage of the smallest particles PM_1 results from their greater dispersion in the space, but the total concentration PM_1 during more intensive ventilation is also smaller.

CONCLUSIONS

The results of calculations of ventilation parameters and measurements in the laboratory showed that:

- the capacity of ventilation can be determined according to the prescribed ventilation rate per one persons and number of students or workers inside;
- the function of ventilation improve the inside microclimate from the point of view concentration of CO_2 and dust pollution;
- the biggest percentage of dust particles in this type of laboratory are small size particles PM_1;
- thermal state of indoor microclimate is positively influenced by the thermal radiation from the surrounding walls.

ACKNOWLEDGEMENTS. Supported by Internal grant agency of Faculty of Engineering, Czech University of Life Sciences in Prague no: 2015:31170/1312/3114 and no: 2015:31140/1312/3106

REFERENCES

Act No. 262/2006 Coll. Government Regulation No. 361/2007 Coll. Laying down the conditions for the protection of health at work. Changes: 9/2013 Coll. 48 pp. (in Czech).

Cidlina, J., Müller, M. & Valášek, P. 2014. Evaluation of Adhesive Bond Strength Depending on Degradation Type and Time. *Manufacturing Technology* **14**(1), 8–12.

Court, R., Sutcliffe, M. & Tavakoli, S. 2001. Ageing of adhesively bonded joints–fracture and failure analysis using video imaging techniques. *International Journal of Adhesion & Adhesives* **21(**6), 455–463.

Chysky, J. Drkal, F., Hemzal, K., Kubíček, L. & Nový, R 1993. *Ventilation and Air Conditioning*. BOLIT, Brno, 560 pp. (in Czech).

Kic, P., Kalvoda, T. & Zavadil, V. 2007. Energy savings by heat recovery in ventilation. *Conference Proceedings–3rd International Conference on Trends in Agricultural Engineering.* CULS, Prague, 215–218.

Müller, M. 2014. Influence of adhesives storing temperature on adhesive bond strength. *Manufacturing Technology* **14**(1), 71–75.

Müller, M. 2013. Research of liquid contaminants influence on adhesive bond strength applied in agricultural machine construction, *Agronomy Research* **11(**1), 147–154.

Müller, M. & Valášek, P. 2012. Degradation medium of agrokomplex–adhesive bonded joints interaction. *Research in Agricultural Engineering* **58(**3), 83–91.

Müller, M. & Valášek, P. 2014. The logistics aspects influencing the resultant strength of adhesives at practical application. *Agronomy Research* **12**(1), 285–290.

Zajicek, M. & Kic, P. 2014. Heating of large agricultural and industrial buildings. *Agronomy Research* **12**(1), 237–244.

Agronomy Research **14**(4), 1351–1360, 2016

Detection and characterization of wear particles of universal tractor oil using a particles size analyzer

M. Kučera[1*], Z. Aleš[2] and M. Pexa[2]

[1]Technical University in Zvolen, Faculty of Faculty of Environmental and Manufacturing Technology, Department of Mechanics, Mechanical Engineering and Desing, Študentská 26, SK 96053, Zvolen, Slovak Republic
[2]Czech University of Life Sciences, Faculty of Engineering, Department of Quality and Dependability of Machines, Kamycka 129, CZ 16521, Praque 6, Czech Republic
[*]Correspondence: marian.kucera@tuzvo.sk

Abstract. Oil contamination is the most common and serious source of machine failure. Therefore, lubrication oil testing and analysis is one of the most important condition monitoring (CM) techniques for machinery maintenance and failure diagnosis. Oil analysis consists of determination of physical-chemical properties, contamination and wear debris analysis (WDA). One of the modern methods how to detect wear particles is LaserNet Fines (LNF). The technology is an extension of effective laboratory microscope analysis and was developed specifically to address the shortfalls of monitors that measure only particle size or elemental concentration. Universal tractor oil (UTTO) is the multipurpose oil for the lubrication of the transmission, rear axle, differential, wet brakes, and hydraulic system fed by the common oil reservoir.
The aim of this work is detection and characterization of friction particles during lifetime of two different universal tractor transmission oils samples with using of laser particle counter LaserNet Fines-C and their comparing, synthetic ester-based UTTO oil and mineral-based UTTO oil.

Key words: contaminants in oil, counting particles, image analysis, oil condition monitoring.

INTRODUCTION

Condition monitoring and maintenance are two essential components of the modern industry (Perić et al., 2013; Vališ et al., 2015). The purpose of condition monitoring is to detect faults occurring in machinery maintenance; on the other hand, is defined to maintain and extend, the lifetime of machinery. With regard to monitoring methods, oil analysis has been considered as an and effective approach because of its capability to reveal the wearing condition of the machinery through the analysis of oil properties and wearing particles (Raadnui, 2005; Yuan et al., 2005; Gonçalves et al., 2010; Kumar et al., 2013). Tribotechnical diagnostics examines wear products and lubricants used by the objectification of the technical state of the monitored object and evaluation of quality lubricants.

Wear is one of the major factors that contribute to the creation of failures and with this is connected generation of wear particles. Wear particles come into in lubrication system, where they cause contamination and degradation of lubricating properties and consequently it may result in major failure of machines (Kučera et al., 2013; Hönig, 2015). Wear particles analysis, based on particle size, shape and surface texture examination, have an important role in the diagnosis of machine wear. The size, shape and surface texture of wear particles are affected by the variations in machine running conditions. With increasing wear increases as their size and shape (Mihalčová & Hekmat, 2008; Henneberg et al., 2015). Important information about wear modes, wear mechanisms and wear severity can be obtained from the analysis of particle morphology and operating costs can be greatly reduced if the onset of machine failure can be predicted (Stachowiak et al., 2008; Leemet et al., 2014; Novák et al., 2014).

Tractors usually work in highly specific conditions including extremely high or low temperatures, in differnt position and slopes, under the influence of thick dust and exposed to different chemical agents and often work many hours under full load. Universal tractor transmission oils (UTTO) are designed for hydraulic and transmission systems of agricultural and forestry tractors. The main functions of the UTTO oils are: lubrication of gearbox, rear axle and gears; power transfer and hydraulic system lubrication; providing adequate cooling and friction wet brakes.

It is estimated that, at present, approximately 60% of all lubricants end up in soil and water (Majdan et al., 2014; Pexa et al., 2015). More than 95% of these materials are mineral oil based compounds, which have become prominent ever since the discovery of petroleum as they have superior quality at an affordable price. In view of their high ecotoxicity and low biodegradability mineral oil-based lubricants constitute a considerable threat to the environment (Kučera & Rousek, 2008; Tkáč et al., 2014). Possibilities of improving the condition of the environment and decreasing the level of its pollution by fillings of gearboxes and hydraulic circuits of agricultural and forest machinery replacing mineral oils by biodegradable oils. The impact of these fluids to different parts of the gear and hydraulic circuit of the machinery has not been fully clear yet. Therefore, it is necessary to perform more laboratory and field testing (Kosiba et al., 2013; Kumbár & Dostál, 2013; Máchal et al., 2013; Majdan et al., 2013; Valach et al., 2013; Veselá et al., 2014; Zhu et al., 2015). This paper describes the use automatic particle counter and classifier LNF-C for determination of friction particles of tested transmission oils.

This device is not only used for classification of particles the oil, but also for the direct analysis of wear and contamination according to the standardized code purity.

MATERIALS AND METHODS

For the purpose of the operational experiments were used two samples of oils, biodegradable fully synthetic transmission oil EP Gear Synth 150 – Panolin and mineral-based transmission oil Gyrogate CLP 150. A detailed description of the samples of operating oils is shown in Table 1. Transmission oil EP Gear Synth 150 is fully synthetic, biodegradable high-performance oil for industrial gear boxes, roller bearings and slide bearings. Oil contains additives against oxidation, corrosion and wear. It has excellent high pressure properties and excellent oxidation stability at high temperatures. Due to its outstanding anti-wear properties, reduces micro-wear of surface roughness on friction surfaces in aggregates. In case of any leakage fully decomposed by soil or water micro-organisms, without affecting the environment and practically free of deposits (methods OECD 201 to 203). Biodegradability according to OECD 301 B and OECD 306 is more than 60%. Transmission oil Gyrogate CLP 150 is primarily recommended for lubricating enclosed gear units working under severe shock operating conditions as well as constructing and farming machineries working under high pressure at high speed and low torque. This oil is formulated from carefully selected base stocks sulphur/phosphorous extreme pressure (EP) additives.

Table 1. Description of samples of tested oils

Oil code	Type of oil	Performance class	Viscosity mm^2 s^{-1} v 40 °C	Viscosity mm^2 s^{-1} v 40 °C	Viscosity Index	FZG Load Stage
SE	Universal (tractor oil)	GL-4	150	18.8	142	12
MO	Universal (tractor oil)	GL-4	135–165	13.6	> 95	12

Rear gearboxs of wheel tractor Zetor 12145 were used for experiment (Fig. 1). Mineral transmission oil was filled to the left hand side end rear gearbox, biodegradable transmission oil was filled to the right hand side end rear gearbox.

There are several methods how to assess the technical condition of lubricating oil. LaserNet Fines-C (LNF-C) was used for the carried out long-term stability test of biodegradable transmission oil and mineral transmission oil used in tractor end rear gear boxes dependent on operating time (the test period 450 days). LNF-C is an automated optical oil debris device, which combines the functions of a highly accurate particle counter as well as a particle shape classifier. The basic operating principle of the LNF-C is illustrated in Fig. 2.

Figure 1. Tooth gear of end gear box (Aleš, 2009).

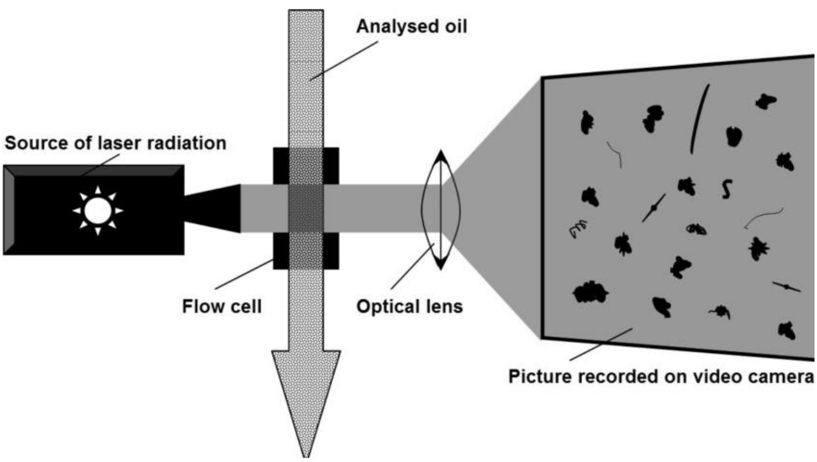
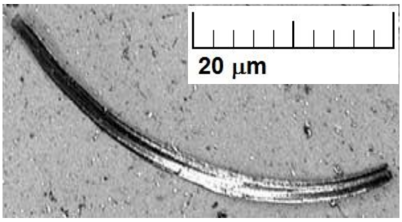
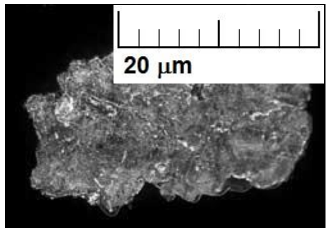


Figure 2. The basic principle of the measuring device LNF-C.

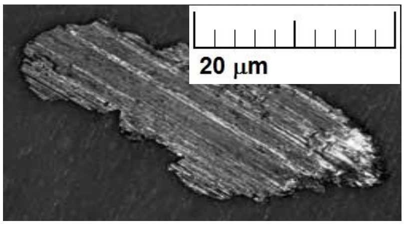
A representative oil sample is taken from the lubricating system and brought to the instrument. The oil is drawn through a patented viewing cell that is back-illuminated with a pulsed laser diode to freeze the particle motion. The coherent light is transmitted through the fluid and imaged onto a digital CCD camera. Each resulting image is analyzed for particles, with several thousand images ultimately used to determine the characteristics of the suspended particles and to obtain good counting statistics. Concentrations are measured for particle sizes between 4 μm to over 100 μm. These images are analyzed using Neural Network Artificial Intelligence and machine learning to automatically classify particles larger than 20 μm into categories such as: fatigue wear, sliding wear, cutting wear and non-metallic particles (sand and dirt), Fig. 3. The whole process of analysis takes about three minutes and the results of the analysis are displayed to the operator of the analyzer after the evaluation of the oil sample.



Cutting wear particle



Fatigue wear particle



Severe sliding wear particle

Figure 3. Classifications of Wear Debris Particles.

Particles are sized directly and results can be displayed by ISO Code (> 4 μm, > 6 μm, and > 14 μm), or other codes such as the NAS Code (5–15 μm, 15–25 μm, 25–50 μm, 50–100 μm and > 100 μm). The direct imaging capability of this instrument eliminates the need for calibration with a test dust. Air bubbles greater than 20 μm are ignored and the laser is powerful enough to process heavily sooted (black) oils.

Measurement results from the laser particle counter are quite complex and therefore it is important to select only those data that suitable describes particles resulting from wear. The most widespread approach of measuring the number of particles is a standardized method of measuring the cleanliness code according to ISO 4406:1999.

Methodology of taking oil samples was according to standard procedures, immediately after stopping the tractor. Oil sampling were carried out at irregular intervals, because it was an operational test and there was taken into consideration the needs of the operation of the tractor.

Seven oil samples (Gyrogate CLP 150, EP Gear Synth 150) were taken from the end gear boxes of wheel tractor during the long-term experiment (450 days).

RESULTS AND DISCUSSION

According to the results mineral transmission oil contained twice more particles in comparison with biodegradable transmission oil. The total amount of 1,026,851 particles was detected in one *ml* of transmission oil Gyrogate CLP 150 after the first sampling. In the seventh sample was detected in 1 *ml* of oil 4,754,078 particles, what from the first sampling represents an increase in the number of particles by 463%. In case of transmission biodegradable oil EP Gear Synth 150, the total amount of 1,508,561 particles was detected in 1 ml after the first sampling, in the seventh sample was already in one *ml* of 3,336,710 particles, what from the first sampling represents an increase in the number of particles by 221% (Fig. 4). The most frequent particles and their mean and maximum sizes are listed in Tables 2–5. The increase and large number of fatigue particles is of particular concern. The LNF-C image map of particle silhouettes was electronically filtered to show only fatigue particles. Selection of detected particles is shown in Figs 5, 6.

Table 2. The most frequent particles present in used mineral transmision oil (sample 1)

	Number of particles (ml^{-1})	Size of particles – Std.Dev. (μm)	Size of particles – Mean (μm)	Size of particles – Max (μm)
Cutting	2,053,5	16.1	31.2	153.9
Severe sliding	6,379,6	12.0	29.3	156.8
Fatigue	13,606,7	12.5	29.4	189.2
Non-metallic	9,150,3	10.1	27.7	145.9
Unclassified	608,6	30.3	42.2	257.3
Fibers	397			

Table 3. The most frequent particles present in used mineral transmission oil (sample 7)

	Number of particles (ml^{-1})	Size of particles – Std.Dev. (μm)	Size of particles – Mean (μm)	Size of particles – Max (μm)
Cutting	1,492,7	7.5	25.3	129.4
Severe sliding	6,708,9	6.0	25.0	76.5
Fatigue	17,800,1	7.2	25.7	122.0
Non-metallic	8,489,9	5.1	23.9	85.7
Unclassified	669,7	12.2	28.1	91.0
Fibers	205			

Table 4. The most frequent particles present in used biodegradable transmission oil (sample 1)

	Number of particles (ml^{-1})	Size of particles – Std.Dev. (μm)	Size of particles – Mean (μm)	Size of particles – Max (μm)
Cutting	4,340,4	15.6	28.9	356.8
Severe sliding	6,585,7	12.2	28.7	160.0
Fatigue	5,895,6	13.9	28.9	193.8
Non-metallic	19,625,5	11.1	29.3	145.6
Unclassified	733,6	26.7	35.4	200.3
Fibers	904			

Table 5. The most frequent particles present in used biodegradable transmission oil (sample 7)

	Number of particles (ml^{-1})	Size of particles – Std.Dev. (μm)	Size of particles – Mean (μm)	Size of particles – Max (μm)
Cutting	1,492,1	7.7	26.6	86.2
Severe sliding	6,255,5	8.1	26.2	138.6
Fatigue	25,910,0	8.2	26.7	190.5
Non-metallic	10,614,9	6.0	24.4	101.5
Unclassified	736,4	14.3	29.9	115.6
Fibers	123			

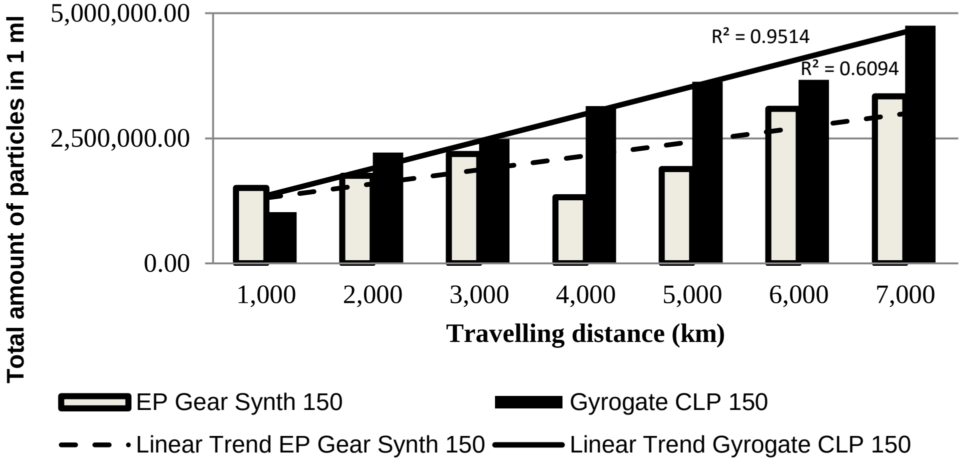


Figure 4. The course of the total amount of particles: 1 – mineral transmission oil, 2 – biodegradable transmission oil.

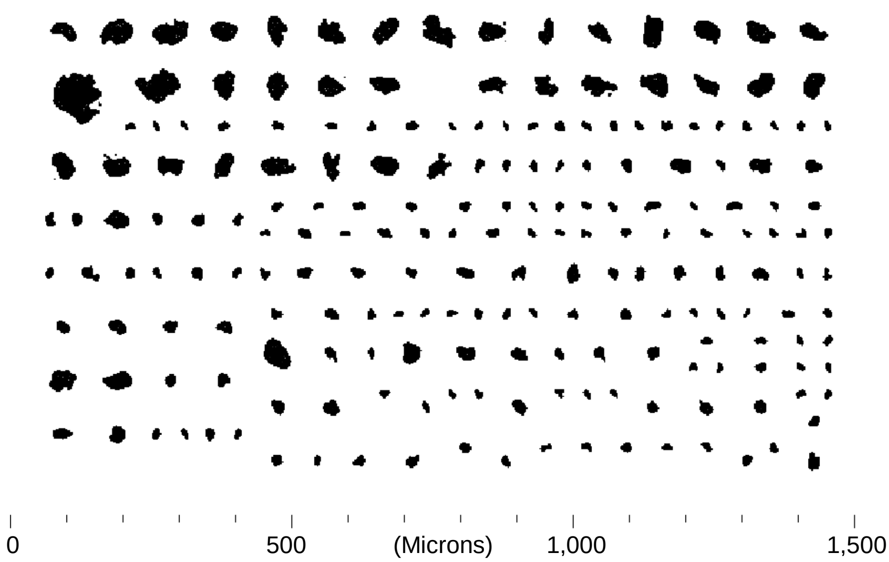


Figure 5. Record of fatigue particles detected in mineral transmission oil.

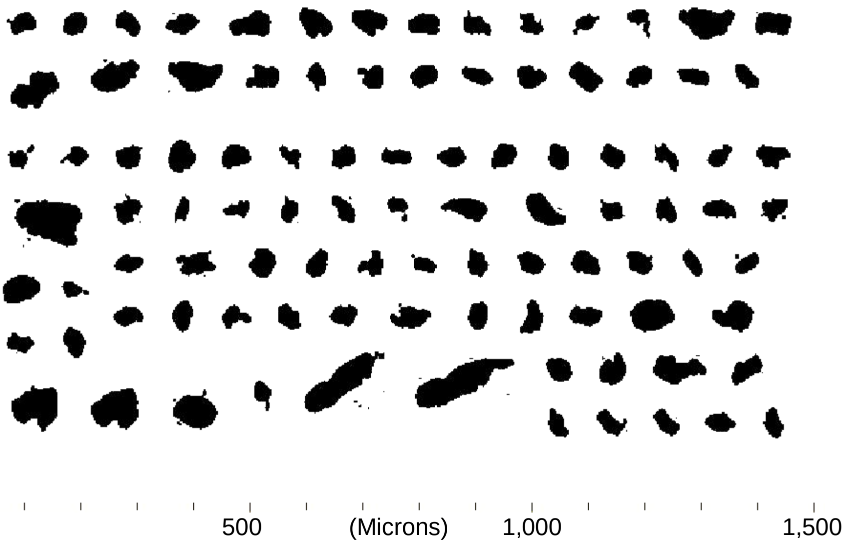


Figure 6. Record of fatigue particles detected in biodegradable transmission oil.

More transparent information on distribution of particles in the mineral transmission oil provides a Fig. 7. Describes the percentage of each type of particles in the size range of 20–25 μm. The biggest change is visible in the proportion of fatigue particles constituting the individual oil samples, which showed an increase from 18% to 53%. Conversely, the proportion of non-metallic particles decreased from 49% to 28%.

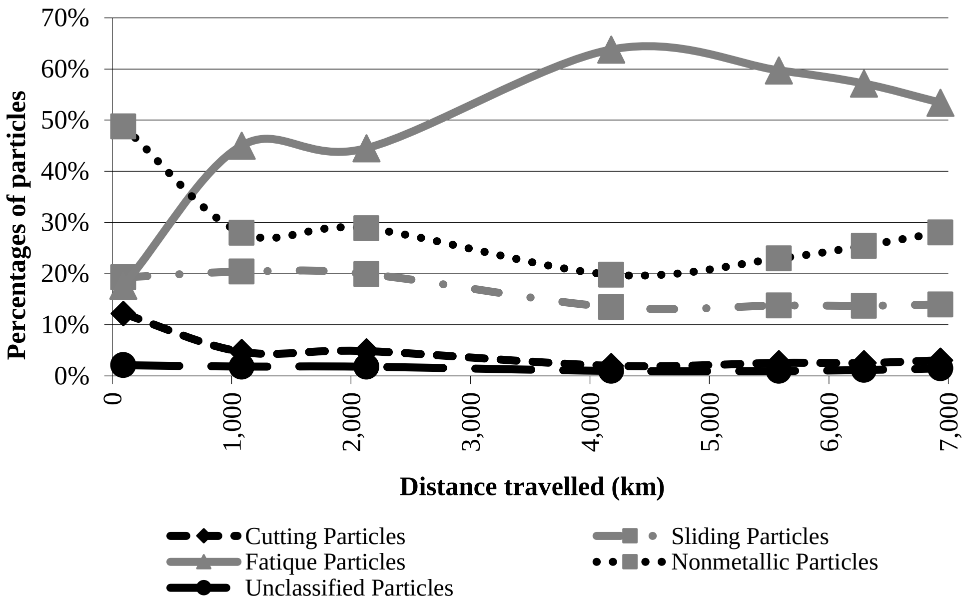


Figure 7. Percentage representation of different particles in the size range 20–25 μm (mineral transmission oil).

Fig. 8 provides information on distribution of particles in the biodegradable transmission oil. The data presented shows that already after the first receipt of a sample containing 41% of particles of fatigue. Such a high proportion of particles may have occurred by particles in an end gear box there still the experiment was run. A sample of seven shows a 48% particle fatigue, an increase of 7%.

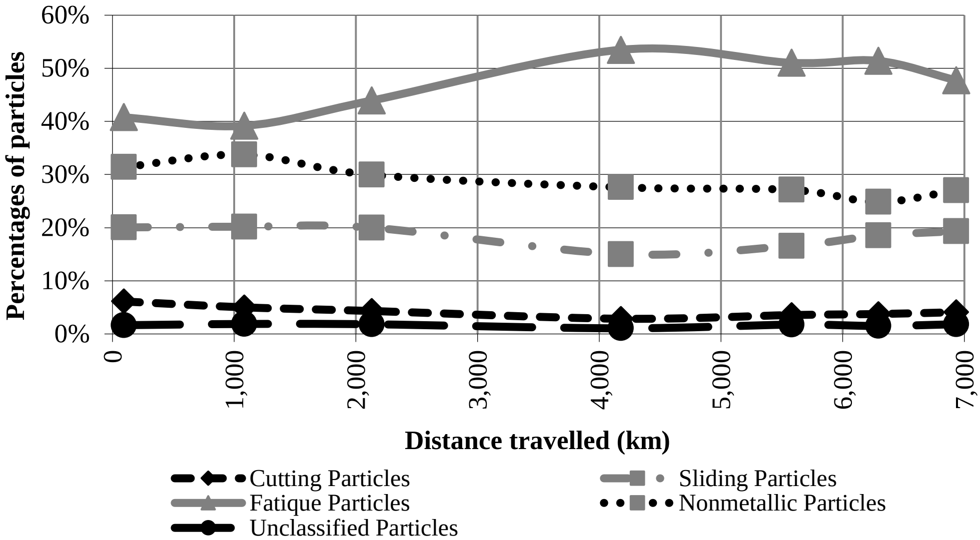


Figure 8. Percentage representation of different particles in the size range 20–25 μm (biodegradable transmission oil).

Decrease of number of wear particles may be partly due to measurement error. Important consideration of wear particle contamination of gear oil is also focused on trend of cleanliness code according to ISO 4406: 1999. Cleanliness code changed during the experiment from value 28/26/22 to >28/27/23.

CONCLUSIONS

The experiment was aimed to compare the conventional mineral oil and biodegradable oil. The measuring device MPH II was used for a precise monitoring of operating time of the end gear boxes. The information on the travelling distance is the most important parameter of the data obtained in the case of the exact operating time monitoring. For experiments, the attention paid to the creation of particles during a period of operation. For evaluation it was used desktop laser particle counter and classifier LNF-C. LNF-C has been applied to the detection of mechanical wear in diesel engines and particulate contamination in transmission systems. The ability of LNF-C to identify and quantify particle types allows its results to be used for fault identification, root cause analysis and recommendation of remedial action.

The measurement results showed a faster increase in the particle wear when compared to mineral oil biodegradable transmission oil. In view of the increase in the percentage of particles over the 20 μm flavor seems the biodegradable oil. Even in this respect it can be concluded that the biodegradable oil equivalent to petroleum-based oils.

For more accurate evaluation of the results, it would be appropriate to do an experiment that would include both approaches, i.e. chemical-physical analysis as well as determination of the technical state machine based on the analysis of the components in universal tractor transmission oil.

ACKNOWLEDGEMENTS. Ministry of Education, Science, Research and Sport of SR supported this work, Contract VEGA No. 1/0676/14.

REFERENCES

Aleš, Z. 2009. Field experience with transmission oil EP Gear Synth 150. *Research in Agricultural Engineering* **55**(1), 18–23.

Gonçalves, V.D., Almeida, L.F. & Mathias M.H. 2010. Wear Particle Classifier System Based on an Artificial Neural Network. *Strojniški vestnik – Journal of Mechanical Engineering* **56**, 284–288.

Henneberg, M., Eriksen, R.L., Jørgensen, B. & Fich, J. 2015. A quasi-stationary approach to particle concentration and distribution in gear oil for wear mode estimation. *Wear* **324–325**, 140–146.

Hönig, V. 2015. Morphological Classification of Nonferrous Wear Particles in Engine Oil Using Pherrographical Method. *Manufacturing Technology* **15**(4), 530–534.

Kosiba, J., Tkáč, Z., Hujo, Ľ., Tulík, J., Ševčík, P., Šinský, V. & Rašo, M. 2013. Effect of ecological energy carries on flow characteristics of tractor hydraulic pump. *Journal of Central European Agriculture* **14**(4), 1415–1425.

Kučera, M., Aleš, Z., Ivandič, Ž. & Hujo, Ľ. 2013. Possibility of hydraulic fluids with a low environmental impact application in agriculture and transport machinery. *Journal of Central European Agriculture* **14**(4), 1575–1584.

Kučera, M. & Rousek, M. 2008. Evaluation of thermooxidation stability of biodegradable recycled rapeseed-based oil NAPRO-HO 2003. *Research in Agricultural Engineering* **54**, 163–169.

Kumar, M., Mukherjee, P.S. & Misra, N.M. 2013. Advancement and current status of wear debris analysis for machine condition monitoring: a review. *Industrial Lubrication and Tribology* **65**, 3–11.

Kumbár, V. & Dostál, P. 2013. Oil additive and its effect. *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis* **61**(3), 691–697.

Leemet, T., Allas, J., Madisso, M., Adoberg, E. & Saar, R. 2014. Testing a method for evaluating the performance of coatings on end mill in semi-industrial conditions. *Agronomy research* **12**(1), 263–268.

Máchal, P., Tkáč, Z., Kosiba, J., Jablonický, J., Hujo, Ľ., Kučera, M. & Tulík, J. 2013. Desing of a laboratory hydraulic device for testing of hydraulic pumps. *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis* **61**(3), 1313–1319.

Majdan, R., Tkáč, Z., Kosiba, J., Abrahám, R., Jablonický, J., Hujo, Ľ., Mojžiš, M., Ševčík, P. & Rášo, V. 2013. Evaluation of tractor biodegradable hydraulic fluids on the bassi of hydraulic pump wear. *Research in Agricultural Engineering* **59**, 75–82.

Majdan, R., Tkáč, Z., Stančík, B., Abrahám, R., Štulajter, I., Ševčík, P. & Rašo, M. 2014. Elimination of ecological fluids contamination in agricultural tractors. *Research in Agricultural Engineering* **60**, 9–15.

Mihalčová, J. & Hekmat, A.H. 2008. Tribotechnická diagnostika v prevádzke použitých olejov I. Metódy hodnotenia častíc opotrebovania v olejoch. *Chemické listy* **102**, 358–362.

Novák, P., Müller, M. & Hrabě, P. 2014. Research of a material and structural solution in the area of conventional soil processing. *Agronomy Research* **12**(1), 143–150.

Perić, S., Nedić, B., Trifković, D. & Vuruna, M. 2013. An Experimental Study of the Tribological Characteristics of Engine and Gear Transmission Oils. *Strojniški vestnik – Journal of Mechanical Engineering* **59**, 443–450.

Pexa, M., Čedík, J., Mařík, J., Hönig, V., Horníčková, S. & Kubín, K. 2015. Comparison of the operating characteristics of the internal combustion engine using rapeseed oil methyl ester and hydrogenated oil. *Agronomy Research* **13**(2), 613–620.

Raadnui, S. 2005. Wear particles analysis – utilization of quantitative computer image analysis: a review. *Tribology International* **38**(1), 871–878.

Stachowiak, G.P., Stachowiak, G.W. & Podsiadlo, P. 2008. Automated classification of wear particles based on their surface texture and shape features. *Tribology International* **41**, 34–43.

Tkáč, Z., Hujo, Ľ., Tulík, J., Kosiba, J., Uhrinová, D. & Šinský, V. 2014. Greening of agricultural and forestry tractors. *Acta Universitatis Agriculturae et Silviculturae Mendelianae* **62**(5), 1135–1139.

Valach, M., Mareček, J., Hlaváčová, Z., Trávniček, P. & Glos, J. 2013. Determination of impurities in biofuels with use of particle size analyser. Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis **LXI**, 813–817.

Vališ, D., Žák, L. & Pokora, O. 2015. Failure prediction of diesel engine based on occurrence of selected wear particles in oil. *Engineering Failure Analysis* **56**, 501–511.

Veselá, K., Pexa, M. & Mařík, J. 2014. The effect of biofuels on the quality and purity of engine oil. *Agronomy Research* **12**(2), 425–430.

Yuan, C., Peng, Z., Zhou, X. & Yan, X. 2005. The surface roughness evolutions of wear particles and wear components under lubricated rolling wear condition. *Wear* **259**, 512–518.

Zhu, Z., Li, F., Li, G., Domg, D. & Wang, Y. 2015. Fault Diagnosis of Gearbox Based on Laser Particle Size Analysis. In*: International Conference on Intelligent Systems Research and Mechatronics Engineering.* ISRME, Zhengzhou, China, pp. 1578–1582 (in English).

Agronomy Research **14**(4), 1361–1371, 2016

Link between static radial tire stiffness and the size of its contact surface and contact pressure

M. Kučera[1,*] M. Helexa[1] and J. Čedík[2]

[1]Technical University in Zvolen, Faculty of Environmental and Manufacturing Technology, T.G. Masaryka 24, SK 96053 Zvolen, Slovak Republic.
[2]Czech University of Life Sciences Prague, Faculty of Engineering, Kamýcká 129, CZ 16521, Praha – Suchdol, Czech Republic
[*]Correspondence: marian.kucera@tuzvo.sk

Abstract. The article is devoted to the description of the experimental results regarding the measurement of static radial deformation characteristics of the selected tire and its impact on the size of the contact surface and contact pressure. The given measurement was carried out on the diagonal tire Mitas TS05 10.0/75-15.3 PR10 in the area of the soil test channel. The radial deformation characteristics of the tires in question were determined for inflation pressures of 300 kPa, 220 kPa, 160 kPa and 100 kPa, with a radial stress of the tire varying in the range of 567.9 kg to 1025.09 kg. The prints of the tire's contact surfaces were made at the same time for the corresponding inflation pressure and the corresponding radial stress. The size of these prints was subsequently planimeterized by the digital polar planimeter Koizumi KP-90N. The values of the medium contact pressure on a solid support were subsequently calculated from the tire radial stress values and the obtained contact surfaces. The calculated static radial stiffness values were obtained through the linearization of the measured deformation characteristics according to Jante. The course of the deformation characteristics and the calculation of static radial stiffness imply that static radial stiffness is significantly dependent on the tire inflation pressure. A suppler tire structure at a lower inflation pressure allows for greater values of the contact surfaces and lower values of contact pressures. This feature can be used when selecting appropriate tire inflation pressures when driving off-road to reduce soil degradation and improving the vehicle's passability through the terrain.

Key words: terramechanics, landscape, mobile machines, wheeled chassis.

INTRODUCTION

The radial stiffness of tires (whether static or dynamic) does not only affect the cushioning of the energy means in the terrain, but also other characteristics of the tire relating to its contact with the surface of the terrain it moves on. It affects the size of the tire's contact area, the size of the contact pressure, the size of the internal as well as external rolling resistance component, and thus affects the energy losses in the overall performance applied to the wheels of mobile working means (Antille et al., 2013; Abrahám et al., 2014). Radial tire deformation characteristics of mobile technology used in forestry and agriculture are therefore an important attribute for solving contact problems between the tire and the surface. The size of the contact pressure is influenced mainly by the size of the tire’s contact area and its normal stress. The size and course of the tire's contact pressure greatly affects how this will behave, for example, on soil, how it will damage the soil (e.g. by compression or excessive slipping) and what driving and operating properties the mobile means will achieve with it under the given soil conditions (Braunack, 2004; Čedík & Pražan, 2015). Research tire deformation characteristics was dealt with in the past by several authors, for example, Dočkal et al. (1998), Zhang et al. (2002), Krmela (2008), Koutný (2009), and, who in their work also highlighted the impact of tire deformation properties on their driving and contact properties. In the research of mutual ties between the tire wheel deformation characteristics and contact variables, especially the size of the contact area and the contact pressure distribution on a solid support, progressive methods of research using various physical principles of tactile sensing elements have also been used. These allow precisely determining the composition of the contact pressure in the tire's contact area with the surface, and accurately determine the size of the contact area. Thus the conceived work is indicated by authors, such as De Beer & Fisher (1997), who applied a tactile matrix consisting of strain-gauge sensing elements to map the contact area and contact pressure. An interesting application of tactile sensing elements, or a force sensor consisting of tactile sensing elements, was introduced by the authors Roth & Darr (2012). To monitor the contact pressure of the tire and the size of the contact surface, they used Tekscan FlexiForce tactile force transducers, which they installed directly on the tractor tire tread close to the herringbone tread figures. What is interesting about this work is the fact that they used the above method of installing the sensors to monitor the contact voltage between the tire and the soil surface. Optical methods are also used for the investigation of contact tasks and their relation with the deformation characteristics of tires. The utilization of holographic interferometry methods in this area is described by authors such as Castillo et al. (2006).

As seen from the above brief overview, the topic is still relevant and it is currently being dealt with through advanced technologies brought by microelectronics. In this article, we will also try to suggest a link between the radial deformation characteristics of the selected tire and the size of the contact area and contact pressure.

MATERIALS AND METHODS

We investigated the radial deformation characteristics of the selected tire for different values of inflation pressure and different values of vertical stress in soil test channels (Fig. 1). The vertical load on the tire was inferred through steel weights from the value of 567.90 kg to 1,025.09 kg. We selected the stress on the tire so that at a given tire inflation pressure we would not exceed the maximum stress indicated by the manufacturer. The construction of the supporting frame of the wheel (Item 3, Fig. 1) does not allow to achieve a tire stress lower than 480 kg. It is due to the fact that the entire drive mechanism of the tested wheel is mounted on this item, which is used in the traction tire tests (together with Items 5 and 6, Fig. 1). As a test tire we selected a Mitas TS05 10.0/75-15.3 PR10 ply tire with a tread profile. Its basic technical parameters are listed in the following Table No.1.

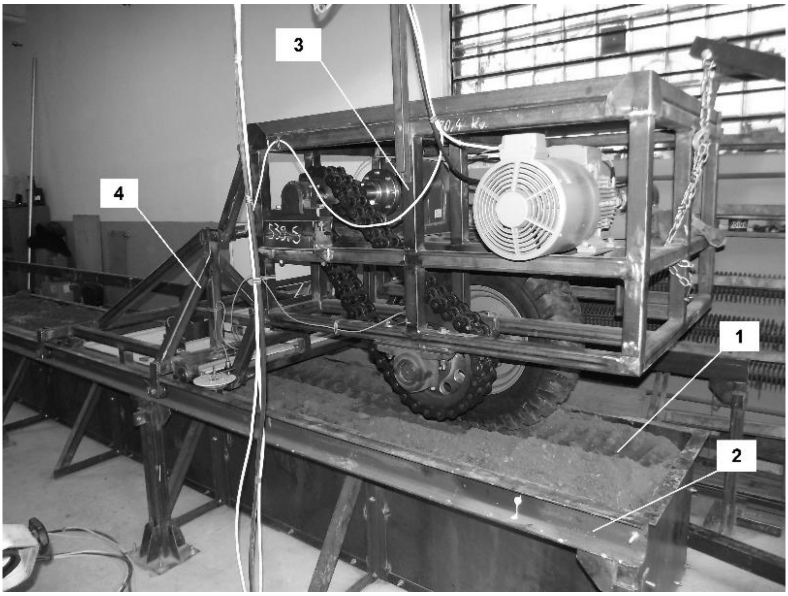


Figure 1. Soil test channel: 1 – soil test channel's body (frame); 2 – side guiding; 3 – wheel support frame; 4 – the guide frame, 5 – tensile force sensor; 6 – brake device.

Table 1. Basic technical parameters of the monitored tire

Tire type	Dimension	PR	Tread profile	Rim	Width (mm)	Diameter (mm)	Radius (mm)	Rolling circumference (mm)
itaMs	TS05 10.0/ 75-15.3 PR10	10	TS 05	9.00 x 15.3	264	790	395	2,295

We have carried out the actual measurement of the radial deformation characteristics so that we lifted the supporting frame with the mounted tire using a workshop crane with a lifting capacity of 5,000 kg, and supported the wheel on the evened-out soil surface with a 15 mm thick steel substrate. We examined the actual tire compression using an altimeter with a nominal size of 1,000 mm. In addition to these measurements, we investigated the necessary parameters of the tire's contact area with the substrate. We imprinted the contact surface of the tire on rough drawing paper, painting it with ink beforehand. We always made two imprints for the given load and tire inflation pressure. One of the contact surfaces of the tire with the solid substrate and the second of the imprint surface, which is closer to the contact area, is on the soil surface. We then determined the size of the contact surface and the tire contact surface via a Koizumi KP-90N digital polar planimeter (Fig. 2). The obtained radial tire deformation characteristics were obtained for the following inflation pressures: 300 kPa, 220 kPa, 160 kPa and 100 kPa.

From the obtained deformation characteristics, we then calculated the static radial stiffness of the examined tire. The course of dependence of the vertical stress on the tire deformation is a second degree polynomial in the form:

$$Q = A.y + B.y^2 \text{ [N]} \quad (1)$$

where: Q – vertical stress on the tire, [N]; A, B – functional dependence constants Q (y), [-]; y – vertical deformation of the tire, [m].

The linearization of the dependence was carried out according to Jante (Cvekl et al., 1976) on the basis of the statement that the work expended to deform the tire, expressed as follows:

$$E_p = \int_0^{y_{max}} (A.y + B.y^2) dy \text{ [J]} \quad (2)$$

is as big as the work expended to deform the tire in a linearized form. The sought constant of the linearized stress process stiffness then follows from the following equation:

$$E_p = \int_0^{y_{max}} c.ydy = \frac{1}{2}.c.y_{max}^2 \text{ [J]} \quad (3)$$

where: E_P – work expended to deform the tire, [J]; c – radial static stiffness of the tire, [N m^{-1}]; y_{max} – maximum vertical tire deformation at the corresponding stress and given inflation pressure, [m].

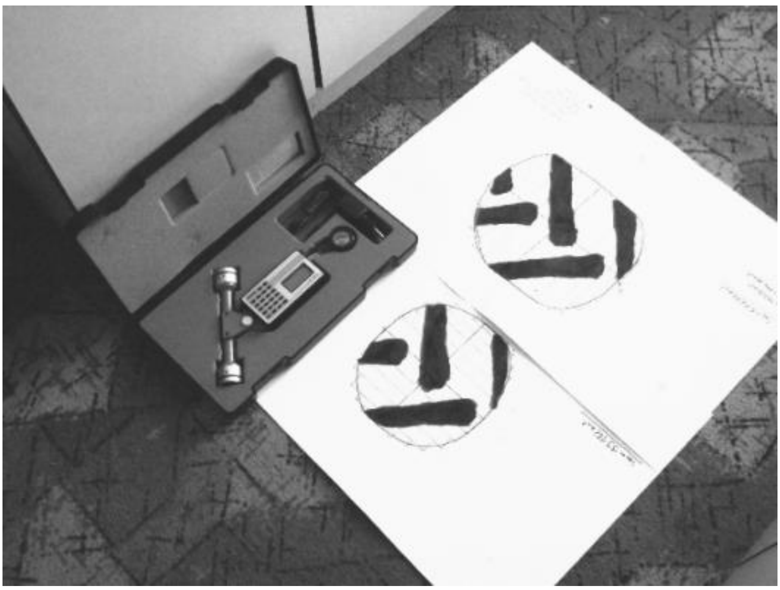


Figure 2. Koizumi KP-90N digital polar planimeter.

We then calculated the mean contact pressure values from the values of the measured contact surface and vertical load.

RESULTS

The results of the measurements and calculation of work expended for the tire deflection and static radial stiffness of the tire are shown in Table 2. All the calculations and reported functional dependencies of work were developed in a MS Excel spreadsheet. The measured tire deformation characteristics for individual inflation pressures are graphically illustrated in Fig. 3. The given functional dependencies of the tire stress depending on the vertical deformation can be approximated by a second degree polynomial. The obtained functional dependencies, indicating the coefficient of determination, are shown in Table 3.

Table 2. Measured and calculated results, the Mitas TS05 10.0/75-15.3 PR10 tire

Load (kg)	Normal Force (N)	Pressure (kPa)	Tire rolling radius (mm)	Deformation of tire (mm)	Work expended on deformation (J)	Stiffness (N m^{-1})
1,025.09	10,056.13	300.00	376.00	19.00	94.77	525,000
847.14	8,310.44	300.00	379.00	16.00	69.19	
709.30	6,958.23	300.00	381.00	14.00	54.82	
567.90	5,571.10	300.00	384.00	11.00	36.88	
0.00	0.00	300.00	395.00	0.00	0.00	
1,025.09	10,056.13	220.00	373.00	22.00	126.46	522,500
847.14	8,310.44	220.00	377.00	18.00	90.53	
709.30	6,958.23	220.00	380.00	15.00	67.98	
567.90	5,571.10	220.00	384.00	11.00	43.18	
0.00	0.00	220.00	395.00	0.00	0.000	
847.14	8,310.44	160.00	376.00	19.00	76.39	423,200
709.30	6,958.23	160.00	379.00	16.00	53.57	
656.48	6,440.07	160.00	380.00	15.00	46.88	
567.90	5,571.10	160.00	382.00	13.00	34.86	
0.00	0.00	160.00	395.00	0.00	0.000	
847.14	8,310.44	100.00	369.00	26.00	64.99	192,300
709.30	6,958.23	100.00	372.00	23.00	42.20	
656.48	6,440.07	100.00	373.00	22.00	35.52	
567.90	5,571.10	100.00	375.00	20.00	23.53	
0.00	0.00	100.00	395.00	0.00	0.00	

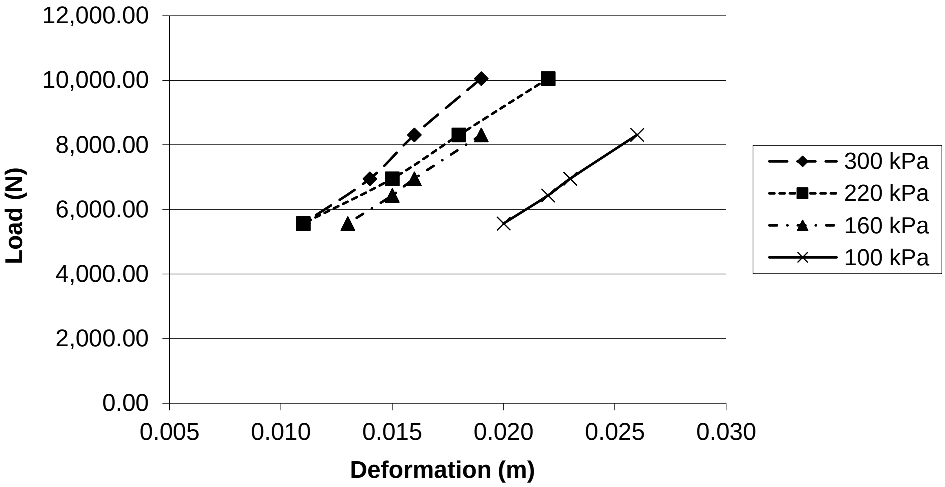


Figure 3. Radial deformation characteristics of the examined tire Mitas TS05 10.0/75-15.3 PR10

We subsequently used the coefficient values of these obtained approximation functional dependencies (Table 3) to calculate the potential energy (deformation work) according to Equation 2 and to calculate the radial static stiffness of the tire according to Equation 3.

Table 3. Dependencies of the deformation characteristics for the Mitas TS05 10.0/75-15.3 PR10

Tire inflation pressure	Function	R^2
300 kPa	$y = 1E+07.x^2 + 208,866.x + 1,800,2$	0.9977
220 kPa	$y = 6E+06.x^2 + 199,416.x + 2,586.4$	0.9993
160 kPa	$y = 1E+06.x^2 + 424,967.x – 136.92$	0.9995
100 kPa	$y = 1E+06.x^2 + 410,363.x – 3,060.6$	0.9995

Note: y – vertical load on the tire, [N] x – tire deformation, m.

The results of measuring the contact surface size and the contact area of the examined tire for individual stresses and tire inflation pressures are shown in Table 4. This table also shows the calculation of the mean contact pressure for individual stresses and the imprint surfaces, as well as the tire contact surface. Unfortunately at present we do not have a device that would allow us to measure the value of mean contact pressure or to measure the total contact pressure distribution in the tire's contact area, so we just proceeded to their calculation.

DISCUSSION

The dependence of tire deflection on the stress (Fig. 3) is non-linear and describable by the polynomial of the second degree (quadratic function). The indicated static radial stiffness values were obtained by the linearization of these functions according to Jante (Cvekl et al., 1976), Table 2. The dependence of the tire imprint area on the stress and inflation pressure (Fig. 4) shows that the imprint area clearly increases with an increasing radial load and decreasing tire inflation pressure. The maximum is reached at an inflation pressure of 100 kPa and a maximum stress of 847.14 kg. In this dependence, we may discern some variation consisting in a significant reduction of the tire contact area depending on the stress and inflation pressure when inflated to 160 kPa. This may be caused by certain flaws in the performance of the measurement or a small number of performed measurements.

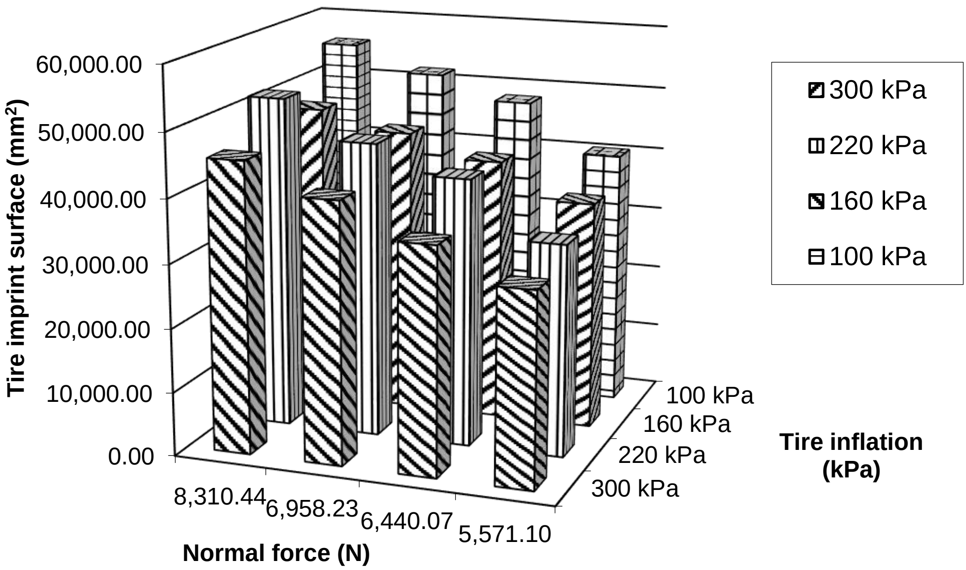


Figure 4. Dependency of the tire imprint surface on the normal force and inflation pressure.

The tire contact area with a solid substrate depending on the stress and inflation pressure behaves essentially the same as in the previous case.

In the dependence of the mean tire contact pressure on the load and inflation pressure (Fig. 5) we can observe that the mean contact pressure of the tire increases not only due to increasing vertical stress, but also due to the rising inflation pressure of the tire. It reaches its maximum at 300 kPa inflation pressure and a vertical stress of 1,025.09 kg. The dependency of the mean tire contact pressure on a hard substrate depending on the tress and inflation pressure for a contact surface has a similar course as in the previous example.

Regarding the mutual size proportion of the imprint surface and the tire contact area (Table 4), based on the measured data we can say that the tire contact area was on average 3.14 times smaller than the imprint surface. The contact surface essentially represents a contact area of the tread profile on a solid substrate. It is affected by the fullness of the tread profile, i.e. the number and arrangement of gear figures of the tires with an arrow tread profile.

Table 4. The results of the size measurements of the contact surface and the monitored tire's contact area

Load (kg)	Normal force (N)	Inflation pressure (kPa)	Track width (mm)	Track length (mm)	Deformation (mm)	Imprint surface (mm^2)	Contact area (mm^2)	Mean contact pressure (imprint) (Pa)	Mean contact pressure (contact) (Pa)
1,025.09	10,056.13	300.00	230.00	245.00	19.00	45,561.19	17,085.25	220,717.08	588,585.65
847.14	8,310.44	300.00	220.00	220.00	16.00	40,820.27	14,115.40	203,586.19	588,750.12
709.30	6,958.23	300.00	212.00	205.00	14.00	35,475.40	12,775.18	196,142.48	544,668.10
567.90	5,571.10	300.00	200.00	190.00	11.00	30,260.13	9,165.63	184,106.91	607,824.99
0.00	0.00	300.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1,025.09	10,056.13	220.00	228.00	260.00	22.00	52,120.40	15,450.52	192,940.44	650,860.48
847.14	8,310.44	220.00	222.00	229.00	18.00	46,196.07	13,605.38	179,895.03	610,820.38
709.30	6,958.23	220.00	221.00	223.00	15.00	41,888.78	12,634.47	166,112.09	550,734.06
567.90	5,571.10	220.00	210.00	188.00	11.00	33,182.52	10,200.62	167,892.58	546,152.98
0.00	0.00	220.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
847.14	8,310.44	160.00	221.00	243.00	19.00	47,674.24	15,995.35	174,317.27	519,553.71
709.30	6,958.23	160.00	220.00	225.00	16.00	44,865.21	14,285.08	155,091.95	487,097.94
656.48	6,440.07	160.00	219.00	222.00	15.00	41,385.37	13,875.04	155,612.24	464,147.85
567.90	5,571.10	160.00	218.00	200.00	13.00	35,905.52	11,465.00	155,159.96	485,922.29
0.00	0.00	160.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
847.14	8,310.44	100.00	220.00	285.00	26.00	55,756.47	18,910.41	149,048.95	439,463.95
709.30	6,958.23	100.00	218.00	256.00	23.00	51,681.50	15,579.77	134,636.82	446,619.75
656.48	6,440.07	100.00	219.00	234.00	22.00	48,005.95	15,140.11	134,151.50	425,364.81
567.90	5,571.10	100.00	220.00	210.00	20.00	40,330.40	12,700.44	138,136.47	438,654.02
0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

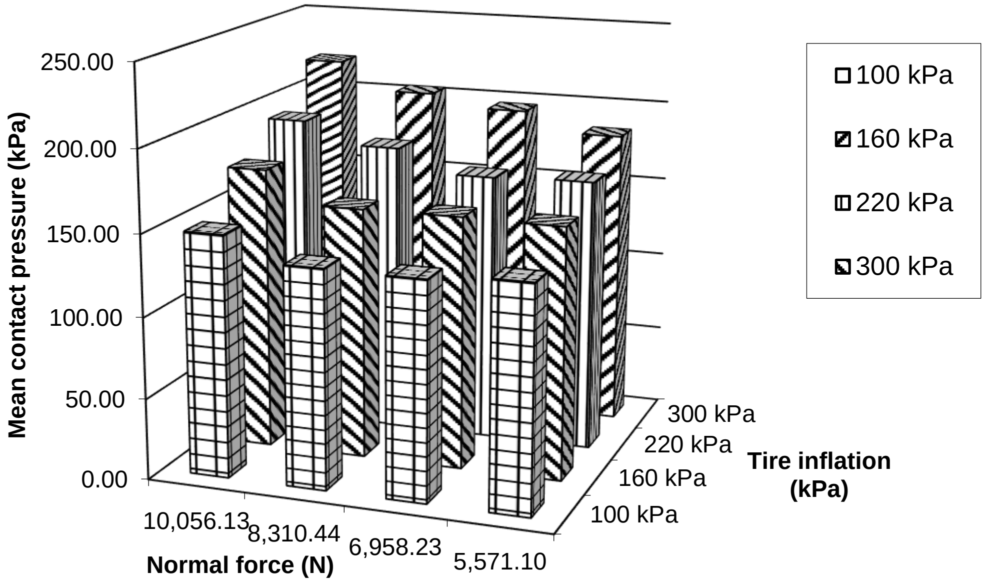


Figure 5. Dependency of the mean tire contact pressure (Imprint surface) on the stress and inflation pressure.

As mentioned above, we just calculated the value of the mean contact pressure using the known value of the vertical tire stress and the measured imprint surface and the contact area. Currently we do not have technical equipment that would allow us to measure this parameter or determine the distribution of the contact pressure in the tire's contact area. Several authors suggest in their work that the mean contact pressure value is approximately equal to the tire inflation pressure (Faria & Oden, 1992; Grečenko, 1995; Noor & Peters, 1995;). However, this ideal situation would be valid if the tire was perfectly elastic. In reality, it is not. Our results showed the following. At a tire inflation pressure of 100 kPa, the mean contact pressure value when considering the imprint area was around 127 kPa to 189 kPa, which is consistent with the theory that the real value of the mean contact pressure in a real tire is always greater than the tire inflation pressure. At a tire inflation pressure of 160 kPa, the values of mean contact pressures were approximately on a level equal to the tire inflation pressures. At the inflation pressure of 220 kPa, the contact pressure was somewhat lower, moving at 168 kPa to 193 kPa. At a tire inflation pressure of 300 kPa we obtained mean contact pressure values of 184 kPa to 221 kPa.

Given that the tire contact area is on average 3.14 times smaller than the entire imprint area, the mean contact pressure values are also greater by this fold, ranging from 440 kPa at the tire inflation pressure of 100 kPa, to 588 kPa at the inflation pressure of 300 kPa and maximum stress.

The course of the deformation characteristics and the calculation of static radial stiffness (Fig. 2, Table 2) show that this is heavily dependent on the tire inflation pressure. The lower the tire inflation pressure, the more pliable the tire (lower radial stiffness). At inflation pressures of 100 kPa it is nearly 2 times lower than at 300 kPa. The radial static stiffness value and thus the flexibility is affected not only by the tire inflation pressure, but also the very structure of the tire. It depends on whether the structure of the tire is radial or diagonal, the number of cord layers, and the material of cord layers.

A suppler tire structure at lower inflation pressure allows for greater values of the contact surfaces (at a given load) and lower values of contact pressures (Schreiber & Kutzbach, 2008; Barosa & Magalhães, 2015). This feature can be used when selecting an appropriate tire inflation pressure for off-road driving on a flexible substrate to reduce soil degradation and reduce the rolling resistance of the tire. On a solid surface, however, the reduced tire inflation pressure at the given stress clearly leads to the increased internal component of the tire rolling resistance. Here, therefore, we strive to achieve that the tire is adequately stiff (inflated to the highest pressure proportionate to its maximum stress), which provides an acceptable rolling resistance value while reaching the optimum life.

CONCLUSION

In conclusion, we would like to mention that the very soil test channel which we conducted our measurement on is not quite suitable for detecting the deformation characteristics of tires. The main limiting parameter is the fact that it does not allow us to ensure the lower stress of the observed tire than 480 kg without having to dismount the wheel drive mechanism. As mentioned above, the vertical stress on the tire is inferred here by means of mechanical weights, their manual handling cumbersome, time-consuming and physically strenuous for the equipment operation staff. A device called the static adhezor is more preferable for verifying the deformation characteristics of the tire wheels, enabling the accurate measurement of individual deformation characteristics (not only in the radial direction) of the tires. Our workplaces, however, currently do not have this piece of equipment. In the future we would like to continue in the given research area of deformation characteristics and refine the given measurements to the desired level.

The measurements performed by us do not provide any fundamentally new results, but confirm the view that the tire inflation pressure, as well as the selection of an appropriate tire size for specific mobile work equipment, plays an important role in the energy efficiency of these machines. We think that we have managed to suggest a link between the radial stiffness of the tire and the size of its contact area and contact pressure. These characteristics of tires must be reviewed even before the tire is fitted to the specific mechanization means. Based on the results of this verification, it is then possible to determine the tire’s suitability for the particular mechanization means, so that its work in the terrain is as efficient as possible.

ACKNOWLEDGEMENT. The paper was created within the solution of grant project VEGA MŠ SR No. 1/0676/14.

REFERENCES

Abrahám, R., Majdán, R., Šima, T., Chrastina, J. & Tulík, J. 2014. Increase in tractor drawbar pull using special wheels. *Agronomy Reseach* **12**(1), 7–16.

Antille, D.L., Ansorge, D., Dresser, M.L. & Godwin, R.J. 2013. Soil displacement and soil bulk density changes as affected by tire size. *Transactions of the ASABE* **56**(5), 1683–1693.

Barbosa, L.A.P. & Magalhães, P.S.G. 2015. Tire tread pattern design trigger on the stress distribution over rigid surfaces and soil compaction. *Journal of Terramechanics* **58**(1), 27–38.

Braunack, M.V. 2004. A tyre option for sugarcane haulout trucks to minimise soil compaction. *Journal of Terramechanics* **41**(4), 243–253.

Castillo, J., Pérez de la Blanca, A., Cabrera, J.A. & Simón, A. 2006. An optical tire contact pressure test bench. *Vehicle System Dynamics* **44**(3), 207–211.

Čedík, J. & Pražan, R. 2015. Comparison of tyre for self-propelled sprayers. *Agronomy Research* **13(**1), 53–62.

Cvekl, Z. & Dražan, F. 1976. *Teoretické základy transportních zařízení (Theoretical foundation of transport equipment)*. SNTL/Alfa, Praha-Bratislava, 320 pp. (in Czech)

De Beer, M. & Fisher, C. 1997. Contact stresses of pneumatic tires measured with the vehicle-road surface pressure transducer array (VRSPTA) system for the University of California at Berkeley (UCB) and the Nevada Automotive Test Center (NATC). *Confidential contract research report CR-971053*, Division of Roads and Transport Technology, CSIR, Pretoria, South Africa, 13pp.

Dočkal, V., Kovanda, J. & Hrubec, F. 1998. *Pneumatiky (Tires).* ČVUT, Praha, 71pp. (in Czech)

Faria, L.O. & Oden, J.T. 1992. Tire modelling by finite elements. *Tire Science and Technology* **20**(1), 33–56.

Grečenko, A. 1995. Tyre footprint area on hard ground computed from catalogue values. *Journal of Terramechanics* **32**(6), 325–333.

Koutný, F. 2009. *Geometry and mechanics of pneumatic tires*. UTB, Zlín, 142 pp. (in Czech)

Krmela, J. 2008. *Systémový přístup k výpočtovému modelování pneumatik I (System approach to computational modelling of tyres – I. Part)*. Tribun EU, Brno, 102 pp. (in Czech)

Noor, A.K. & Peters, J.M. 1995. Reduction technique for tire contact problem. *Computer and structures* **60**(2), 223–233.

Roth, J. & Daar, M.J. 2012. Measurement of normal Stresses at the soil-tire interface. *Agricultural and Biosystems Engineering* **55**(2), 325–331.

Schreiber, M. & Kutzbach, H. 2008. Influence of soil and tire parameters on traction. *Research in Agricultural Engineering* **54**(2), 43–49.

Zhang, X., Rakheja, S. & Ganesan, R. 2002. Stress analysis of the multi-layered system of truck tire. *Tire Science and Technology* **30**(4), 240–264.

Agronomy Research **14**(4), 1372–1379, 2016

Soil weed seed bank and factors influencing the number of weeds at the end of conversion period to organic production

J. Kuht*, V. Eremeev, L. Talgre, H. Madsen, M. Toom, E. Mäeorg and A. Luik

Estonian University of Life Sciences, Kreutzwaldi 1, EE51014 Tartu, Estonia
*Correspondence: jaan.kuht@emu.ee

Abstract. In 2008 an experiment was set up on the field in Eerika experimental station (Estonian University of Life Sciences) as a 5-field crop rotation: red clover, winter wheat, pea, potato and barley undersown with red clover. The objective of the study was to measure the content of weed seeds in the soil and to evaluate the diversity of the species at the end of the period of converting to organic production. In conventional farming systems without fertilizer (Conv I) and conventional farming with mineral fertilizer (Conv II) herbicides were used for weed control. All the crops in Conv II system received P 25 kg ha^{-1} and K 95 kg ha^{-1}, but the application rates of mineral nitrogen fertilizer differed. In organic systems (Org I – organic farming based on winter cover crop and Org II - organic farming based on winter cover crop and manure), the winter cover crops (ryegrass after winter wheat, winter oilseed rape after pea, winter rye after potato) were sown after the harvest and were ploughed into the soil as green manure in spring. The content of annual weed seeds was the lowest in red clover that had 17.7% less weed seeds in the soil of Org II system compared to control (Conv I). In winter wheat the content of winter annual weed seeds was 50–76% higher compared to other crops. By the end of 2009 the content of organic carbon (Corg %) in the soil had increased significantly in both organic systems which results in higher activity of organisms that decrease the viability of weed seeds.

Key words: organic farming, soil, weed seeds, seed bank, crop rotation, winter cover crops.

INTRODUCTION

The conversion to organic farming is related to several problems. During the conversion period many growers observe the decrease in crop yields as no synthetically produced pesticides and fertilizers are used anymore. On the contrary Carolyn et al. (2012) found that the yields of organically produced corn and soybean remained the same during the 3-year conversion period and even increased compared to the yields of conventional farming in the 4th year. The conversion period to organic production lasts at least two years in Estonia (Palts & Vetemaa, 2012). As chemical pest control products cannot be used, the most challenging task is to control the weeds and poor weed control is often cited as a major reason for lower yields in organic production (Gianessi & Reigner, 2005). Most weeds start to germinate from viable seeds which have been incorporated into the soil over time. Environmental conditions in soil, including temperature, water content, compaction, texture and air content can impact the timing of germination and the number of germinated seeds (Egley, 1995). With intensive cultivation and compaction especially in the conventional production systems the balance of soil air and water regime has been interrupted and its structure destroyed

(Verhulst et al., 2010). In conventional farming where agricultural machinery is intensively used (including fertilization and chemical pest control) the soil is more compact. It has been observed that after 6 times of wheeling the bulk density of soils increased by 0.15 Mg m^{-3} whereas soil penetration resistance increased by 3.0 MPa compared to the unmanaged soils (Reintam et al., 2009).

The soil weed seed bank consists of many different species and dominant species can account for up to 70–90% of the seed number in soil. The amount of weed seeds considerably varies depending on soil type, crops grown, crop rotation, cultivation methods and the use of herbicides (Grundy & Jones, 2002). Therefore each method that enables to reduce the soil weed seed bank in organic agriculture is of high value. Today, Estonian farmers usually apply herbicides to control weeds. After conversion to organic farming this tool is no longer available and weed control has to be accomplished by inversion tillage, mechanical weeding, weed suppressing crop rotations and other methods usually applied in organic agriculture. This research is valuable because organic farming may continue to gain importance in the future and there were no studies on the effects of organic crop production on weed seed bank in Estonia at the end of the period of converting to organic crop production.

The objective of the study was to determinate the content of weed seeds in the seed bank and to evaluate the diversity of the species at the end of the period of converting to organic production.

MATERIALS AND METHODS

In 2008 an experiment was set up in test site of the Estonian University of Life Sciences in Eerika (58°22′ N, 26°40′ E) as a 5-year rotation: red clover (*Trifolium pratense* L.), winter wheat (*Triticum aestivum* L.), pea (*Pisum sativum* L.), potato (*Solanum tuberosum* L.) and barley (*Hordeum vulgare* L.) undersown with red clover. First 5-year rotation ended in 2012. Samples for measuring the weed seedbank were collected in September 2010, at the end of conversion period (2008–2010) to organic production. The experiment was set up in four replications (80 plots), size of the plot was 60 m^2 in a systematic block design. Each plot was 6 meters wide and 10 m long. Organic and conventional plots were separated with an 18 m long section of mixed grasses to avoid contamination with synthetic pesticides, mineral fertilisers and winter cover crops. In systems Conv I (conventional farming without fertilizers (as control)) and Conv II (conventional farming with mineral fertilizers) the weed content was performed with herbicides. In conventional system Conv II all the crops received phosphorous (P 25 kg ha^{-1}) and potassium (K 95 kg ha^{-1}). The amount of nitrogen (N) varied depending on the crop: for pea N 20 kg ha^{-1}, for barley undersown with red clover N 120 kg ha^{-1}, for winter wheat and potato N 150 kg ha^{-1}. Plots with red clover did not receive any mineral fertilizers and chemical pest control. Two organic farming systems (Org I and Org II) were investigated. In both systems winter cover crops as green manure were used. Cover crops were sown right after the harvest: ryegrass (*Lolium perenne* L.) after winter wheat, winter oilseed rape (*Brassica napus* L., *var. oleifera, subvar. biennis*) after pea, winter rye (*Secale cereale* L.) after potato. Before sowing the subsequent crop all cover crops were ploughed into the soil as green mature. In the organic system Org II fully composted cattle manure was added in the autumn 2009 and in spring 2010 at a rate 40 t $ha^{-1}$and ploughed into soil. To analyse soil chemical parameters soil samples were collected at depths of 0–25 cm in spring 2008 and 2009. Organic C (Corg %) and total nitrogen content were measured by Dumas dry combustion method, by using the elemental analyser VarioMAX. Samples for measuring the weed seed bank were collected in September 2010, at the end of conversion period (2008–2010) to organic production. The weed seed bank samples were taken with soil borersafter crop harvest and before autumn ploughing. From each plot 16 soil samples were taken from the depth of 0–25 cm soil layer. Samples of each plot were mixed together in a bucket. The samples were air-dried and 500 g of each sample were sieved and washed through a 0.25 mm sieve. Weed seeds were separated from the soil by potassium carbonate (K_2CO_3) aqueous solution. For preparation of the solution 2.0 kg of potassium carbonate was dissolved in 1.8 l of water. A cone penetrometer (Eijkelkamp Penetrologger with 69 degree, 1 cm^2 cones) was used for measuring the penetration resistance of soil. The number of weed seeds in seed bank was calculated to an area of 1 m^2 using method described by Vipper (1989) with two different formula. We convert these into a joint formula as shown below (Eq. 1):

$$N = \frac{h \cdot D_b \cdot n \cdot 10}{S_p} \tag{1}$$

where: N – number of viable seeds (n m^{-2}); h – depth of plough layer (cm); D_b – soil bulk density (g cm^{-3}); n – counted number of seeds in the soil sample; S_p – weight of dry soil sample (g).

The species composition of weed seed communities and the number of seeds of each species were used to assess the biodiversity.

The diversity indexes of weed seed species were calculated as Shannon-Wiener diversity index (Shannon, 1948) of weed species diversity *H'* (Eq. 2):

$$H' = -\sum_{i=1}^{s} pi \ln(pi) \tag{2}$$

where the p_i's are the proportion of all observations in the i^{th} species category.
Simpsons' index (Simpson, 1949) of weed species domination (Eq. 3):

$$\lambda = \sum_{i=1}^{s} pi^2 \tag{3}$$

where: p_i is the share of i^{th} species in the sample.
The formula to calculate Pielou evenness index (Pielou, 1966; Boyce, 2005) is (Eq. 4).

$$J' = \frac{H'}{H'max} \tag{4}$$

where: $H'_{max} = \ln(S)$; S – number of species.

The results were analysed by using STATISTICA 7.0: ANOVA, Fisher (LSD) test (Statsoft Inc, 2005). Correlation analysis was used to study the correlation between different number of weed seeds and some indicators of soil physical properties. Linear correlation coefficients between variables were calculated, the significance of coefficients being $P < 0.001$, $P < 0.01$, $P < 0.05$.

RESULTS AND DISCUSSION

On average, the lowest content of weed seeds was observed in the Conv II system (Table 1). On average for the crop rotation there were 7,500 less seeds per m^2 than in Conv I. In Org II system where cover crops and manure were used there were 11.0% more weed seeds than in Conv II system, but 14.3% less weed seeds compared to control (Conv I). Within crops there were 2,800–9,100 less seeds per m^2 in red clover variants, while wheat variants had the highest number of weed seeds (Table 1). There were more than ten times less seeds of winter weeds compared to summer weeds and also these were more unevenly distributed, causing these results to be out of confidence limits. Only in winter wheat plots the significant (71.0%) decrease of the number of seeds of winter weeds was observed in Conv II system and 35–37% decrease in organic systems Org I and Org II compared to Conv I system (Table 1).

The lower abundance of seeds of summer weeds compared to Org I system was apparent for all the crops where manure had been applied in Org II system, where statistically significant decrease of weed seeds was observed: 14.0% for undersown barley, 17.0% for red clover, 26% for winter wheat and for pea (Table 1). In Org I system the number of seeds of summer weeds remained within the experimental deviation limits, only exception being potato where significant (28.0%) decrease of weed seeds was observed compared to control variant.

Table 1. Number of annual (summer, winter and total) weed seeds in the soil of the different crops in 2010

Crop and preceding crops	Weed seeds	Number of weed seeds, 1,000 seeds per m^2				
		Conv I	Conv II	Org I	Org II	Average
Barley, undersown	Summer annual	30.38^{a*}	32.62^{a}	34.72^{a}	26.04^{b}	30.94
1) potato	Winter annual	1.96^{a}	0.70^{a}	2.10^{a}	1.82^{a}	1.65
2) pea	Total	32.34^{a}	33.32^{a}	36.82^{a}	27.86^{b}	32.59
Red clover	Summer annual	29.40^{a}	17.50^{b}	32.48^{a}	24.64^{b}	25.95
1) barley, undersown	Winter annual	0.14^{b}	1.12^{ab}	0.84^{ab}	2.80^{a}	1.23
2) potato	Total	29.54^{a}	18.60^{b}	33.32^{a}	27.44^{b}	27.23
Winter wheat	Summer annual	37.24^{a}	20.72^{b}	42.84^{a}	27.72^{b}	32.13
1) red clover	Winter annual	6.86^{a}	1.96^{c}	4.34^{b}	4.48^{b}	4.41
2) barley, undersown	Total	44.10^{a}	22.68^{b}	41.18^{a}	32.20^{b}	35.04
Pea	Summer annual	28.28^{a}	30.52^{a}	38.08^{a}	25.34^{b}	30.56
1) winter wheat	Winter annual	0.98^{ab}	2.94^{a}	1.54^{ab}	1.12^{b}	1.65
2) red clover	Total	29.26^{a}	33.46^{a}	39.62^{a}	26.46^{b}	32.20
Potato	Summer annual	38.6^{a}	26.26^{b}	27.82^{b}	38.09^{a}	32.70
1) pea	Winter annual	0.91^{a}	1.69^{a}	0.91^{a}	0.78^{a}	1.07
2) winter wheat	Total	39.52^{a}	27.95^{b}	28.73^{b}	38.87^{a}	33.77
Average	Summer annual	32.78^{a}	25.52^{b}	35.19^{a}	28.37^{ab}	30.47
	Winter annual	2.17^{a}	1.68^{a}	1.95^{a}	2.20^{a}	2.00
	Total	34.95^{a}	27.20^{b}	37.14^{a}	30.57^{ab}	32.47

Note. Within the same row, values with different letters are significantly different (ANOVA, Fisher (LSD) test); 1) – preceding crops in 2009; 2) – preceding crops in 2008.

According to Lithuanian authors (Boguzas et al., 2004) there were 28% more weed seeds in plots where manure was applied at the start of conversion period to organic cultivation compared to conventional system, but during the 6th cultivation season the number of weed seeds was similar in both systems. In 7-year organic cultivation experiment in Germany it was concluded that the soil weed seed bank was reduced by 39.0% when grasses undersown with clover were used (Albrecht, 2005).

On average for the crops used in rotation (Table 1) the Shannon-Wiener diversity indexes (H') were similar in Conv I and Org II variants, while being higher by 0.12–0.14 compared to Conv II and Org I variants (Table 2). On the other hand, the Simpson's indexes of domination (λ) of Conv II and Org I variants were lower by 0.05–0.09 compared to Conv I and Org II variants. The effect of fertilization was observed for the Pielou evenness indexes (J'): it was the highest in unfertilized Conv I variant and differed by 0.07 in Conv II (mineral fertilizer), by 0.06 in Org II (manure and winter cover crops) and only by 0.12 in Org I variant (only winter cover crops were used).

Table 2. Species diversity (Shannon-Wiener), Simpson domination index and evenness index of the arable weed seed bank in different crops in 2010

Crops	Shannon-Wiener diversity index, *H'*				Simpson's domination index, λ				Pielou evenness index, *J'*			
	Con I*	Con II	Org I	Org II	ConI	Con II	Org I	Org II	ConI	Con II	Org I	Org II
Barley	0.76	0.53	0.56	0.66	0.65	0.77	0.78	0.68	0.47	0.27	0.29	0.38
R. clover	0.70	0.8	0.56	0.89	0.64	0.64	0.75	0.59	0.44	0.45	0.31	0.43
W. wheat	1.07	0.69	0.90	0.98	0.49	0.68	0.61	0.57	0.49	0.43	0.41	0.50
Potato	0.65	0.66	0.48	0.45	0.69	0.72	0.8	0.81	0.40	0.37	0.25	0.23
Pea	0.75	0.6	0.73	0.77	0.67	0.74	0.67	0.68	0.38	0.31	0.35	0.37
Average	0.79	0.66	0.65	0.78	0.63	0.71	0.72	0.66	0.44	0.37	0.32	0.38

* Con I (or II) = Conv I (or II).

In experiments by Edesi et al. (2012) it was observed that the land use intensity influenced the diversity of weed species. The average values of Shannon-Wiener diversity index were statistically higher in the organic (organic with green manure – 1.70, organic with cattle manure and green manure – 1.65) than in the conventional (1.06; $p < 0.05$) treatment.

According to Albrecht (2003) the activity of organisms detrimental to weed seeds may be increased due to large amounts of organic fertilizers and therefore the soil weed seed bank is reduced. The content of organic carbon (Corg) which formerly decreased due to lower organic matter input and frequent tilling remains the same or increases due to the application of organic fertilizers (Paustian et al., 1997; Blair, 2000). In the present experiment the highest amounts of organic matter were applied in the Org II system where winter cover crops and manure were additionally applied (Table 3). Due to this organic matter the Corg content in soil was significantly increased in both organic cultivation systems by the end of 2009. According to Kauer et al. (2015a; 2015b) the level of Corg in Org I and Org II systems remained higher than in conventional systems also during succeeding growing seasons.

There were 59 species of ground beetles in the present test area in 2010. The dominant species was *Harpalus rufipes*. Zhang et al. (Zhang, 1993; Zhang et al., 1994) found that this species is an important seed predator, whose larvae and adults both have seed predator qualities and according to Lalondea et al., (2012) it has great importance in areas where weed protection methods are limited. *Harpalus rufipes* damages the germination of the seeds of several annual weeds, including Common lambsquarters

(*Chenopodium album* L.), not only through direct consumption of seeds but also through burying activities of larvae and adult beetles to deeper soil layers where germination conditions are unfavourable (Hartke et al., 1998). Seed predators can damage up to 4,000 seeds per m^2 a day. As seed predators may significantly reduce the weed seed bank they may therefore be an important factor against weeds (Honek et al., 2003).

Table 3. Average C inputs (kg ha^{-1}) from main crops, winter cover crop (WCC), manure and weeds (based on the dry matter) in different farming systems per year

Farming system	Main crop	WCC	Weeds	Manure	Total
Conv I	3,226	0	0	0	3,226
Conv II	3,301	0	0	0	3,302
Org I	3,105	562	748	0	4,415
Org II	2,936	562	769	495	4,762

Our results indicated, that higher number of all species of ground beetles and lower number of weed seeds were found in areas where cover crops had been grown for green manure (Org I and Org II systems). The winter cover crops offer additional possibilities for overwintering of ground beetles.

In 2010 no significant differences in numbers of dominant species and other species of ground beetles were observed between variants. But according to Kruus et al. (2012) there was significantly higher number of ground beetles in organic variants of our experiment (especially in plots where pea was grown) in 2011. In 2010, the second most frequent seed predator was *Harphalus affinis* that was mostly abundant in plots where winter wheat was grown. *Harphalus affinis* prefers smaller seeds (Honek et al, 2003). The results of the multifactorial dispersion analysis indicated that the effect of management and the crop grown on the abundance of ground beetles was significant ($F=1.765$ ja $F=2.109$; $P \leq 0.001$).

The abundance and activity of many species of ground beetles is higher in no-tillage areas (Lalondea et al., 2012). For the seed predators to be able to damage the weed seeds in the soils of cultivated fields the physical properties of the soil have to be favourable (e.g. soil has to contain abundance of pores). Excessive compaction of soil affects nutrient uptake of cultivated plants and decreases their ability to compete with weeds (Reintam & Kuht, 2012).

In average the penetration resistance at the depth of up to 40 cm soil layer was lower in the crop rotation of conventional cultivation systems (Conv I and Conv II) compared to organic cultivation systems (Org I and Org II). But at the depth of 5 cm where it's easy for the seed predators to reach the seeds, the penetration resistance of the soil was 0.85–1.15 MPa. The correlative relationship between soil compaction and the number of weed seeds was observed ($r = 0.59$; $P < 0.05$). While at the time of sample collection the soil moisture content was ca 2% higher in organic variants (18.1%) than in conventional farming systems (16.3%), the soil could have lower penetration resistance. Therefore the different top soil conditions between variants could have contributed to the variation in activity of seed predators. According to Sanchez de Cima et al. (2012; 2015) the highest soil total porosity in 2011 was measured in organic system where manure had been applied (Org II, 44.7%) and the lowest in conventional system with no fertilization (Conv II, 40.9%). Hence the conditions for weed seed predators were more favourable in organic variants (especially in Org II) where manure had been applied compared to conventional farming system.

CONCLUSIONS

The unregularity of the number of weed seeds at the start of the conversion period to organic production changed to clear conformity where the variation in the abundance of weed seeds between variants became clearly apparent. Although the lowest number of weed seeds was measured in fertilized variant Conv II, significant reduction of the number of weed seeds in organic system was observed at the end of conversion period. In the soils of the organic cultivation system area where cover crops and manure had been used (Org II) the markedly lower content of weed seeds was observed compared to Org I system where only green manure had been applied. The decrease of the number of weed seeds in Org II system could have been due to the increase of content of soil organic carbon, higher number of species and the activity of seed predators in organic cultivation variants.

Hence the conditions for weed seed predators were more favourable in organic variants where manure had been applied compared to conventional farming system.

ACKNOWLEDGEMENTS. The authors gratefully acknowledge the financial support for this research provided by the ERA-NET CORE ORGANIC project FertilCrop and by Estonian University of Life Sciences project 8–2/P13001PKTM.

REFERENCES

Albrecht, H. 2003. Suitability of arable weeds as indicator organisms to evaluate species conservation effects of management in agricultural ecosystems. *Agric. Ecosyst. Environ.* **98**(1–3), 201–211.

Albrecht, H. 2005. Development of arable weed seedbanks during the 6 years after the change from conventional to organic farming. *Weed Reasearch* **45**(5), 339–350.

Blair, N. 2000. Impact of cultivation and sugar-cane green trash management on carbon fractions and aggregate stability for a cromic luvisol in Queensland, Australia. *Soil Tillage and Research* **55**, 183–191.

Boyce, R.L. 2005. Life under your feet: Measuring soil invertebrate diversity. *Teaching Issues and Experiments in Ecology, Volume 3*, Ecological Society of America http://tiee.ecoed.net/vol/v3/experiments/soil/abstract.html. Last accessed. 23.03.2016.

Boguzas, V., Marcinkeviciene, A. & Kairyte A. 2004. Quantitative and qualitative evaluation of weed seed banks in organic farming. *Agronomy Research* **2**(1), 13–22.

Carolyn, D., Kemp, L., Jane Sooby, J. & Sullivan, E. 2012. Organic farming for health and prosperity. *Organic Farming Research Foundation*, 75 pp.

Edesi, L., Järvan, M., Adamson, A., Lauringson, E. & Kuht, J. 2012. Weed species diversity and community composition in conventional and organic farming: a five-year experiment. *Žemdirbystė (Agriculture)* **99**(4), 339–346.

Egley, G.H. 1995. Seed germination in soil: Dormancy cycles. In: *Seed development and germination.* Marcel Dekker, New York, pp. 529–543.

Gianessi, L. & Reigner, N. 2005. Barriers to widespread conversion from Chemical Pest Control to non-Chemical Methods in US Agriculture, Pest and Nutrient Management. Track 1. In: *Proceedings of the Third International Conference on the Future of Agriculture*. August 7–9, 2006, Sacramento, California, 63–68. Harrison, S. & Gallandt. E.R. 2012. Behavioural

studies of *Harpalus rufipes* De Geer: An Important Weed Seed Predator in Northeastern US Agroecosystems. *International Journal of Ecology*, 6 pp.
Grundy, A.C. & Jones, N.E. 2002. What is the weed seed bank? In: *Weed Management Handbook* (ed R.E.L. Naylor), Blackwell Science and BCPC, Oxford, pp. 39–62.
Hartke, A., Drummond, F.A. & Liebman, M. 1998. Seed feeding, seed caching, and burrowing behaviors of *Harpalus rufipes* DeGeer larvae (*Coleoptera: Carabidae*) in the Maine potato agroecosystem. *Biological Control* **13**, 91–100.
Honek, A., Martinkova, Z. & Jarosik, V. 2003. Ground beetles (*Carabidae*) as seed predators. *European Journal of Entomology* **100**, 531–544.
Kauer, K., Tein, B., Sanchez de Cima, D., Talgre, L., Eremeev, V., Loit, E. & Luik, A. 2015a. Soil carbon dynamics estimation and dependence on farming system in a temperate climate. *Soil & Tillage Research* **154**, 53–63.
Kauer, K., Tein, B., Talgre, L., Eremeev, V. & Luik, A. 2015b. Estimation of soil carbon Dynamics and it's dependence on the farming system. *Agronomy 2015*, pp.16–21.
Kruus, M., Kruus, E. & Luik, A. 2012. Effect of cultivation method on beetles biodiversity. *From science to organic farming*, Tartu, pp. 53–55 (in Estonian).
Lalondea, O., Légèrea, A., Stevenson, F.C., Roya, M. & Vanasse, A. 2012. Carabid beetle communities after 18 years of conservation tillage and crop rotation in a cool humid climate. *The Canadian Entomologist* **5**, 645–657.
Palts, E. & Vetemaa, A. 2012. Mahepõllumajanduse nõuete selgitus tootjale. *Organic farming explanation to manufacturer 2013.* Estonian Ministry of Agriculture, 66 pp. (in Estonian).
Paustian, K., Levine, E., Post, W.M. & Ryzhova, I.M. 1997. The use of models to integrate information and understanding of soil C at the regional scale. *Geoderma* **79**, 227–260.
Pielou, E.C., 1966. The measurement of diversity in different types of biological collections.
Journal of Theoretical Biology **13**, 131–44.
Reintam, E., Trükmann, K., Kuht, J., Nugis, E., Edesi, L., Astover, A., Noormets, M., Kauer, K., Krebstein, K. & Rannik, K. 2009. Soil compaction effects on soil bulk density and penetration resistance and growth of spring barley (*Hordeum vulgare* L.). *Acta Agriculturæ Scandinavica*, *Section B - Soil and Plant Science* **59**(3), 265–272.
Reintam, E. & Kuht, J. 2012. Weed responses to soil compaction and crop management. In: *Weed Control*, INTECH - Open Access Company, pp. 243–264.
Sanchez de Cima, D., Reintam, E. & Luik, A. 2012. Influence of cultivation methods on the some soil physical properties. *From science to organic farming*, Tartu, pp. 15–17 (in Estonian).
Sanchez de Cima, D., Luik, A. & Reintam, E. 2015. Organic farming and cover crops as an alternative to mineral fertilizers to improve soil physical properties. *Inernational Agrophysics* **29**, 405–412.
Shannon, C.E. 1948. A mathematical theory of communication. *Bell System Technical Journal* **27**, 379–423.
Simpson, E.H. 1949. Measurement of diversity. *Nature* 163, 688 pp.
Statsoft. 2005. Statistica 7,0. Copyright 1984–2005. Tulka, OK, USA, 716 pp.
Verhulst, N., Govaerts, B., Verachtert, E., Castellanos-Navarrete, A., Mezzalama, M., Wall, P.C., Chocobar, A., Deckers, J., Sayre, K.D. 2010. Conservation agriculture, improving soil quality for sustainable production system. In: Advances in soil science: food security and soil quality. CRC Press, Boca Raton, FL, USA, 55 pp.
Vipper, H. 1989. Umbrohuseemnete varu mullas. In: Maaviljeluse praktikum, Tallinn. 221–226 (in Estonian).
Zhang, J. 1993. Biology of *Harpalus rufipes* DeGeer (*Coleoptera: Carabidae*) in Maine and dynamics of seed predation. In: *M.S. thesis*, University of Maine, Orono, 154 pp.
Zhang, J., Drummond, F. & Liebman, M. 1994. Spread of *Harpalus rufipes* DeGeer (*Coleoptera*: *Carabidae*) in eastern Canada and the United States. *Entomol. Trends in Agric. Sci*. **2**, 67–71.

Agronomy Research **14**(4), 1380–1385, 2016

Measurement of mulcher power input in relation to yield

F. Kumhála[1,*], J. Chyba[1], M. Pexa[1] and J. Čedík[2]

[1]Czech University of Life Sciences, Faculty of Engineering, Kamýcká 129, CZ 16521 Prague-6 Suchdol, Czech Republic
[2]Research Institute of Agricultural Engineering, p.r.i., Drnovská 507, CZ 16101 Prague-6, Czech Republic
[*]Correspondence: kumhala@tf.czu.cz

Abstract. Mulching is one of relatively energy-demanding operations in plant production. That is why the knowledge of mulcher power input is very interesting and can be used e.g. for mulcher design improvement etc. Field experiments were arranged in order to measure mulcher power input also in relation to yield. The field of about 1.25 ha area was harvested by mulcher MZ6000 produced by BEDNAR FMT Co. This machine has three rotors with vertical axis, working width 6 m and was aggregated with JD 7930 tractor. Power input was measured by torque dynamometer Manner MFI 2500 placed at tractor PTO shaft. Measured data were processed by A/D converter Labjack U 6 and saved. After the harvest, the samples of harvested material from area 6 x 1.65 m were weighted by hands on 102 places in almost regular grid. Average measured mulcher power input was relatively high, 76 kW, with peaks reaching up 145 kW. The yield of harvested material on experimental field was very unbalanced and varied from 0.6 to 13 tonnes per hectare. The amount of measured data allowed the creation of power input and yield maps. By comparing the results from power input and yield measurement it was found that power input significantly depended on the yield. Information of mulcher power input can be used also for harvested material yield mapping.

Key words: mulcher, cutting, power input, yield mapping.

INTRODUCTION

The knowledge of machinery power requirement is important both for machinery development as well as for machinery management. According to Rotz & Muhtar (1992), farm managers use power data to match tractors and implements for efficient and cost effective operations.

Energy demands of different processes of cutting plant materials were studied in past (e.g. O´Dogherty (1982); Persson (1987); Rotz & Muhtar (1992) etc.) while efforts to achieve energy savings during cutting process still remain. New technologies of cutting plant materials were and are still proposed and tested (e.g. Tuck et al. (1991), Zhang et al. (2003), Igathinathane et al. (2007), Maughan et al. (2014) etc.) and energy demands for different plants and different harvesting technologies are still evaluated (e.g. Igathinathane et al. (2010), Wegener & Wegener (2013), Ma et al. (2014), Popp et al. (2015), Lien & Liu, (2015) etc.).

Mulching is among energy intensive crop harvesting operations. It is therefore interesting to deal with mulching energy demands in more details. Processes like mulching were studied in past.

For example, according to O´Dogherty (1982), when using forage harvester, 35% of power only is utilized in chopping and 50% in accelerating the cut material, which in itself is interesting. Other processes than cutting only must be also taken into account.

Persson (1987) published different factors influencing force, energy and power necessary for cutting. In the case of forage harvesters, cutting power increased approximately linearly with wet material feed rate increasing. In the case of rotary mowers, cutting power increased also approximately linearly with forward speed increasing.

Rotz & Muhtar (1992) reported that energy demands of rotary mower are about 5 kW m^{-1} with a range of ± 30% while those of flail mower are in a range of 6 to 15 kW m^{-1} with a typical value of 10 kW m^{-1}.

Taking into account those facts it was decided to measure mulcher power input on tractor PTO shaft in order to better understand its distribution during real harvest. The main aim of this article therefore was to assess mulcher power input distribution during infield tests and to find the influence of different factors on mulcher power needs. This knowledge may be useful for mulcher design improvement.

MATERIALS AND METHODS

The mulcher equipped with three rotors with vertical axis of rotation, type MZ6000, produced by BEDNAR FMT Co. was used for infield tests. The diameter of each rotor was 2 m while 4 knifes are located on each rotor. Therefore, working width of the machine was 6 m and during the measurements it was equipped with John Deere 7930 tractor. Engine power of this tractor was 179 kW. The field of app. 1.25 ha area was harvested during our experiments. Grasslands of different species were grown in our experimental field. Dominating species were *Poaceae (Poa pratense, Phleum pratense, Festuca rubra, Lolium perenne)* in the growth stage from stem elongation to the end of flowering. Important specie was also *Rumex Crispus* after the beginning of flowering.

The measurements of no-load power input were carried out by 23 July 2014 and next day, 24 July 2014, infield measurements were done. Stationary measurements of no-load power were arranged on flat concrete surface. Working height (stubble length) of the machine was set up to usual value of 50 mm. Measurements were done for the range from 500 to 1,000 rpm of PTO shaft (52–105 m s^{-1} knifes peripheral speed).

Mulcher power input was measured by torque dynamometer, type Manner MFI 2500, which was placed at tractor PTO shaft. Torque and shaft rotational speed was measured. Measured data were processed by Labjack U 6 A/D converter. Data were saved every second together with positioning signal from DGPS signal receiver Qstarz BT-Q1000X with positioning precision ± 0.1 to 0.3 m horizontally and ± 0.2 to 0.6 m vertically.

For infield measurements, mulcher stubble length was set to 50 mm (the same as for stationary measurements). It was decided to use forward speed of the mulcher as similar as possible with normal working conditions.

Aerial photos of harvested field were taken from a height of 130 m before and after its harvest using Asctec Falcon 8 drona.

After the harvest, the yield on about one half of the field was determined. 102 samples of harvested material were manually collected and weighted from the areas of 6 x 1.65 m in almost regular grid (see Fig. 2 right).

Data obtained from both measurements were then used for calculation and charting. MS Excel 2010 software was used for calculations and statistical analysis, ArcGIS 10.2 software for maps creation.

RESULTS AND DISCUSSION

The results of mulcher no-load power input measurements can be seen in Fig. 1. It is clear from this graph that no-load power input increased exponentially with PTO rpm increasing. Maximum power input reached 29.15 kW for 1,000 PTO rpm (normal mulcher working rpm). It represented power input of 4.86 kW m^{-1} of working width.

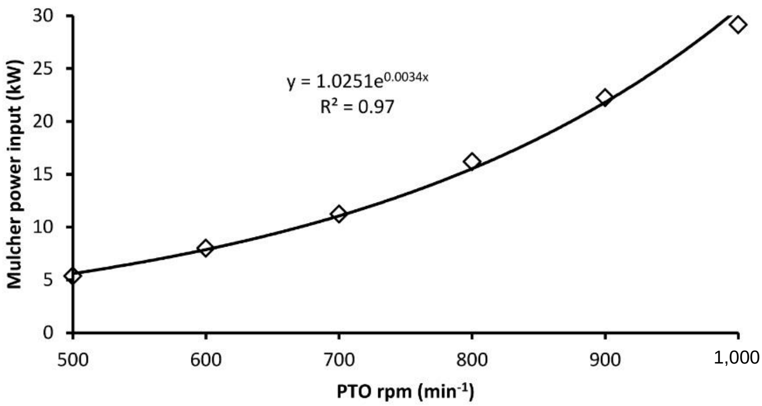


Figure 1. The dependence of mulcher no-load power input on PTO rpm.

The aim of infield measurements was to know power input course during real harvest. That is why forward speed varied in a wide range from 2.98 to 14.32 km h^{-1} with an average of 7.95 km h^{-1}.

Measured mulcher power input also varied in a wide range from 29.86 to 144.25 kW (4.97–24.04 kW m^{-1}) with an average of 79.57 kW. It represents 13.26 kW of average mulcher power input for 1 m of working width. This is in agreement with previously published results for flail mowers power input (6–15 kW m^{-1}; Rotz & Muhtar, 1992) as a comparable machine. Nevertheless, the results obtained were still slightly higher. Authors above reported typical value of 10 kW m^{-1} while our average resulted more than 30% higher. The peaks near to 145 kW were just on the limit of used tractor engine power. It can be caused maybe also by different design of mulching machine. Minimum measured power input corresponded well with the one measured in previous stationary measurement for 1,000 rpm of PTO.

The distribution of measured mulcher power input throughout the field can be seen in the map in Fig. 2 (left).

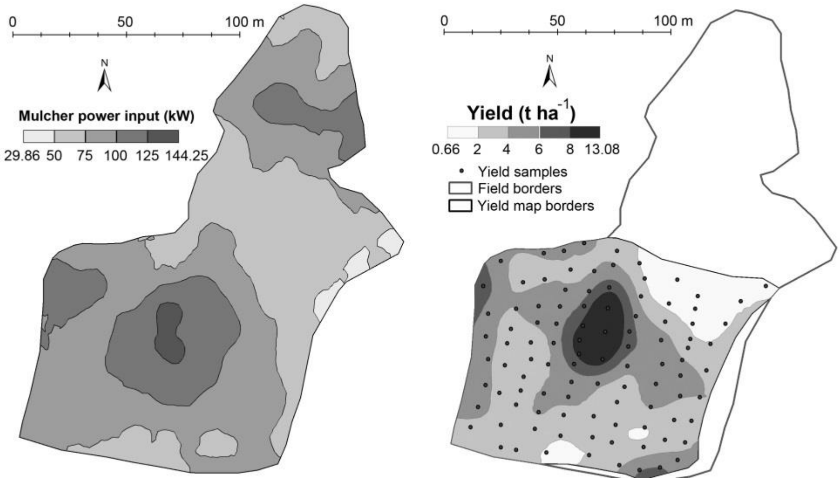


Figure 2. The distribution of mulcher power input measured at tractor PTO shaft during the harvest of experimental field (left) and yield map created in the part of harvested field (right).

In order to study the influence of changes in yield on mulcher power input, a yield map was created from the part of the field where the yield was measured by hands. The yield showed also a wide range of measured values from 0.6 to 13.08 t ha^{-1} with average value of 4.08 t ha^{-1}.

Yield distribution on investigated part of field can be seen in Fig. 2 (right) together with the locations of yield samples collecting areas. Measured mulcher power input can be visually compared with the yield at southern part of the field. It is evident from this comparison that here is a clear dependence of measured power input on harvested grass yield. In the areas with higher grass yield higher conditioner power input was also measured. Taking in mind changing forward speed of harvesting equipment, this result was very interesting. The dependence of these two factors (mulcher power input and yield) was not expected to be so obvious. Persson (1987) reported linear relationship between rotary mower power input and forward speed.

The fact about the mulcher power input dependence on yield was also supported by statistical analysis. 102 points on which hand measurement of grass yield was carried out served as a base for this evaluation. Mulcher power input data from the buffer with a diameter 6 m, the centre of which was each from those 102 points, were averaged and then compared with yield. Summary statistics of the data used for next statistical comparison are provided in Table 1.

Table 1. Summary statistics of the variables used for the statistical evaluation of the dependence of mulcher power input on harvested grass yield

Summary Statistics	Count	Mean	Median	Std. Dev.	Minimum	Maximum	Skewness
Measured grass yield (t ha^{-1})	102	4.11	3.61	2.46	0.66	13.1	1.34
Mulcher power input (kW)	102	90.1	90.44	13.77	68.6	130.5	0.68

Data skewness was in the interval ± 2 in both cases. Common statistical procedures can be used for next data evaluation in this case. Mulcher power input data corresponded well with those displayed in the map (see Fig. 2 left) from investigated part of the field. The dependence of measured mulcher power input on measured yield is expressed graphically in Fig. 3. It follows from this graph that mulcher power input data depended linearly on yield data with sufficient coefficient of determination.

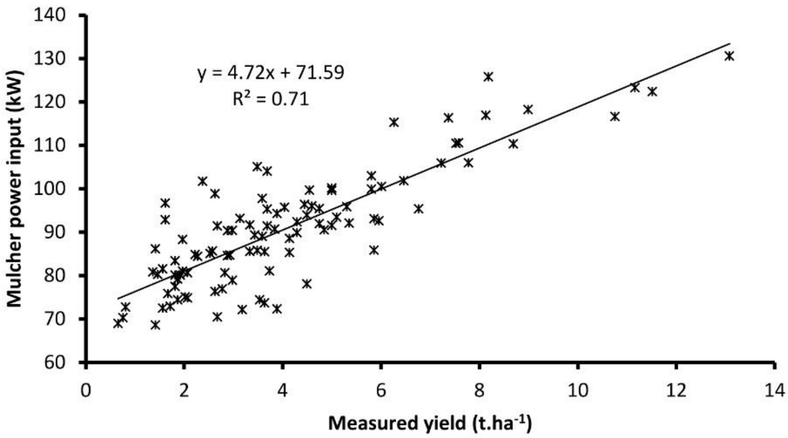


Figure 3. The dependence of measured mulcher power input on measured yield.

Aerial photos of experimental field were taken before (Fig. 4 left) and after (Fig. 4 right) its harvest by mulcher. Fig. 4 (left) well corresponded with yield distribution throughout the field. Darker area represented higher yield can be seen in this figure at the same place as in the yield map. Working paths of harvesting machine are clear from right side of Fig. 4.

Figure 4. Aerial photos of the experimental field before (left) and after its harvest by mulcher.

CONCLUSIONS

Relatively high no-load power input of the mulcher with vertical axis of rotation in comparison with total one was measured. Measured total mulcher power input was also of about 30% higher than the published in literature. In this context, it might be interesting to deal with mulcher design changes or different machine set-up (mainly different PTO rpm) for different harvesting conditions. It could lead to energy savings during mulching operation.

During the harvest, mulcher power input significantly depended on harvested grass yield although travel speed changed significantly. Side effect of mulcher power input measurement can be its use for grasslands yield maps creating. Aerial photos supported results achieved and it can also help with the optimization of working paths.

ACKNOWLEDGEMENTS. This work was supported by Technology Agency of the Czech Republic, project No. TA03010138.

REFERENCES

Igathinathane, C., Womac, A.R. & Sokhansanj, S. 2010. *Effect of angle of cut on corn stalks mechanical cutting strength and energy.* ASABE paper no. 1008644. ASABE, Michigan, USA, 15 pp.

Igathinathane, C., Womac, A.R., Sokhansanj, S. & Narayan, S. 2007. *Size reduction of wet and dry biomass by linear knife grid device.* ASABE paper no. 076045. ASABE, Michigan, USA, 15 pp.

Lien, C.-C. & Liu, H.-W. 2015. Shear characteristics of napier grass stems. *Applied Engineering in Agriculture* **31**(1), 5–13.

Ma, S., Karkee, M., Scharf, P.A. & Zhang, Q. 2014. Sugarcane harvest technology: a critical overview. *Applied Engineering in Agriculture* **30**(5), 727–739.

Maughan, J.D., Mathanker, S.K., Fehrenbacher, B.M. & Hansen, A.C. 2014. Impact of cutting speed and blade configuration on energy requirement for *Miscanthus* harvesting. *Applied Engineering in Agriculture* **30**(2), 137–142.

O´Dogherty, M.J. 1982. A review of research on forage chopping. *Journal of Agricultural Engineering Research* **27**(4), 267–289.

Persson, S. 1987. *Mechanics of cutting plant materials.* ASAE, Michigan, USA, 288 pp.

Popp, M.P., Searcy, S.W., Sokhansanj, S., Smartt, J. & Cahill, N. 2015. Influence of weather on the predicted moisture content of field chopped energy sorghum and switchgrass. *Applied Engineering in Agriculture* **31**(2), 179–190.

Rotz, C.A. & Muhtar, H.A. 1992. Rotary power requirements for harvesting and handling equipment. *Applied Engineering in Agriculture* **8**(6), 751–757.

Tuck, C.R., O´Dogherty, M.J., Baker, D.E. & Gale, G.E. 1991. Laboratory studies of the performance characteristics of mowing mechanisms. *Journal of Agricultural Engineering Research* **50**(1), 61–80.

Wegener, J. & Wegener, T. 2013. Kinematics and geometry of helical chipping with cylindrical helical blades. *Transactions of ASABE* **56**(4), 1291–1297.

Zhang, M., Sword, M.L., Buckmaster, D.R. & Cauffman, G.R. 2003. Design and evaluation of a corn silage harvester using shredding and flail cutting. *Transactions of ASAE* **46**(6), 1503–1511.

Agronomy Research **14**(4), 1386–1394, 2016

Low degradation of a-Si solar panels of the building integrated PV power plant in Prague historical area

M. Libra[1,*], T. Olšan[1], V. Avramov[2] and V. Poulek[1]

[1]Czech University of Life Sciences Prague, Faculty of Engineering, Department of Physics, Kamycka 129, CZ 16521 Prague, Czech Republic
[2]ENESA, joint-stock company, Prague, Czech Republic
[*]Correspondence: libra@tf.czu.cz

Abstract. The unique photovoltaic power plant installed in Prague on the roof of the new buildings of National Theatre in Prague has been investigated. As the new buildings are very close to the old historical building of National Theatre designed in late 19th century, the PV power plant has to be totally invisible from the streets of Prague to not disturb historical panorama of the city. Flexible a-Si photovoltaic foils in the nearly horizontal position have been used because the placing is in the urban conservation area in the historical city centre. The operation started in the autumn 2009. The photovoltaic power plant is described in this paper and results of its operation are presented. The energy production data indicate that the degradation of the nearly horizontally installed a-Si panels is below 5% within 5 years period.

Key words: Photovoltaics, thin film a-Si panels; degradation; soiling.

INTRODUCTION

Recently investigation of the energy efficient building is more and more important especially because of the increasing availability of the renewable energy sources. Different types of PV panels and PV arrays were described for instance in next reports: photovoltaic (Poulek & Libra, 2000; Libra et al., 2011), photothermal (Cerón et al., 2015; Matuška et al., 2015), hybrid (Crisostomo et al., 2015). A review about the photovoltaic self-consumption in buildings and household power consumption was written for example in (Luthander et al., 2015; Munkhammar et al., 2015), data about building energy consumption and renewable energy consumption were presented in (Depoorter et al., 2015; Mathew et al., 2015). Measurement of energy production from BIPV system including a-Si PV panels is presented in (Davis et al., 2003) and (Dougherty el al., 2005).

The photovoltaic (PV) power plant in Prague on the National Theatre roof was designed and installed during the years 2008 and 2009. There was a photovoltaic's boom in the Czech Republic due to subsidiary policy and a number of larger or smaller solar PV power plants have been built. This boom culminated in the year 2010 and then a strict change of legislation has been adopted. Approximately 2000 MW_p (in total) of PV power plants and PV systems were installed in the Czech Republic before 1st January 2011 and this value remains same up to the present time.

A reconstruction of the Service Building roof and New Scene Building roof was realized from 2008 to 2009 and the unique PV power plant was designed and installed on the roofs. This power plant exhibits certain specific features and it is thus interesting from several points of view. With respect to its location in Prague historical area and national heritage protection it was impossible to use a classical construction with southward inclined PV panels based on crystalline silicon. It was very imperative to decide for a construction that would fully rest on the roof with its entire surface and would not interfere with the roof's contour in this precious locality. The flexible photovoltaic foils based on thin semiconductor layers have been therefore used to conform to the modern outlook of the buildings in a maximum measure.

Our many years of experience in the field of photovoltaics was already summarized in the book (Poulek & Libra, 2010). In this paper, we will describe a PV power plant of a completely different construction mentioned above and discuss our results of five-years monitoring of its operation.

The similar PV power plants were installed like building integrated (BIPV) or field installation. They were constructed like on-grid or off-grid. The reference (Dursun & Zden, 2014) shows for example the off-grid PV power plant used for irrigation. The construction of flexible PV foils on other bases is dealt with in detail elsewhere (Larsen-Olsen et al., 2012). The other various types of electrical interconnection for photovoltaic arrays are discussed in the reference (La Manna et al., 2014). The partially shaded PV system was tested and discussed in the reference (Kofinas et al., 2015). Another building integrated PV (BIPV) systems are investigated also in (Mandalaki et al., 2014; Shan et al., 2014).

Figure 1. PV power plant on the National Theatre roofs (New Scene Building left, Service Building right).

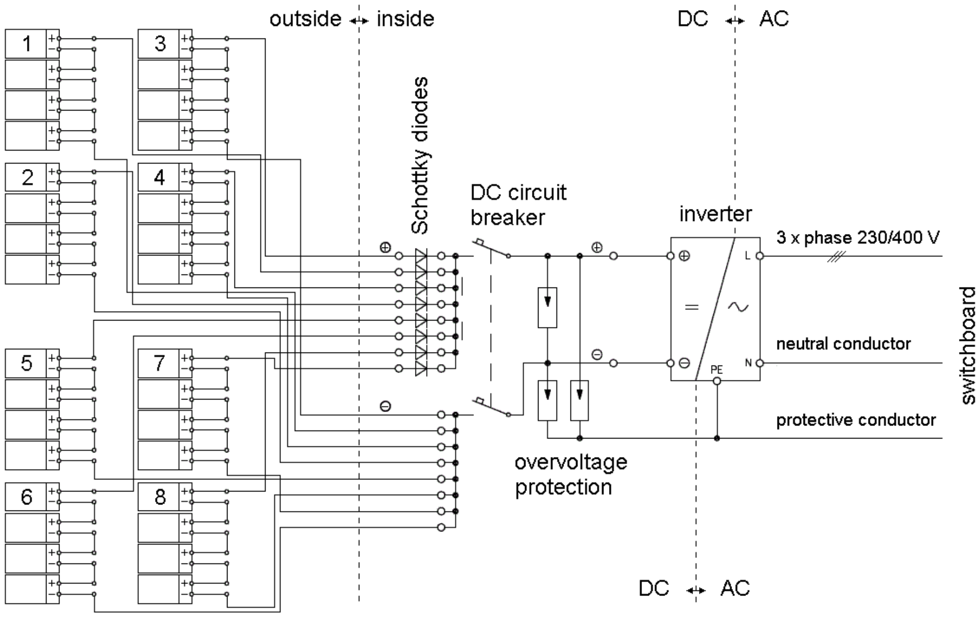


Figure 2. Wiring diagram of the PV power plant on the National Theatre New Scene Building roof.

MATERIALS AND METHODS

The PV power plant on the New Scene Building roof of Prague National Theatre (see Fig. 1 left) was designed so that it comprises two identical parts on the southern and northern halves of the roof. The only difference is given by the fact that the southern part was inclined by about 3° southward and the northern part by about 3° northward. Flexible PV foils of the nominal output power 0.406 kW_p have been used. PV cells based on thin semiconductor layers are encapsulated in the plastic material, they are mutually interconnected and they are directly integrated into the common roof PVC foils. Waterproof connectors are located on their back side. In both parts of this PV power plant, four PV foils were connected in series, eight of these series were connected in parallel and via a three-phase invertor Fronius IG 150 Plus, the generated electric power was supplied to the main power network. Fig. 2 shows the wiring diagram. On the National Theatre New Scene's roof are altogether 64 foils with an overall rated output of 26 kW_p (in two independent branches per 13 kW_p). A certain difference in the generated electric power can be expected, because one branch is slightly inclined southward and the other northward.

PV power plant on the National Theatre Service Building roof (see Fig. 3) was designed in the form of four independent branches. Flexible PV foils on an identical basis have been used, however with a somewhat lower nominal output power 0.203 kW_p. In two of these branches always six PV foils have been connected in series, these four series have been connected in parallel and via a single-phase invertor Fronius IG 40 the generated electric power was supplied into main network. In the other two branches, six PV foils were connected in series, five of these series were connected in parallel and via a single-phase invertor Fronius IG 60 the generated electric power was supplied into main network. Altogether 108 foils with the overall nominal output power 22 kW_p (in four separate branches of 2 x 4.9 kW_p and 2 x 6.1 kW_p) have been installed on the National Theatre Service Building roof. It is evident from Fig. 3 that part of this PV power plant is inclined about 3° eastward a part of the PV power plant is inclined about 3° westward to allow draining of water and self-cleaning of dust.

Figure 3. PV power plant on the National Theatre roofs (Service Building).

RESULTS AND DISCUSSION

The results of five-years monitoring of the electric power production by the PV power plant described above are presented in the following diagrams. Fig. 4 shows results from the PV system on the National Theatre New Scene Building roof, Fig. 5 shows results from the PV system installed on the National Theatre Service Building roof. To make the results comparable the values are recalculated to 1 kW_p of installed peak output power. It is evident that the year-round values correspond with the values expectable in Prague (50° north latitude) and that in winter months the amount of produced electric power is affected by the snow deposits on the roofs. Provided that snow would be regularly removed the amount of produced electric energy would be somewhat higher, but this could not be proved. This is evident from the zero amount of produced electric energy in January 2010 and from the minimum amount in December 2010. In the years 2011 and 2014 there was nearly no snowfall in Prague.

We can also see from these diagrams (Fig. 4) that on the New Scene Building there is always the amount of produced electric energy higher in parts inclined southward in comparison with parts inclined northward. On the Service Building roof, inclined eastward and westward, the values are not comparable and they are displayed like one value (Fig. 5).

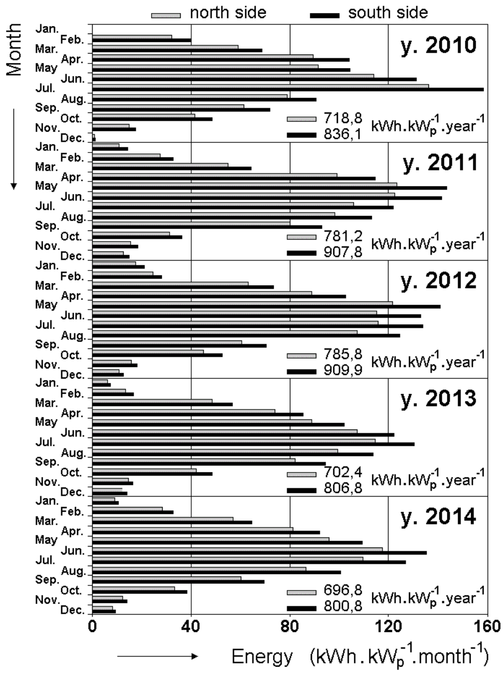


Figure 4. Electric energy produced in the PV power plant on the National Theatre New Scene Building roof during the years 2010–2014.

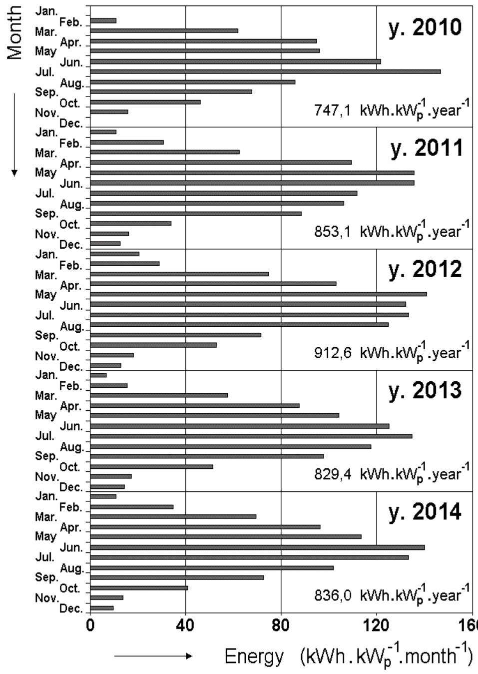


Figure 5. Electric energy produced in the PV power plant on the National Theatre Service Building roof during the years 2010–2014.

The PV panel area projection into the plane perpendicular to the Sun radiation is given by the incidence angle cosine ($S' = S_0 \cos\alpha$, where S_0 is the PV panel area and α is the incidence angle). The inclination of PV systems orientated northward and southward is approximately $\varphi = \pm 3°$. The incidence angle is 67° and 73°, respectively south/north part, at a low Sun elevation of 20° at the noon and the difference in the PV panels area projection into the plane perpendicular to the Solar radiation direction amounts to about 33%. The incidence angle is 27°and 33°, respectively south/north part, at a high Sun elevation of 60° at noon and the difference of the PV panels area projection into the plane perpendicular to the Solar radiation direction amounts to about 6%. Comparison of the results from the months in 2011 with a low Sun elevation, when the results were not distorted by snow deposits, reveals that the difference between the amounts of the produced electric energy was about 20%, in January it was even 31%. This difference is lower than the value of 33% evaluated above as along to the direct Sun radiation a small part of electric energy is also produced by the diffuse components, regardless of the incidence direction. In cloudy weather the difference between the produced electric energy is negligible. On the other hand, in spring and summer months with high Sun elevation the difference between the amounts of produced electric energy is about 15%. This difference is higher than the value of 6 % evaluated above as the Sun is at high elevations only for few hours round noon and for majority of the day it is at lower elevations and it does not radiate precisely from south. However, the difference is lower than in the winter months.

Finally Fig. 6 shows low degradation of the PV power plant energy production ~3% and ~4% respectively within 5 years period. It is less than expected as the plastic laminated a-Si degradation should be about 5% and the additional loss because of soiling (Cano, 2011) should be at least 2–3%.

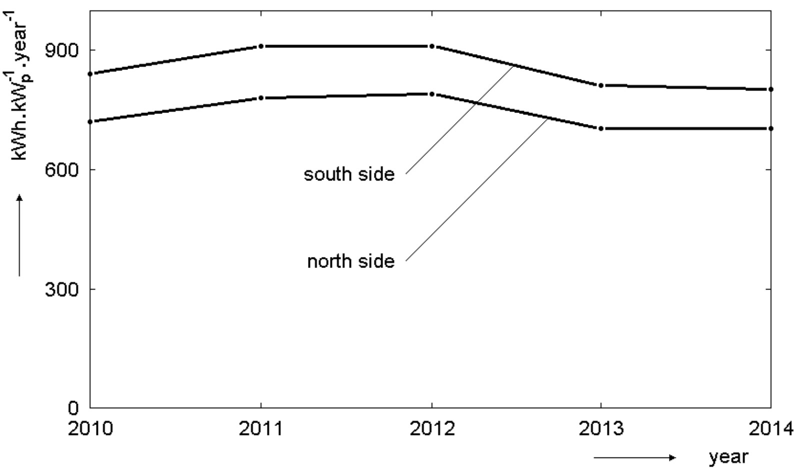


Figure 6. The annual energy production during the years 2010÷2014.

Tests with the same flexible PV foil were executed already in 2009 at the Czech University of Life Sciences Prague. Fig. 7 shows the PV foil with the nominal output peak power 0.406 kW_p. Fig. 8 presents examples of measurements of the instantaneous output power in dependence on the time during the selected days in 2009. The amount of the produced electric energy is given by the area under the graph because the amount of the electric energy produced in the time period Δt is given by the equation $W = \int_{\Delta t} P \, \mathrm{d}t$, where P is the instantaneous output power and t is the time. There are examples of the sunny days and cloudy days as well and the total produced electric energy amount is written. The average produced electric energy amount corresponds with our expectation and with the PV power plant mentioned above during the corresponding period (the years are different).

CONCLUSIONS

We consider the reconstruction of the National Theatre roofs with the incorporated PV power plant a suitable solution as the theatre management behaves ecologically (‘green’ solution). Regardless of the fact that the PV power plant described above can cover only a small part of the power consumption of the theatre, the roofs are purposefully used. The PV power plant construction on the basis of flexible PV foils was the only acceptable alternative with respect to the Prague historical centre conservation requirements. The power plant is not visible and the view on the Neo-Renaissence building of the National Theatre is not distracted as well as the view on the New Scene Building and Service Building.

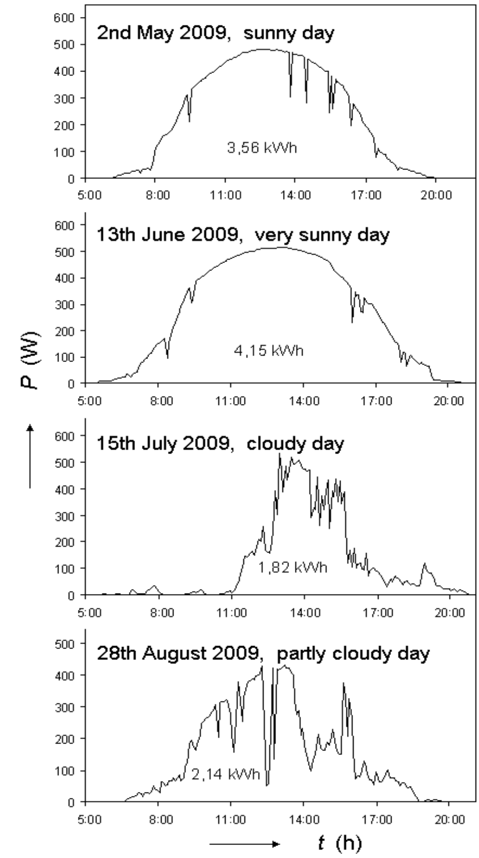


Figure 7. The PV foil with the nominal output peak power 0.406 kW_p at the Czech University of Life Sciences Prague.

Figure 8. Examples of the instantaneous output power of the PV foil in dependence on the time during the selected days in 2009.

The energy production within the 5 years period is better than expected. The energy production degradation is ranging from 3÷4%. It is low value for a-Si thin film panels laminated in polymer foils. The typical degradation value is about 5% (Radue & Dyk, 2010). Additionally, the panels are installed with very low tilt angle 3 degrees only. The polluted air in the center of big city is contributing to substantial soiling of the panels. So the soiling loss alone can contribute to 2–3% of the degradation. These results indicate that a-Si PV panels laminated in plastic film can have low degradation of the energy production even if it is installed horizontally in polluted urban environment.

Although the difference between the tilled angle of the both sides of the PV system is 6° only, the annual energy production difference is cca 15%.

We intend to continue in the collection of data and it will be certainly interesting to observe how the measured values will change in connection with the whole construction ageing. Another 440 kW_p BIPV power plant with the same a-Si PV panels in Prague is installed on the roof of the stadium of the SK Slavia football club (Fig. 9). The data have been collected too. Annual energy of this PV system production in the years 2011–2015 was in the range 789÷654 kWh kW_p^{-1} $year^{-1}$. The lifetime of the PV panels was simulated in (Hasan & Arif, 2014). The comparison with our collected data will be interesting. These data will be of interest also for designers of other roof PV systems.

Figure 9. PV power plant on the roof of the SK Slavia football club, Prague.

REFERENCES

Cano, J. 2011. Photovoltaic Modules: Effect of Tilt Angle on Soiling. Thesis, Arizona State University.

Cerón, J.F., Perez-Garcia, Solano, J.P., Garcia, A. & Herrero-Martin, R. 2015. A coupled numerical model for tube-on-sheet flat-plate solar liquid collectors. Analysis and validation of the heat transfer mechanisms. *Applied Energy* **142**, 275–287.

Crisostomo, F., Taylor, R.A., Surjadi, D., Mojiri, A., Rosengarten, G. & Hawkes, E.R. 2015. Spectral splitting strategy and optical model for the development of a concentrating hybrid PV/T collector. *Applied Energy* **141**, 238–246.

Davis, M. W., Fanney, A.H. & Dougherty, B.P. 2003. Measured Versus Predicted Performance of Building Integrated Photovoltaics. *Journal of Solar Energy Engineering* **125**, 22–27.

Depoorter, V., Oró, E. & Salom, J. 2015. The location as an energy efficiency and renewable energy supply measure for data centres in Europe. *Applied Energy* **140**, 338–349.

Dougherty, B.P., Fanney, A.H. & Davis, M.W. 2005. Measured Versus Predicted Performance of Building Integrated Photovoltaics – Round 2. *Journal of Solar Energy Engineering* **127**, 314–323.
Dursun, M. & Zden, S. 2014. An efficient improved photovoltaic irrigation system with artificial neural network based modeling of soil moisture distribution - A case study in Turkey. *Computers and Electronics in Agriculture* **102**, 120–126.
Hasan, O. & Arif, A.F.M. 2014. Performance and life prediction model for photovoltaic modules: Effect of encapsulant constitutive behavior. *Solar Energy Materials and Solar Cells* **122**, 75–87.
Kofinas, P., Dounis, A.I., Papadakis, G. & Assimakopoulos, M.N. 2015. An Intelligent MPPT controller based on direct neural control for partially shaded PV system. *Energy and Buildings* **90**, 51–64.
La Manna, D., Beránek, V, Sedláček, P., Mareš, J., Poulek, V., Bican, P. & Korostenský, T. 2014. Reconfigurable electrical interconnection strategy for photovoltaic arrays: A review. *Renewable and Sustainable Energy Reviews* **33**, 412–426.
Larsen-Olsen, T.T., Andersen, T.R., Andreasen, B., Bottiger, A.P.L., Bundgaard, E., Norrman, K., Andreasen, J.W., Jorgensen, M. & Krebs, F.C. 2012. Roll-to-roll processed polymer tandem solar cells partially processed from water. *Solar Energy Materials & Solar Cells* **97**, 43–49.
Libra, M., Beránek, V, Sedláček, P., Mareš, J., Poulek, V., Bican, P. & Korostenský, T. 2011. Comparison of photovoltaic power plants of various design and location in the Czech Republic. *Fine Mechanics and Optics* **56**(5), 156–159 (in Czech).
Luthander, R., Widén, J., Nilsson, D. & Palm, J. 2015. Photovoltaic self-consumption in buildings: A review. *Applied Energy* **142**, 80–94.
Mandalaki, M., Tsoutsos, T. & Papamanolis, N. 2014. Integrated PV in shading systems for Mediterranean countries:Balance between energy production and visual comfort. *Energy and Buildings* **77**, 445–456.
Mathew, P.A., Dunn, L.N., Sohn, M.D., Mercado, A., Custudio, C. & Walter, T. 2015. Big-data for building energy performance: Lessons from assembling a very large national database of building energy use. *Applied Energy* **140**, 85–93.
Matuška, T., Sourek, B., Jirka, V. & Pokorny, N. 2015. Glazed PVT Collector with Polysiloxane Encapsulation of PV Cells: Performance and Economic Analysis. *International Journal of Photoenergy*, 2015, Article ID 718316.
Munkhammar, J., Widén, J. & Rydén, J. 2015. On a probability distribution model combining household power consumption, electric vehicle home-charging and photovoltaic power production. *Applied Energy* **142**, 135–143.
Poulek, V. & Libra, M. 2000. A New Low Cost Tracking Ridge Concentrator. *Solar Energy Materials and Solar Cells* **61**(2), 199–202.
Poulek, V. & Libra, M. 2010. Photovoltaics, theory and practice of solar energy utilization. ILSA, Prague, 169 pp. ISBN 978-80-904311-2-6.
Radue, C. & Dyk, E.E. 2010. A comparison of degradation in three amorphous silicon PV module technologies. *Solar Energy Materials & Solar Cells* **94**, 617–622.
Shan, F., Tang, F., Cao, L. & Fang, G. 2014. Dynamic characteristics modeling of a hybrid photovoltaic–thermal solar collector with active cooling in buildings. *Energy and Buildings* **78**, 215–221.

Agronomy Research **14**(4), 1395–1405, 2016

Proposal for filtration system for biodegradable lubricants in agricultural tractors

R. Majdan[1,*], Z. Tkáč[1], R. Abrahám[1], M. Szabó[1], M. Halenár[1], M. Rášo[2] and P. Ševčík[2]

[1]Slovak University of Agriculture in Nitra, Faculty of Engineering, Department of Transport and Handling, Tr. A. Hlinku 2, SK 94976 Nitra, Slovak Republic
[2]Slovnaft, a.s., member of MOL Group, Vlčie hrdlo 1, SK 82412 Bratislava, Slovak Republic
[*]Correspondence: radoslav.majdan@gmail.com

Abstract. This paper presents a filtration system for universal tractor transmission oils (UTTO) to eliminate contamination, namely all kinds of particles and water. The aim of the research is the proposal of a universally useful filtration system for increasing the cleanliness level of biodegradable oils. The filtration systems consist of a filter housing with filter element, hoses, quick couplings and a measurement device to set the flow rate and pressure of the filtered oil. A measurement device (CS 1320) was used to monitor the cleanliness level of oil during filtration. The quality of the filtration system was evaluated according to kinematic viscosity at 40 °C, total acid number, concentration of additives (Ca, S and Mg) and content of chemical elements (Fe, Cu, Si, Al, Pb, Ag, Ni and Mn). The filtration system was designed for all tractor types because it can be connected to implement hydraulic circuit by houses and quick couplings. The filtration system was tested in the new type of tractor Zetor Forterra 11441 after completing 900 engine hours (oil contamination exceeded limits). On the basis of the performed filtration, it can be concluded that this a simple and affordable filtration system reduces the concentration of the most dangerous contamination: iron (Fe) by up to 32.95% and silicium (Si) by up to 22.23%. There was only a slight decrease in the concentration of additives recorded after use of the filtration system. The kinematic viscosity and the total acid number didn't exceed the prescribed limits.

Key words: ecological oil, lubricants contamination, agricultural tractor, lubricating properties.

INTRODUCTION

Environmental regulation has forced users and producers of machineries to use ecological oils in hydraulic systems that come into the contact with the environment Drabant et al. (2010). Biodegradability has become one of the most important design parameters both in the selection of base fluids and in the overall formulation of the finished lubricant (Mendoza et al., 2011). The cleanliness level is one of the most important conditions affecting the application of biodegradable oils in agricultural tractors. The universal tractor oils in transmission and hydraulic systems are polluted by residues of old fillings from attachments (such as ploughs, trailers, etc), contamination from environment and wear particles. At present tractors are fitted with filters that provide sufficient filtration for mineral and synthetic oil types. A standard filtering capacity of the tractor filters is 20 μm, in most cases., Hujo et al. (2012), Kosiba et al.

(2012) and Majdan et al. (2014) described the contamination of universal tractor oils in many tractors operating in agriculture. The application of biodegradable oils requires a higher cleanliness level in comparison with conventional oils. Contamination and moisture affect the decomposition of biodegradable lubricants, which lose their properties and so cannot meet requisite functions. Therefore, the highest possible cleanliness level is the base condition for the use of biodegradable oils.

Tractor use significantly affects economic effectiveness as well as environmental pollution in agriculture (Korenko & Žitňák, 2008). The UTTO in the hydraulic and transmission system of a tractor is the connecting link between various parts, and as it is operated it absorbs contamination, moisture and heat, which can cause a decrease in lubricant properties. The reliability of all hydraulic and transmission systems in tractors depends on lubricant oil properties. If the lubricant cannot meet the requisite functions, abnormal wear and malfunction can occur. Ileninová et al. (2008), Tóth et al. (2012) and Tóth et al. (2014) confirm this fact in their works.

Because of frequent accidents in operational location, ground contamination with liquid lubricants is very probable. For these reasons, the designs of machines make an effort to lubricate with biodegradable lubricants (Rédl et al. 2012).

Using the filtration system, a high cleanliness level of universal tractor oil can be provided. The filtration system was designed to realize additional filtration to increase the cleanliness level of universal tractor transmission oil as a base condition for the use of biodegradable oil types. The function of the filtration system was verified during test operation in a 11441 tractor.

MATERIAL AND METHODS

The filtration system consisting of a filtration device (3), and measurement device (2) HT 50 A (XPS Corporation, USA) is connected to the implement hydraulic circuit of the tractor by hoses (18), Fig. 1. Strainer (7) is a standard tractor filter with filtering capacity 20 μm (in the case of most tractors). This is the sufficient filtering capacity for mineral and synthetic oils. A filter element (13) realizes the second stage of oil filtration. It is a paper filter element type H 1081 (Mann+Hummel, GmbH., Germany) with filtration capacity 10 μm and the ability to remove water from oil. Therefore, the smaller particles of contamination are removed during the second stage of oil filtration. This is the way in which reach a higher cleanliness level for the use of biodegradable oils.

The tractor hydraulic pump (4) pumps the universal tractor transmission oil through the filtration device (3). Thus, the filtration device does not need to be equipped with a pump, making its construction easier. In this case, a low-pressure filter housing (up to 0.2 MPa) of FS 02 type (Kovolis Hedvikov, a. s., Czech Republic) was used. The filtration device needs to have the flow adjusted to ensure a low pressure. To test the filtration device we used the tractor Zetor Forterra 11441 which does not have a regulating hydraulic pump so it is not possible to set the desired flow rate in the hydraulic circuit. Consequently, a measuring device (2) was connected to the filtration device in series. Requisite flow value 0.2 $dm^3 s^{-1}$ was set using a restrictor (17) of this device (2). The measuring device HT 50A was used for hydraulic heating of the tractor oil fill before filtration and for setting the desired flow during filtration. The measuring device mentioned above can be replaced with a simple throttle valve and flow meter. Filtration efficiency was monitored by measuring the cleanliness level of the oil that enters the filter. A part of the oil entering the filter flows through the measuring device (3) CS 1320 (Hydac Ltd., Germany), which measures the cleanliness level according to ISO 4406 (1999). This device continuously counts the particles in the oil using the optical principle. To measure the cleanliness level, only a low oil flow was used. The low flow rate was set by a throttle valve (15) in this device. The cleanliness level according to ISO 4406 (1999) is determined by counting the number and size of particles in the oil. The standard defines the cleanliness level of particles larger than 4 μm, 6 μm and 14μm.

As an example: if 15 particles (in 100 ml of oil) larger than 4 μm, 5 particles (in 100 ml of oil) lager than 6 μm and 3 particles lager than 14 μm are counted, the ISO 4406 (1999) code level is 4/3/2. Cleanliness level definition per ISO 4406 (1999) are shown in Table 1. The step to the next cleanliness level means double or half the number of particles.

Table 1. Cleanliness levels per ISO 4406 (1999)

Number of particles per 100 ml	Number of particles per 1 ml	Cleanliness levels
1–2	0.01–0.02	1
2–4	0.02–0.04	2
4–8	0.04–0.08	3
8–16	0.08–0.16	4
etc.	etc.	etc.

The filtration system has been designed so that it can be made using different types of filter housings, which are available on most farms. The advantage of the system is its connection by quick couplers (9) to the implement hydraulic circuit of the tractor. Connection does not need additional assembly, which is characterized by simplicity. It is universally applicable to different types of tractors.

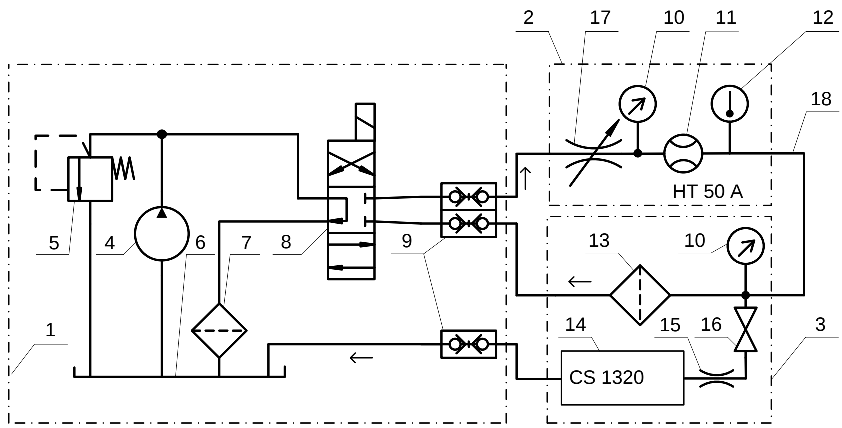


Figure 1. Filtration system: 1 – hydraulic system of tractor; 2 – measuring device type HT 50 A; 3 – filtration device; 4 – tractor hydraulic pump; 5 – pressure relief valve; 6 – tank; 7 – strainer; 8 – directional control valve; 9 – quick coupling; 10 – pressure gauge; 11 – flow meter; 12 – temperature sensor; 13 – filter element of filtration device; 14 – measuring device type CS 1320; 15 – throttle valve; 16 – shut-off valve; 17 – restrictor; 18 – hose.

Specification of filtered oil

The oil, which was used in a Zetor Forterra 11441 tractor, is a newly developed biodegradable oil made from poly-alpha-olefins synthetic base oil. This oil was chosen, because it has high chemical stability and miscibility with mineral oils that are in common use. The oil is part of the group of universal tractor transmission oils (UTTO) designed for tractors and produced by MOL Group, Hungary. The oil mentioned above is not commercially available because it is only in its testing phase at present.

The main specifications of the oil are as follows:

– kinematic viscosity at 100 °C: 10.22 mm^2 s^{-1};
– kinematic viscosity at 40 °C: 58.14 mm^2 s^{-1};
– viscosity index: 165;
– pour point: -42 °C (Tulík et al., 2013).

This type of oil was tested under laboratory conditions before its application in the agriculture tractor. Tulík et al., (2013) present more information about the biodegradable oil's properties and its test under laboratory conditions.

Evaluation of filtering quality

Using the agricultural tractor under operating conditions, the function of the filtration device and filtering quality were evaluated. Oil filtration was tested after 900 engine hours of tractor operation. The filtration of the oil filling the tractor transmission and hydraulic system was evaluated according to the following procedure:

Monitoring of particle contamination in the oil was realized on the basis of the cleanliness level during filtration. Device CS 1320 was used to evaluate particle contamination on the basis of the ISO 4406 (1999) standard.

After filtration particle contamination was stated from the oil sample in the accredited laboratory Wearcheck (Hungary). Using ICP (inductively coupled plasma) spectrometry, particle contamination was stated according to the content of chemical elements (Fe, Cu, Si, Al, Pb, Ag, Ni and Mn) which represent the wear of transmission and hydraulic system. Vähäoja et al. (2005) and Kučera et al. (2014) determine the presence of chemical elements (mentioned above) as markers of wear.

Changes in the chemical and physical properties of the filtered oil were evaluated according to kinematic viscosity at 40 °C and total acid number (TAN). The concentration of additives was evaluated on the basis of the chemical elements content (Ca, S and Mg). The ICP spectrometry method was used.

All these parameters were analysed from oil samples in an accredited laboratory (Wearcheck, Hungary) after filtration.

The cleaning of the transmission and hydraulic system oil fill makes sense only if the chemical and physical parameters of the fluid meet the prescribed technical limits. Lubricating properties of fluids can be best evaluated on the basis of kinematic viscosity (physical parameter of fluid) which has a decisive influence on the formation of an oil film. Stachowiak & Bachelor (2005) confirm this fact about kinematic viscosity.

Kinematic viscosity is evaluated based on the positive or negative tolerance of the value measured after the filtration in comparison with the value of new oil. Therefore, the kinematic viscosity of new oil must be evaluated. The deviation of kinematic viscosity is calculated by using the formula:

$$\Delta_{KV} = \frac{\nu_N - \nu_F}{\nu_N} \cdot 100 \quad (1)$$

where: Δ_{KV} – deviation of kinematic viscosity, %; ν_N – kinematic viscosity of the new oil, mm^2 s^{-1}; ν_F – kinematic viscosity after the filtration, mm^2 s^{-1}.

The total acid number (TAN) is the parameter which evaluates the chemical properties of lubricating oil. Its value describes oil's ability to eliminate acid compounds by virtue of alkaline additives. This parameter is used to evaluate the degradation processes of the oil. Therefore, the measurement of total acid number is very important in stating the technical properties and durability of filtered oil.

Additives concentration was monitored on the basis of the relevant content of chemical elements (Ca, S and Mg). The concentration of three elements that characterize the complex of additives, namely calcium, sulphur and manganese was measured before and after filtration to calculate changes in their content. A decrease in the content of these elements in an oil sample is calculated by using the following formula:

$$\Delta_{AD} = \frac{AD_{BF} - AD_{AF}}{AD_{BF}} \cdot 100 \quad (2)$$

where: Δ_{AD} – decrease of chemical elements representing the additives, %; AD_{BF} – content of chemical elements (Ca, S or Mg) before filtration, mg kg^{-1}; AD_{AF} – content of chemical elements (Ca, S or Mg) after filtration, mg kg^{-1}.

A decrease in the content of chemical elements which represent fluid contamination is calculated on the basis of information on polluted and filtered oil. Impurity content represents fluid contamination. A decrease in the content of chemical elements which represent fluid contamination is calculated by using the formula:

$$\Delta_{C} = \frac{C_{BF} - C_{AF}}{C_{BF}} \cdot 100 \quad (3)$$

where: Δ_C – decrease in chemical elements content representing particle contamination, %; C_{BF} – content of chemical elements of particle contamination before filtration, mg kg^{-1}; C_{AF} – content of chemical elements of particle contamination after filtration, mg kg^{-1}.

Oil samples were taken after completing 150, 450 and 900 engine hours during the tractor operation and after filtration. A representative sample of new oil was taken before filling the tractor transmission and hydraulic system with oil. This sample was marked as new oil. Oil filtration was realized after competing 900 engine hours when the particle contamination exceeded limits stated in the internal documents of the Wearcheck, laboratory, Hungary.

RESULTS AND DISCUSSION

The filtration device (Fig. 2) was made by simply placing the filter housing on the stand with hose adapters for connecting, and it was designed at the Department of Transport and Handling. A filter cartridge was placed in the aluminium housing of the filtration device. The filtration capability of the paper element was 10 μm.

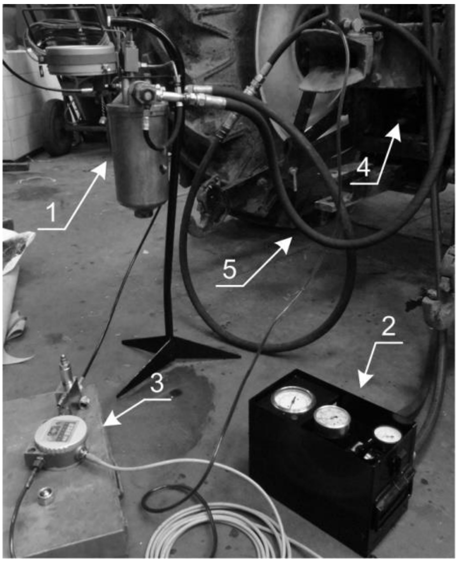


Figure 2. The filtration and measuring devices connected to the agricultural tractor type Zetor Forterra 11441: 1 – filter housing with filter element, 2 – measuring device type HT 50 A, 3 – measuring device type CS 1320, 4 – agriculture tractor type Zetor Forterra 11441, 5 – hoses.

The design of the low-pressure filter housing required the setting of a relatively low flow rate through the filtration device (0.2 dm^3 s^{-1}). Despite this low flow value, one filtering of the whole oil fill (in our case 120 dm^3) took about 10 minutes only. We filtered the oil fill three times to improve the quality of filtration. If a pressure filter housing designed for the hydraulic pump flow of a given tractor type was used, it would be possible to filter the oil fill without the restrictor. The filtering system would be simplified and filtration time shortened.

Máchal et al. (2013) published the design of a filtration device which cleans the UTTO during tractor operation continually. In this case the filtration device is placed on the tractor and requires a tractor hydraulic system with the possibility of flow setting. This filtration device is suitable only for tractors with relatively low level of oil contamination due to high quality maintenance, because filtration capability is only 2 μm. The high level of oil filtration is not suitable for all operating conditions. Máchal et al. (2013) presented a more expensive and less universal concept of a filtration device compared with the filtration device described in this paper.

Singh & Suhane (2014) suggested another filtration concept to eliminate contamination from the hydraulic oil in a tractor. To remove contaminants (mainly magnetic particles) a modification in the tractor hydraulic system was proposed. In the proposed hydraulic system a magnetic filter is fixed in the suction line of the hydraulic system before the suction filter. Our filtration method doesn't require modification of tractor because filter housing with filter element uses the oil from the implement hydraulic circuit. It is only necessary to connect the quick couplers. The suggested filtration system is able to remove all kinds of oil contamination thus also non-magnetic particles and water in contrast to the filtration concept presented by Singh & Suhane (2014).

Kinematic viscosity (Fig. 3) is a parameter that can decrease or increase during operation. In this case, a decrease in kinematic viscosity was calculated Δ_{KV} = 6.89% according to Eq. (1). The decrease of kinematic viscosity does not exceed the limit of 10% which is prescribed for the UTTO. Thus, kinematic viscosity was within the prescribed limits after filtration.

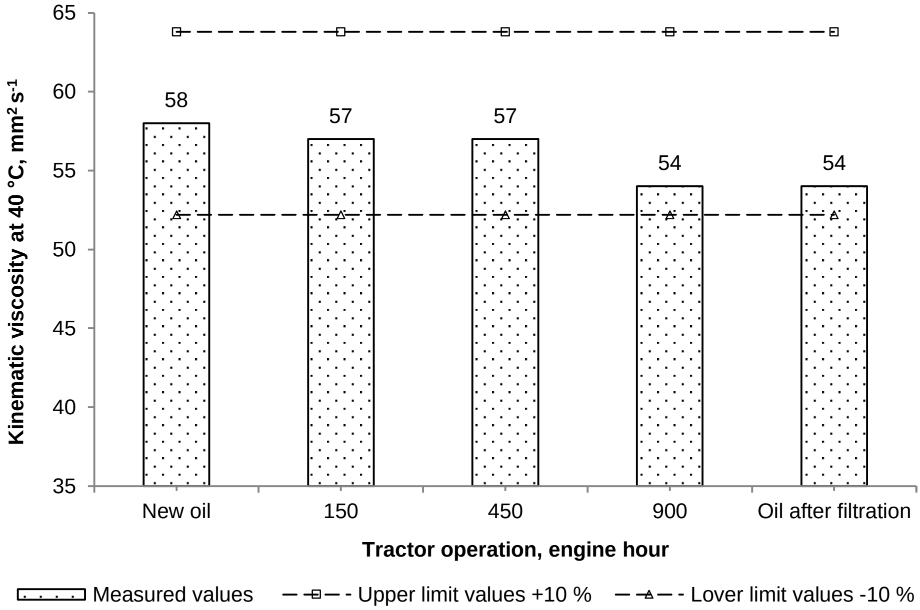


Figure 3. Kinematic viscosity of oil during the tractor operation and after filtration.

A gradual increase in total acid number (Table 2) represents a process of oil degradation. During tractor operation, the limit value 3.5 mg KOH g^{-1} wasn't exceeded. The producer of the oil (MOL Group, Hungary) stated the limits for its universal tractor transmission oils (UTTO). The value of total acid number is the same before and after filtration. Therefore, the process of filtration doesn't influence the chemical properties of the lubricating oil in tractor. The total acid number together with kinematic viscosity was measured to state the physical and chemical properties of the filtered oil because some types of oil filters could eliminate some additives and thus degrade the lubricating oil. In this case the filtration device doesn't change the properties mentioned above and so fulfils the base condition of oil filtration.

Table 2. The results of total acid number

Tractor operation, engine hour	0	150	450	900	After filtration
Measured total acid number, mg KOH g^{-1}	1.19	1.42	3	3.2	3.2
Limit value for total acid number, mg KOH g^{-1}	3.5				

The correct design of filtration device removes contamination from the oil and doesn't reduce the content of additives which improve the chemical and physical properties of the base oil. The content of additives is one of parameters describing the technical state of oil. Therefore, it is very important to evaluate the quality of filtration on the basis of concentration of chemical elements which represent additives in oil. A decrease in the concentration of chemical elements that represent additives Δ_{AD} was calculated according to Eq. (2) using measured values shown in Fig. 4.

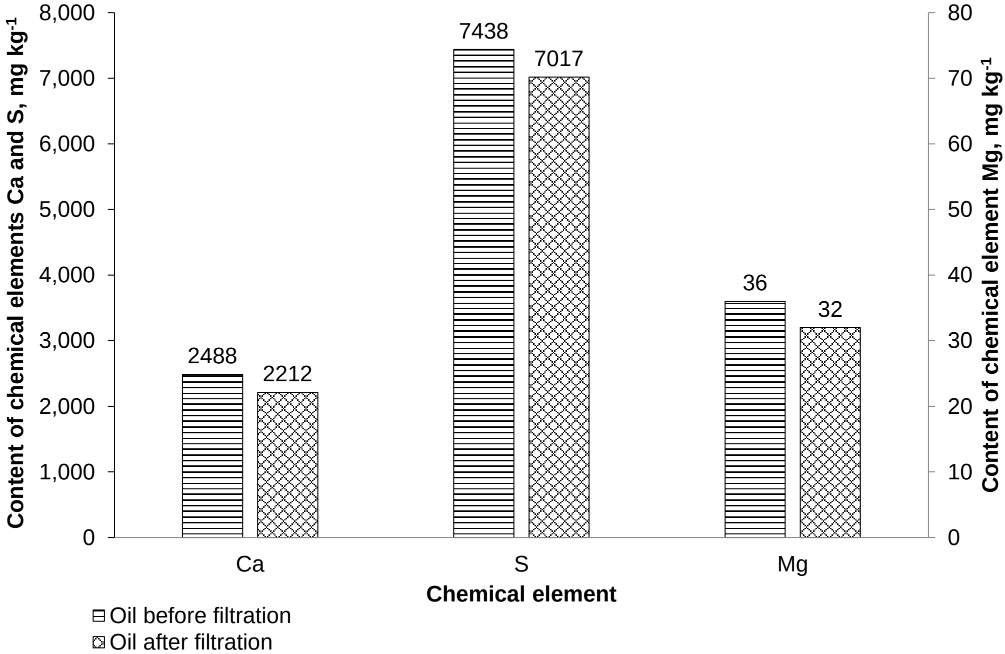


Figure 4. Decrease in chemical elements, which represent additives in oil after filtration.

The largest decrease was observed in the measurement of manganese 11.11% and calcium 11.09%. In the case of sulphur a decrease of only 5.66% was measured. Therefore, in the monitored oil, there was only a slight decrease in the concentration of additives recorded.

The physical and chemical properties of the ecological oil UTTO, as quality evaluation parameters, were monitored during tests performed by Vižintin & Kržan (2003). The authors focused on kinematic viscosity, additive content and oxidative stability. Based on these parameters, they evaluated the properties of the sunflower-oil-based fluid UTTO with AW and EP additives. In operating tests, they did not notice any exceeding of limits in the physical and chemical parameters of the used oil.

Mendoza et al. (2011) present the results of using the ecological fluid in the Agria agricultural tractor. During this oil test, the author evaluated the physical and chemical properties of the oil as a base condition for its application in an agricultural tractor.

Kučera & Rousek (2008) evaluated the kinematic viscosity of the oil type NAPRO-HO. This oil did not exceed the limit viscosity value of 10% during tests.

In our case, we evaluated the same oil parameters because they are important in the evaluation of an oil's technical parameters, which influence the reliable operation of agricultural tractors.

Fig. 5 shows an increase in the concentration of particles in oil during tractor operation. Contamination reaching high concentrations of iron and copper was observed after completing 900 engine hours. Therefore, filtration was performed with the designed filtration device. This figure also shows a decrease in the concentration of polluting chemical elements after filtration. This decrease was calculated according to Eq. (3). The decrease in concentration of the most dangerous elements reached value: 32.95% for iron, 22.23% for silicon, 6.66% for copper and 33.34% for aluminium. The other elements didn't reach a concentration considered dangerous for the lubricated system because they didn't exceed limits. The concentration of these elements, namely chrome, tin and lead, reached only a low value before filtration and therefore their elimination due to filtration was not important. The accredited laboratory Wearcheck (Hungary) together with the oil producer stated the levels of oil contamination and limit values according to technical information presented by Evans (1997).

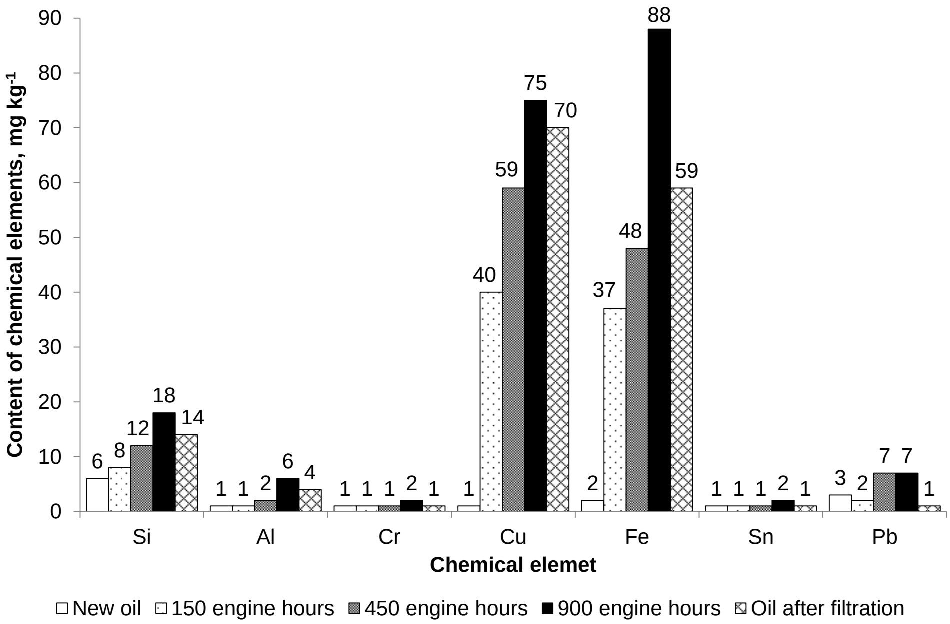


Figure 5. The content of chemical elements, which represent oil contamination before and after filtration.

Table 2 shows the results of cleanliness level measurements using the device CS 1320, which was connected to the filtration device during filtration. During filtration, a decrease in the concentration of particle contamination occurred in three stages. They are identified in Table 3 as measurements no. 1, 2 and 3. The stage represents one filtration of the whole oil fill. The table shows three measurements of cleanliness level during oil filtration. The next measurement didn't show changes in comparison to one before. It was realized to ensure that the filtration was completed. Measurement results of the cleanliness level show a reduction in the largest particles (> 14μm), which are the most dangerous for the transmission and hydraulic system of the tractor.

Table 3. Results of cleanliness level according to ISO 4406 (1999) during the oil filtration

Size of particles		Measurement 1.	2.	3.
> 4 μm	ISO class	24	24	24
	number of particles per 0.1 dm^3	8,000,000–16,000,000		
> 6 μm	ISO class	23	23	23
	number of particles per 0.1 dm^3	4,000,000–8,000,000		
> 14 μm	ISO class	10	9	8
	number of particles per 0.1 dm^3	500–1,000	250–00	130–250

CONCLUSION

This contribution deals with the design and use of a filtration system designated to ensure the reliable operation of agricultural tractors with regard to an application of ecological lubricants which require a clean oil fill. The designed filtration system ensures a clean fluid during its operation in the tractor. Removing particle contamination, the filtration system can be used for all types of oils to increase cleanliness level.

The filtration system can be used easily for different types of tractors because it is connected to the implement hydraulic circuit. It can be universally used for the newest tractor types, too. It can be made from the various filter housings available on most farms. Based on the measurements, we can conclude that the designed filtration system is suitable for cleaning universal tractor transmission oils used in tractors. The manufacturing of the filtration system is simple and affordable.

Fig. 5 shows the progress of fluid contamination up to completing 900 engine hours and a significant decrease in the most dangerous contaminants after filtration. A positive filtration effect was shown during cleanliness level measurement, too. Table 3 shows a reduction in the largest particles (> 14μm) from class 10 to class 8 (according to standard ISO 4406 (1999)) due to the filtration.

ACKNOWLEDGEMENT. Supported by the Ministry of Education of the Slovak Republic, Project Vega 1/0337/15 'Research aimed at influence of agricultural, forest and transport machinery on environment and its elimination on the basis of ecological measures application'.

REFERENCES

Drabant, Š., Kosiba, J., Jablonický, J. & Tulík, J. 2010. The durability test of tractor hydrostatic pump type UD 25 under operating load. *Research in Agricultural Engineering* **56**, 116–121.

Evans, J. 1997. Wear limits versus trends. *Technical bulletin of Wearcheck* **15**, 1–2.

Hujo, Ľ., Kosiba, J., Jablonický, J. & Tulík, J. 2012. Load characteristics of three-point tractor linkage. In*: Naučni trudove – zemedelska technika i technologii, agrarni nauki i veterinarna medicina, remont i nadeždnosť.* University of Rousse, Rousse, pp. 172–176 (in Bulgaria).

Ileninová, J., Mihalčová, J. & Košťáliková, D. 2008. Evaluation of hydraulic fluid properties in aero-engine. In*: Reotrib 2008.* Institute of Chemical Technology, Prague, pp. 118–122 (in Czech Republic).

ISO 4406 1999. Hydraulic fluid power – Fluids – Method for coding the level of contamination by solid particles.
Tulík, J., Hujo Ľ., Stančík, B. & Ševčík, P. 2013. Research of new ecological synthetic oil-based fluid. *Journal of Central European Agriculture* **14**, 1384–1393.
Kosiba, J., Varga F., Mojžiš M. & Bureš, Ľ. 2012. Load characteristics of tractor Fendt 926 Vario for simulation on experimental bench). *Acta Facultatis Technicae* **17**, 63–72.
Korenko, M. & Žitňák, M. 2008. Machines utilization during harvest and transport of straw bales for energetic purpose. In*: Perspective in Education Process at Universities with Technical-Orientation in Visegrad Countries: International Science Conference*. SUA in Nitra, Nitra, pp. 275–279. (in Slovak Republic).
Kučera, M. & Rousek, M. 2008. Evaluation of thermooxidation stability of biodegradable recycled rapeseed-based oil NAPRO-HO. *Research in Agricultural Engineering* **54**, 163–169.
Majdan, R., Tkáč, Z., Stančík, B., Abrahám, R., Štulajter, I., Ševčík, P. & Rášo, M. 2014. Elimination of ecological fluids contamination in agricultural tractors. *Research in agricultural engineering* **60**, 9–15.
Kučera, M., Bujna, M., Korenková, M. & Hass, P. 2014. Possibilities of using ecological fluid in agriculture. *Advanced Materials Research* **1059**, 61–66.
Mendoza, G., Igartua, A., Fernandez-Diaz, B., Urquiola, F., Vivanco, S. & Arguizoniz, R. 2011. Vegetable oils as hydraulic fluids for agricultural applications. *Grasas y aceites* **62**, 29–38.
Máchal, P., Majdan, R., Tkáč, Z., Stančík, B., Abrahám, R., Štulajter, I., Ševčík, P. & Rášo, M. 2013. Design and verification of additional filtration for the application of ecological transmission and hydraulic fluids in tractors. *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis* **61**, 1305–1311.
Rédl, J., Váliková, V. & Kročko, M. 2012. Mathematical Model of Sliding Couple Lubricated With Biolubricants. *Acta technologica agriculturae* **15**, 46–52.
Singh, D. & Suhane, A. 2014. Modification of hydraulic system of tractor for removal of magnetic particles from hydraulic oil. *International Journal of Engineering Research and Development* **10**, 56–60.
Stachowiak, G.W. & Bachelor, A.W. 2005. *Engineering Tribology*. Elsevier, Burlington, 801 pp. (in USA).
Tóth, F., Rusnák, J. & Kadnár, M. 2012. Monitoring of geometric cylindricity tolerance changes on a test sliding pair using the oils Madit PP 80 and Mobil Mobilube SHC. *Acta technologica agriculturae* **15**, 100–102.
Tóth, F., Rusnák, J., Kadnár, M. & Čavojský, P. 2014. Effect of selected ecological lubricants on the wear of defined sliding bearing. *Acta technologica agriculturae* **17**, 13–16.
Vähäoja P., Välimäki, I., Heino K., Perämäki P. & Kuokkanen K. 2005. Determination of Wear Metals in Lubrication Oils: A Comparison Study of ICP-OES and FAAS. *Analytical Sciences* **21**, 1365–1369.
Vižintin, J. & Kržan, B. 2003. Tribological properties of vegetable based universal tractor transmission oil. In*:* Rotrib ´03. University 'Dunarea de Jos' of Galati, Galati, pp. 221–227 (in Serbia).

Agronomy Research **14**(4), 1406–1416, 2016

Software development for Qualimetrical ergonomics of a workplace

D.G. Maksimov[1,*] and H. Kalkis[2]

[1]Institute of Economics and Management, Udmurt State University, Universitetskaya street 1, bld. 4, RU 426034 Izhevsk, Russia
[2]Faculty of European Studies, Riga Stradins University, Dzirciema street 16, LV-1007 Riga, Latvia
[*]Correspondence: maksim.dan.gen@gmail.com

Abstract. Ergonomics is the science investigating the person and the activity within the process management aiming at improvements of labor conditions and labor process at workplace. The microelement analysis as part of ergonomics allows in quantitative measures estimate time that is expended and to analyse effective use of time, as one of the major indicators. Along with an indicator of time it is necessary to consider and other indicators influencing man during commission of labor process which can be presented in the quantitative form, using science a qualimetry. The aim of the research is to analyze scientific literature on qualimetrical ergonomics of a workplace and develop software for practical evaluation of qualimetrical ergonomics. At the crossroads of a qualimetry and ergonomics the system of the microelement analysis was discovered. The research provides approach in software development for the microelement norm-fixing at the beginning of process automation.

Key words: ergonomics, qualimetry, microelement analysis, workplaces.

INTRODUCTION

The investigations carried out on society labour activities and finding the solution for design problems of the workplaces proves that primary elements of production systems functioning are regulated by the conventional principles of international law.

Among the scientific directions of labour economics essential value is gained by ergonomics. Ergonomics is the science investigating human and his or her activity in conditions of operations management with the purpose of improvement of tools, conditions and work process. Ergonomics development has long history (George & Jones, 2004) and as science discipline it developed since 1949 (Eldholm & Murrell, 1973; Kuorinka, 2000). The term ‘ergonomics’ was accepted in England in 1949 when the group of English scientists established organization ‘The Ergonomic society’. The International Ergonomics Association emphasizes ergonomics intervention which is aimed at appropriate workstations, equipment, production process and design of the product, may occur at different levels, which are determined by ergonomics types of the organisation: micro-ergonomics and macro-ergonomics (Drury, 1995). Ergonomics nowadays is multidisciplinary branch of science, which studies relationship between a human and work, conducts theoretical and practical studies of interrelation between a human and work environment (production technologies, machines, instruments, etc.) at micro- and macro-ergonomic level, and, on the basis of these studies, works out methods, which optimise work conditions corresponding to human's physical and mental abilities (Kalkis, 2014; IEA, 2016).

In the EU countries basically the term Ergonomics at Work is used, in the US, most commonly the synonym – Human Factors & Work Design is applied (Kalkis, 2014). In Russia in the first part of the XX century it was offered (Bogdanov, A.A.) the term 'ergologiya' and now in practice it is accepted the English term 'ergonomics'.

The ergonomics is interconnected with real parameters of technological development of system 'man-machine', and problems of coordination of a design of machinery with performance data of the person. Now there were insufficient private recommendations of psychophysiology and occupational health. In total there was a need of coordination of local recommendations in order to coordinate holistic system of requirements of various type of work and conditions (Hendrick, 2002).

In order to go beyond tightly engineering approach with considered ergonomic problem, it is important to set the task differently and see not only 'the man and the machine" principle, but also what is happening inside the machine – objectification of intrinsic forces of human. From there derives the term 'qualimetry' were needs of nature attract to problems of ergonomics and quantitative measurement of the quality comes into measurement system. Proceeding from such postulate the research is focused on software development that includes qualimetrical ergonomics principles of a workplace.

The aim of the research is to analyze the available literature on the topic of ergonomics and qualimetrical ergonomics and develop computer software with microelement norm-fixing principles.

MATERIALS AND METHODS

Taylor and Gilbret's method according to the microelement analysis of labor movements of a human body in labour processes called by system of the Methods Time Measurement (MTM), and its various modifications (Schmid, 1957; Maynard et al., 2012; Miller, 2013) and practical receptions became one of methodical forms of association of research problems and design of labor processes in real workplaces (Freivalds & Niebel, 2009). The motions are assigned to fundamental principles and groups of motions that are not precisely evaluated with ordinary watch time study procedures. It is also the result of the studying a large sample of various processes with a time measurement device capable to capture very short elements – microelements of the movements (Heizer & Render, 2011). The system of the microelement analysis reached considerable perfection, however, there is an essential shortcoming.

The micro-elemental rate fixing is one of the most perspective and developing methods of the organization of unity of labour norms, increase of their quality and possibility of research by drawing up computer programs (for example, TiCon3, ProKondigital, TiCon MTMergonomics, TaskMaster 2000) for justification and calculation of labour input of performance of a certain type of works (Orefkov & Perevoschikov, 2005; Maksimov, 2014). One of the main advantages of microelemental norm-fixing is that it allows to create in short terms standards without carrying out time consuming researches.

The system of the microelement analysis has reached considerable perfection. However, it has a shortcoming too.

The MTM (De Almeida & Ferreira, 2015) and BSM method (the Russian option of MTM) dismembering labor process on ‘microelement’, fixes only duration of time of each element. However, it doesn't consider ergonomic parameters of the performed work, the static moments creating static intensity of muscular system of the person, logical (information) sequence of the analysis of objects of attention in labor process outside the analysis (Orefkov & Perevoschikov, 2005).

Partial association of these methods is that BSM is more focused on the universality to rationing in various industries, also it is the classification considering the quantitative and qualitative parameters influencing time of performance of microcells that are developed. But the shortcoming is that this system differs in complicated coding system. Therefore at the biomechanical description of process of work the system of MTM was used.

Taking into account the above described shortcomings, the new method of micro-elemental rate fixing with inclusion of additional parameters of the labor movements including the biomechanical description and tables of their ergonomic indicators is presented in this research.

On the basis of the obtained data the algorithm of calculation of required parameters with use of the developed software is presented.

RESULTS AND DISCUSSION

The computer software has been developed that takes into account several scientific methodologies.

The problem faced by the researchers observing or planning the working process lies in recording or planning time of each movement while the algorithm is being realized.

In order to develop software for qualimetrical ergonomics of a workplace, authors used the logical diagram of labor process algorithm consists of several steps (Perevoschikov, 2015):

1. Observation is carried out for the purpose of taking in and handle basic procedures and transitions.
2. All initial data are filled in the analytical chart.
3. The workplace planning is filled.
4. Analytical results of operations are entered on the reverse side of the chart with the description and left-hand movements singly. At first the content of procedure is written down.
5. After entering each microelement, the researcher must ask: Is the transition not a problem to performer of the work to next movement? If transition to the next microelement is linked with the choice of one or several ways or necessity of a logical action is placed.
6. All actions of the whole cycle of work connected with machining labor object in given workplace are entered in the logical diagram of algorithm, that is, all actions involving calculation of per-piece time, excluding time for rest and natural reasons.

Before starting creation of the computer software it was required to carry out interrelation of the various parameters that are influencing each other. The IDEF0

(Integration definition for function modeling) functional modeling method was applied for representation of all structure in this software development work. The function is a set to the interconnected and interacting operations (actions) which will transform from input to output.

Accordingly to the functional modeling methodology the 'Calculate Labour Intensity' of a process is presented in software development context diagram (Fig. 1).

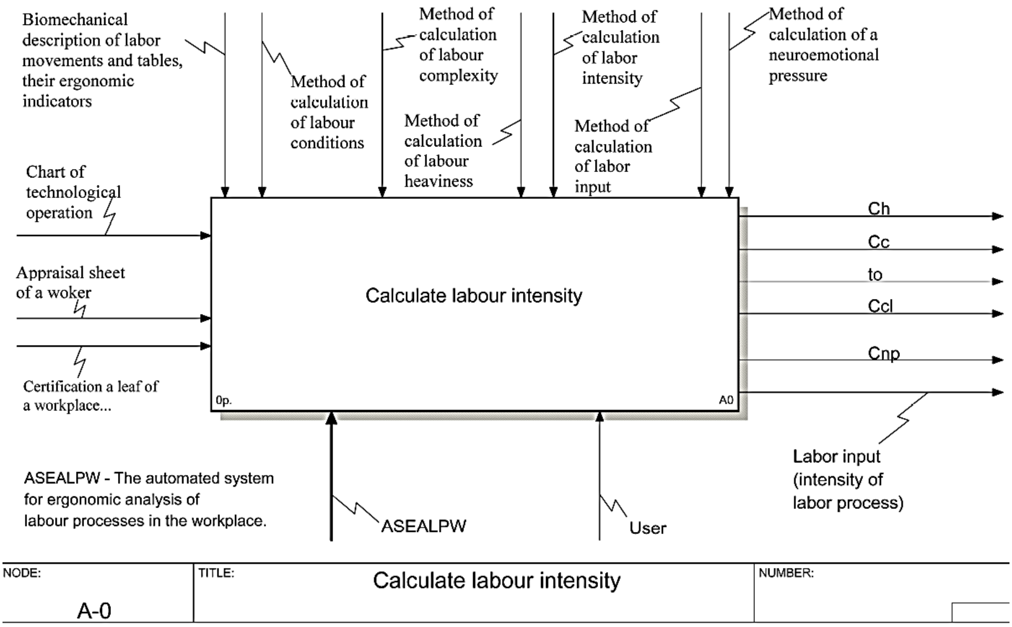


Figure 1. Software development context diagram.

As input of this process is the chart of technological operation (operation is characterized by a rigidity of processed product, workplace, and workers.). It is an appraisal form of a worker and certification page for workplace under the terms of performed work.

The calculation mechanism of labour intensity process performance consists of such elements:

– the developed system of calculation of intensity of labour process;
– the engineer-economist who is the direct user of system.

As process control consists of such steps:

– method of calculation labour conditions;
– method of calculation of labour complexity (intellectual strain (mental labor));
– method of calculation of labour heaviness (physical strain (physical labor));
– method of calculation of labor input;
– method of calculation of labor intensity;
– biomechanical description of labor movements and tables, their ergonomic indicators;
– method of calculation of a neuroemotional pressure.

The main function, in turn, may be divided into nine specific functions which are presented on decomposition diagram ‘Calculate labour intensity’ (Fig. 2).

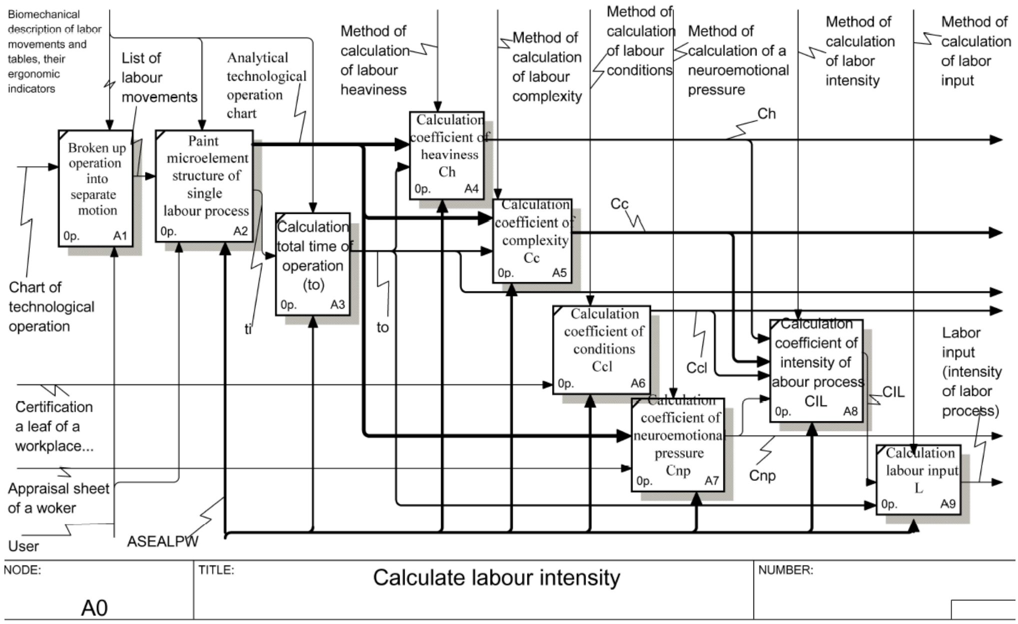


Figure 2. Diagram of decomposition ‘Calculate labour intensity’.

A decomposition diagram serves as representation of the main function and it is possible to model detailed functionality of the developed system.

On the presented decomposition diagram (Fig. 2) it is shown that after the correct input data of functions the calculations are carried out. Hence participation of the engineer and system in the course of calculations is also important and visually presented.

At this development stage of the software tasks of processes A1, A2, A3, A4, A5 are solved and partially solved processes of A8, A9 (Fig. 2).

As next step in software development it will be considered decomposition of function of A4 ‘Calculate coefficient of labour heaviness’ (Fig. 3). This diagram provides possibility to obtain the necessary parameters for calculation of heaviness coefficient, for instance:

– static moment;
– performed mechanical work;
– total physical activity;
– residual calculation of energy;
– heaviness of labor process.

Heaviness of labor process is the part of working capacity connected with physical activity and quantitatively reflects operations ability of work element which changes in time.

Labour heaviness and coefficient of labour heaviness can be calculated on the basis of the following formulas:

a) Heaviness of labor process

$$H = 0.476 \cdot \left(\frac{A}{4{,}189} + \frac{M_{ave}}{442} + \frac{0.06 \cdot \Delta E_o}{t_0}\right) \tag{1}$$

where: H – heaviness of technological operation under research, size dimensionless (relative); A – mechanical power of locomotorium, J min^{-1}; M_{ave} – average statistical moment for operation, Hm; to – total time of operation, sec.; ΔE_o – internal energy expenditure residual of an organism, cal;

b) Coefficient of heaviness

$$K_{\text{т}} = e^{0.125 \cdot (1-H)} \tag{2}$$

Change in value of labor duration without changing the very essence of the process leads to increase or decrease of heaviness of labor process. But change of duration value gives rise to change in movement speed of system of man-labor implement-labor object. Therefore, mechanical work performed by a man in a unit of time increases or decreases. The latter conjures up changes in coefficient of heaviness.

On the diagram (Fig. 3) are shown the necessary parameters in determination process of coefficient of heaviness.

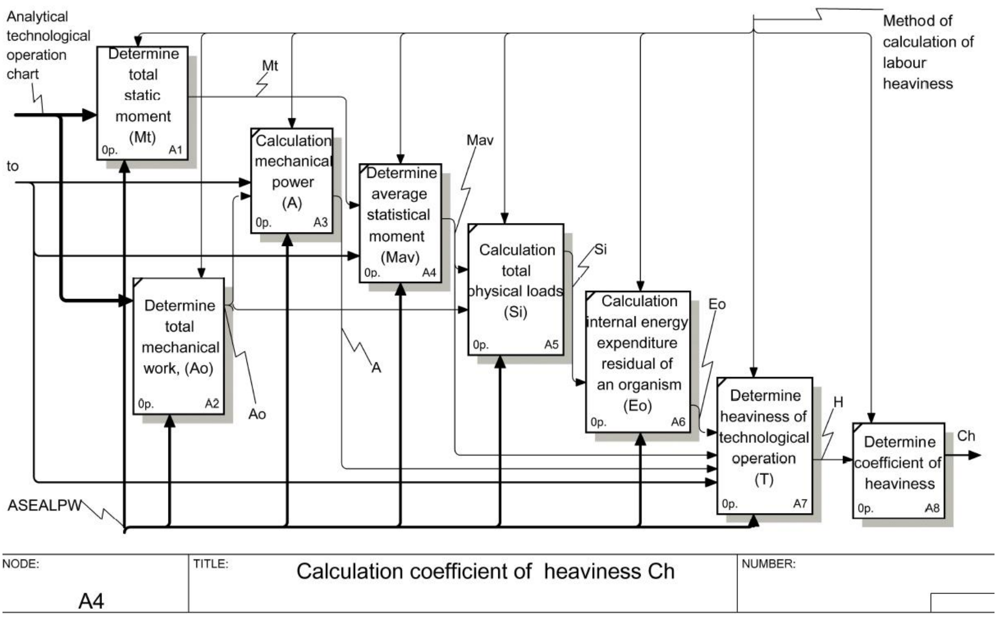


Figure 3. Diagram of decomposition ‘Calculating coefficient of labour heaviness’.

Calculation of the total static moment can be presented more in detail. Decomposition of a function A4.1 ‘Calculate total static moment’ (Fig. 4) visually represents the demanded operations for finding the total static moment.

As shown in Fig. 4, calculation is made automatically on the basis of already known data from analytical operation chart.

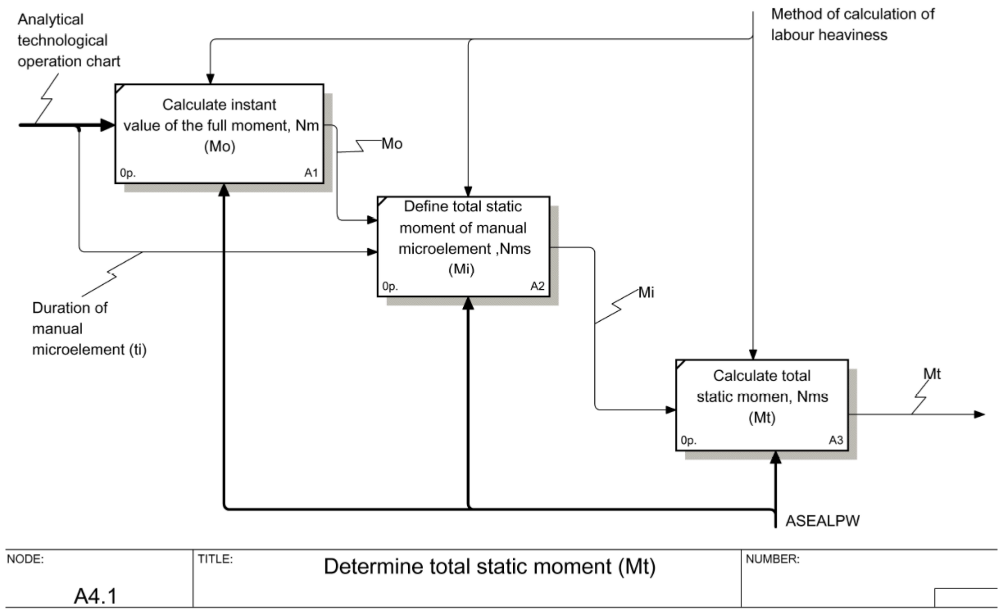


Figure 4. Decomposition diagram 'Calculate total static moment'.

As next step it is important to understand decomposition of a function A5 'Calculate coefficient of complexity' (Fig. 5). This chart represents processes that are calculated on the basis of the following formula:

$$C_c = \frac{\ln(N_0 - \propto \cdot N_б)}{e^{\left(1 - \frac{\alpha \cdot N_б}{N}\right)}} \cdot \left(\frac{\delta}{\delta_o}\right) \tag{3}$$

where: N – total number of algorithmic members in the labor process under research, pcs.; N_o – quantity of operands in algorithm of labor process, psc.; N_b – number of logical conditions in algorithm of labor process, psc.; α – coefficient of logical conditions variety; δ – intensity of processing information in the labor process under research; δ_o – intensity of processing information in base labour process (optimum intensity of information processing).

On examining labor process in the informational aspect, the extent of the subject's contribution to labor complexity must be clear.

Every labor subject is strictly. Personal habits, cognition and skill give concrete expression to his stature as an individual – labor subject. At this stage of research the technique of complexity determination of single labor process demands further research. At the moment the outcome is rather subjective, depending on the researcher who is carrying out the analysis of labor operation.

It should be noted that in the presented software outcome the complexity of single labor process is considered from two parties: information load and intellectual strain of an organism.

As reflected in Fig. 5, several parameters are used for coefficient of complexity calculation. Decomposition of process A5.5 ‘Calculate the relative level of calculate intensity of information processing by the performer’ (Fig. 6) shows necessary indicators for calculation of a relative level of information processing intensity by the process performer.

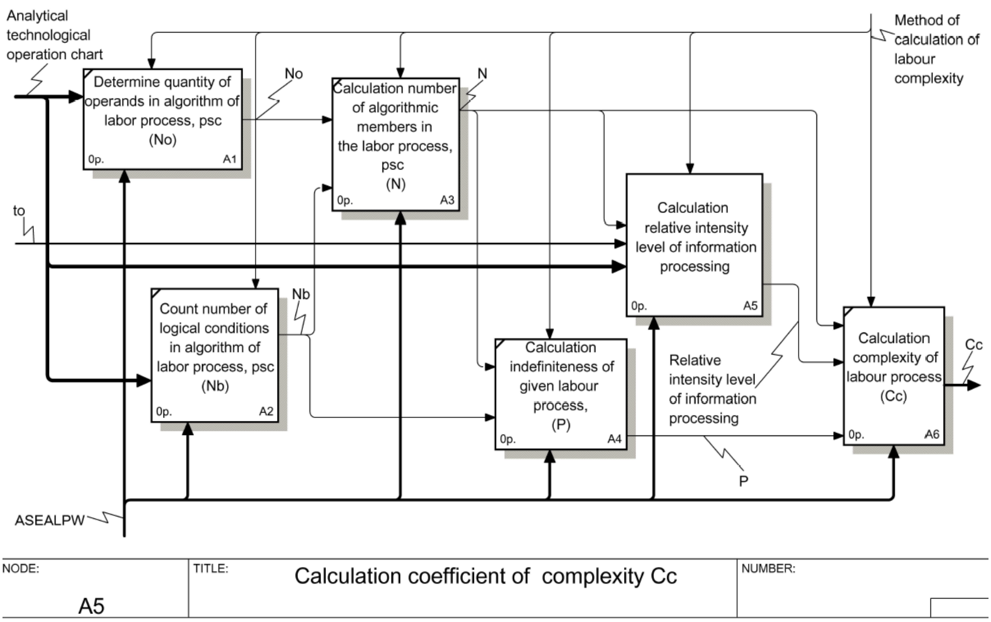


Figure 5. Decomposition diagram ‘Calculate coefficient of complexity’.

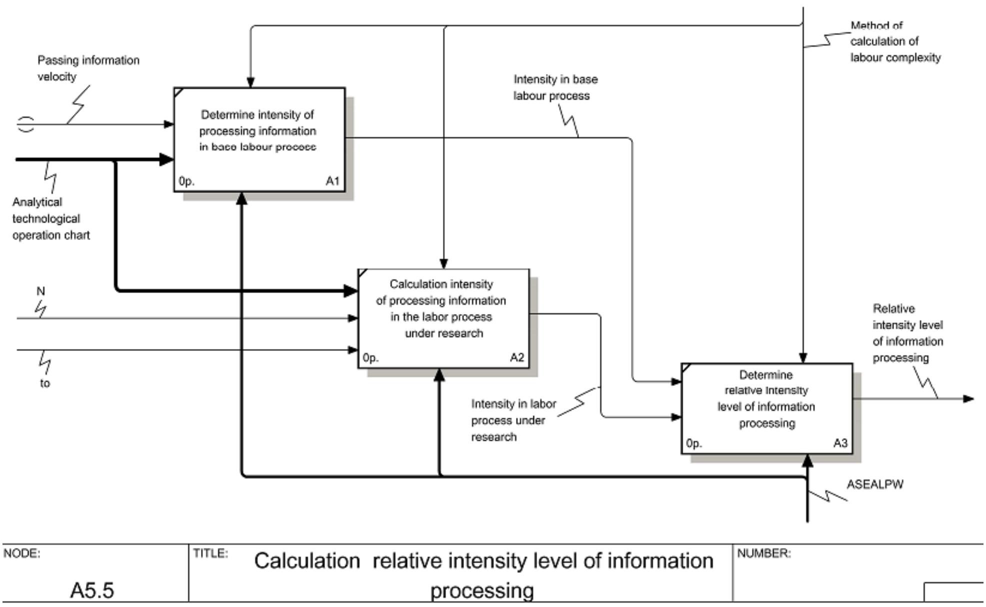


Figure 6. Decomposition diagram ‘Calculate the relative level of calculate intensity of information processing by the performer’.

Determination of all parameters is carried out on the basis of the data presented in analysis of the labor process chart that is filled at the very beginning of all necessary work tasks.

The calculation of intensity of labour process is carried out in such order:

1. analysis of technological operation under research;
2. calculation of coefficient of heaviness (C_h);
3. calculation of coefficient of complexity (C_c);
4. calculation of coefficient of conditions (C_{cl});
5. calculation of coefficient of neuroemotional pressure (C_{np});
6. calculation of coefficient of intensity of labour process.

$$CIL = C_h \cdot C_c \cdot C_{cl} \cdot C_{np} \tag{4}$$

7. calculation of intensity of labour process:

$$I_{lp} = L = CIL \cdot t_o \tag{5}$$

where: L – labour input, work·h^{-1}; t_o – total time of operation, h.

According to the presented concept and the management of a database for ergonomic parameters calculations at the workplaces the computer software was developed. At current stage of development of the software a main objective is to test the program algorithm and find defects in the applied system of work microelement rationing. It is in accordance with other researches that still question remains about the validity of adding specific predetermined times to determine elemential times, since the motion times can change if the sequence is changed (Freivalds & Niebels, 2009). Also researchers constantly have tried to find out the ways to improve MTM methods (Karger & Walton, 1982; Sellie, 1992; Freivalds & Yun, 1994) and one of the most simplified approaches was developed by Zandin (1980) and originally applied at Saab-Scania manufacturing plant in Sweden in 1967 (Zundin, 1980). From this stage the Maynard operation sequence technique (MOST) derived (Maynard, 2001). The topicality to use the predetermined time systems have not decreased. Such systems can be used in many contemporary manufacturing plants, and it can be beneficial only if the people are using these systems right. Each application should involve careful analysis and understanding of the system and its use in proper manner. Authors suggest that special training is necessary for the correct and practical application of these techniques. Today scientists and practitioners can obtain the motion study methods from more than 50 different systems of established predetermined time. Each system provides its own unique predetermined time systems and have various sets of motion-time tables with application rules for using the motion time values. Therefore in further research authors will try to implement various motion patterns with its complexity and characteristics in order to improve software development.

CONCLUSION

At the current stage of work rationing software development the main effort is to create and use various program versions that can help to develop microelement system standards including earlier standards and integrate them all into one general automated control system. Such software will allow to quantify the workload of operators in various kind of manufacturing processes. Future research is necessary to integrate also mental workload and its interaction with physical workload investigation possibilities in the software.

REFERENCES

De Almeida, D. & Ferreira, J.C. 2015. Analysis of the Method Time Measurement (MTM) Methodology through its Application in Manufacturing Companies. *Flexible Automation and Intelligent Manufacturing* **1**, 2–9.

Drury, C.G. 1995. Ergonomics and Quality. In Proceedings of the IEA World Conference (ABERGO), Brazil, 16–20 p.

Eldholm, O.G. & Murrell, K.F.H. 1973. *The Ergonomics Society: A History 1949–1970*, London: Research Society, London, 80 p.

Freivalds, A. & Niebel, B. 2009. Niebel`s Methods, Standards & Work Design, 12th Ed. New York: Mc-Graw Hill, 736 p.

Freivalds, A. & Yun, M.H. 1994. Productivity and Health Issues in the Automation of T-Shirt Turning. *International Journal of Industrial Engineering* **1**(2), 103–108.

George, J. & Jones, G. 2004. Understanding and Managing Organizational Behaviour. 4th Edition. Prentice Hall, 696 p.

Heizer, J. & Render, B. 2011. *Operations Management*, 10th Ed. USA: Prentice Hall, 888 p.

Hendrick, H.W. 2002. An Overview of Macroergonomics. In H.W. Hendrick, B.M. Kleiner (Eds.): *Macroergonomics: Theory, Methods and Applications*, Lawrence Erlbaum, New Jersey, pp. 1–23.

IEA, International Ergonomics Association, *www.iea.cc*, accessed 15.01.2016.

ILO, International Labour Organization, *http://www.ilo.org/global/about-the-ilo*. Accessed 10.01.2016.

Integration definition for function modeling (IDEF0). 1993. Draft Federal information processing standards publication **183**.

Kalkis, H. 2014. *Business Ergonomics Management*. Gutenbergs Druka, 155 p. (in Latvian)

Karger, D.W. & Walton, M.H. 1962. *Advanced Work Measurement.* McGrew-Hill, New York, 632 pp.

Kuorinka, I. 2000. *History of the Ergonomics Association: The First Quarter of Century.* IEA Press, Santa Monica, 696 pp.

Maksimov, D.G. 2014. Emergence and development of microelement norm-fixing. *Bulletin of Udmurt University, Economics & Law* **1**, 68–71.

Maynard, H.B., Schwab, J.L. & Stegemerten, G.J. 2012. *Methods Time Measurement*. Literary Licensing, USA, 302 pp.

Maynard, H.B. 2001. MOST, H.B., Eight Parkway Center, *www.hbmaynard.com.* Accessed 10.01.2016.

Miller, D. 2013. *Towards Sustainable Labour costing in UK Fashion Retail.* Capturing the Gains. The University of Manchester, 45 pp.

Orefkov, V.V. & Perevoschikov, Y.S. 2005. Ergonomics rate fixing of labor. M. Publishing House VCUZh, Izhevsk: UDSU Publishing House, 934 pp. (in Russian).

Perevoschikov, Y.S. 2015. Labor process (engineering-economic research into working standards). – Izhevsk: Publishing house ‘Udmurt university’, 331 pp. (In Russian).
Records management function and information models. The Department of Defense. 1995 (In USA) *http://www.archives.gov/era/pdf/rmsc-19951006-dod-rm-function-and-information-models.pdf*. Accessed 12.12.2015.
Schmid, R.O. 1957. *An analysis of predetermined time system*. Newark, New Jersey, 200 pp.
Sellie, C.N. 1992. Predetermined Motion –Time Systems and the Development and Use of Standart Data. In Salvendy G (ed.): *Industrial Engineering.* John Wiley & Sons, New York, pp. 1639–1698.
System of standard on basic movement (BSM-1), Moscow: Economics, 1989, 123 pp.
Zandin, B. 1980. *MOST Work Measurement Systems*. Marcel Dekker, New York, 204 pp.

Agronomy Research **14**(4), 1417–1426, 2016

Predictors and prevalence of musculoskeletal disorders among sewing machine operators

E. Merisalu[1,*], M. Männaste[1], K. Hiir[1] and A. Traumann[2]

[1]Estonian University of Life Sciences, Institute of Technology, Kreutzwaldi 56, EE51014 Tartu, Estonia
[2]TTK University of Applied Sciences, Pärnu mnt. 62, EE10134 Tallinn, Estonia
[*]Correspondence: eda.merisalu@emu.ee

Abstract. Musculoskeletal disorders (MSD) are a common and most often disabling problem among sewing machine operators and associated to work related factors. The aim of study was to determine work related and individual risk factors and the prevalence of MSDs among sewing machine operators and describe relationships between risk factors and MSDs. The data were collected in random sample method, using parts of a standardized CUPID (Cultural and Psychosocial Influences on Disability) questionnaire. The questions were focused on occurrence of MSDs in different body regions, in the past year and past month. The respondents assessed pain in the neck, lower back, and both on the right and left side of shoulders, elbows, wrists/hands and knees. The questions about individual, physiological and psychological risk factors and health behaviour were included.

The response rate was 43.9%, from 130 sewing machine operators fifty seven of them responded to the questionnaire. They all were women, in mean age 44.4 ± 8.6 years and with average body mass index (BMI) 26.8 ± 6.6 kg m^{-2}. The majority had work experience more than 5 years. Sewing work is monotonous, in steady sitting position, with repetitive movements in elbow, wrist and fingers during a whole workday. The most of respondents (93%) have reported poor autonomy to decide over the working schedule and 75.4% had low decision latitude over what and how to do work. The majority of sewing machine operators get support from the colleagues and management.

Musculoskeletal pain at least in one body site was measured in 91.2% of cases in the past 12 months and among 82.5% of respondents in the past month. More than half of participants reported pain in three or more body sites. The most often pain regions were lower back (66.7%), neck (61.4%), wrist/hand (50.9%) and shoulders (42.1%) in the past year, and neck (45.6%) in the past month. Pearson correlation analysis showed positive relationships between lower back pain and poor autonomy ($p = 0.02$) and BMI ($p = 0.05$) and repetitive elbow bending was related to neck and wrist/hand pain ($p = 0.05$, in both). Regular smoking was related to wrist/hand pain ($p = 0.003$). In conclusion, high prevalence of MSDs among the sewing machine operators has observed, whereas lower back, neck, wrist and shoulders were the most often reported pain regions. Lower back pain correlated positively with BMI and autonomy, smoking with wrist/hand pain and repeated upper limb movements with neck and elbow pain.

Key words: sewing machine operator, musculoskeletal disorders, risk factors.

INTRODUCTION

The prevalence of musculoskeletal disorders (MSD) as work related diseases is high in Estonia and Europe. According to Estonian Health Board statistics (2014), there are 74% of MSDs are recorded with the diagnosis of occupational diseases and as the most common reason for receiving medical absence benefits in Estonia (Buckle & Devereux, 2002; EU-OHSA, 2007a; Health Board, 2014; HSE, 2015). In the Great Britain (2014–2015) the study of working conditions showed, that MSDs constituted 44% from all work related diseases (HSE, 2015). Musculoskeletal disorders are the main cause of sick leave in United States. In 2012, 29% of cases of the lost workdays have recorded because of MSDs (Summers et al., 2015).

Sewing machine operator's work is monotonous, usually with high work pace and whole day repetitive movements of elbow, wrist and fingers. Often the workers are placed on the delimited rooms, sitting closely behind the working tables not always ergonomically designed. Work on the riveting machine demands an awkward position and forced upper limb movements with up-lifted shoulders, causing strain in the neck and upper back. During the most of day the bending of elbow and wrist/hands, with inclined neck and head and upper body has caused high risk of MSDs (Buckle & Devereux, 2002; EU-OSHA, 2007a). A number of cross-sectional studies have demonstrated that sewing machine operators include into the risk group with high probability for pain in the neck and shoulder, upper and lower back and wrist/hand regions (Schibye et al., 1995). Structural damages in the skeletal muscles, tendons, joints and nerves are the main causes of MSDs and often influenced on character of work and working conditions (EU-OSHA, 2007b). The epidemiological studies have shown work related MSDs describing a wide range of inflammatory and degenerative diseases and disorders, resulting in pain and functional impairment, affecting the neck, shoulders, elbows, forearms, wrists and hands (Buckle & Devereux, 2002). Physiological, psychological, physical and individual risk factors could be directly related to MSDs (Buckle & Devereux, 2002; Lu et al., 2015). High work demands, low support by colleagues and managers and poor satisfaction with work can cause strain in musculoskeletal system (EU-OSHA, 2007a).

Earlier studies have shown, that there is a link between individual factors and MSDs. In 2013, it was carried out the study among the Portuguese production workers, with the aim to describe the correlations between BMI and MSDs. The participants were divided into two groups: normal weight (BMI $\leq$ 24.9 kg m^{-2}) and overweight/obesity group (BMI $\geq$ 25 kg m^{-2}). The results have demonstrated, that there was a higher risk for shoulder pain among the participants with overweight (Wang et al., 2007). Positive correlation between work experience and pain in shoulders, elbow and wrist was observed also in Turkey and Denmark, whereas high prevalence of neck (57%), shoulder (51%), and lower back pain (47%) was recorded in Danish population (Deyyas & Tafese, 2014).

The results of the previous study have demonstrated that when to increase the task variety and adopt rotations between different types of workstations, by increasing rest periods and improving the control over psychosocial stressors helps to prevent MSDs among sewing operators (Wang et al., 2007).

The aim of study was to analyse work related and individual risk factors and prevalence of MSDs among sewing machine operators and describe relationships risk factors and MSDs.

MATERIAL AND METHODS

The cross-sectional study was carried out in the largest sewing company in Estonia. The total number of the sewing machine operators in the official record was 130. In random sample method the anonymous electronic questionnaire was used to clear out the main risk factors and prevalence of MSDs. The questionnaire study was performed in Estonian and Russian languages from December 2015 to January 2016. The participation in the study was voluntary.

The questionnaire was based on the international survey '*Cultural and Psychosocial Influences on Disability'* (CUPID) (Coggon et al., 2012), *Baecke Physical Activity Questionnaire* (BQ) (Baecke et al., 1982) and *The Nordic Musculoskeletal Questionnaire* (NMQ) (Kuorinka et al., 1987). The questions about socio-demographic data, sport activities and occupation were included in the Part-A, in total 33 questions. The questions about pain occurrence in different body sites and duration of sick leave in the past 12 months and the past month were used in the Part-B, in total 18 questions. Five questions about general health formed the Part-C. In total 57 questions were included in the questionnaire. The respondents answered to the questions about the incidence of work related risk factors on the Likert scale 1–4, where 1 – never, 2 – seldom, 3 – sometimes, 4 – often. To the questions about the nature of work and prevalence of musculoskeletal pain were answered on the scale 'yes'/'no', regarding to right or left side of body or both. The duration of pain was assessed on the scale 1–3, where: 1 – 1–6 days, 2 – 1–4 weeks, 3 – 1–12 months. How many days did pain prevent them from going work, was measured on the scale 0–3, where: 0 – 0 days, 1 – 1–5 days, 2 – 6–30 days and 3 – more than 30 days. The main activities at work were assessed on the scale 0–4, where: 0 – never, 1 – seldom, 2 – sometimes, 3 – often, 4 – very often. For calculating of Body Mass Index (BMI) the formula [body mass (kg) (height $(m)^2)^{-1}$] was used. Four BMI categories have taken into consideration: underweight (BMI < 18.5 kg m^{-2}), normal weight (BMI 18.5…24.9 kg m^{-2}), overweight (BMI 25...29.9 kg m^{-2}), obesity of the 1st grade (BMI 30…34.9 kg m^{-2}) obesity of the 2nd grade (BMI 35…39.9 kg m^{-2}) and obesity of 3rd grade (BMI 40…44.9 kg m^{-2}) (WHO, 2016).

Statistical analysis. The data of e-questionnaire have saved automatically into the statistical program MS Excel and then transmitted into the program SPSS.23.0 (*Statistical Package of Social Sciences)*. Descriptive statistics (%), X^2-test for groups' comparison and dispersion analysis ANOVA (*Analysis of Variance)* for comparison of averages have used. Pearson and Spearman correlation analyses for measurement of relationships between work related risk factors and MSDs have used, and based on the statistical significance ($p \leq 0.05$). The study was affirmed by the Research Ethics Committee of the University of Tartu (protocol no 253/T-9, 16.11.2015).

RESULTS

The e-questionnaire was sent to 130 sewing machine operators and 57 of them answered to the questionnaire, the response rate was 43.8%. All the respondents were women, in mean age 44.4 ± 8.6 years and 93% had work load 40 hours per week and 7% worked 43–45 h in week. The most of them (82.5%) had work experience in this job more than five years. The main work tasks were: sewing (86%), co-ordination of 10.5% and work on riveting machine 3.5%. About half of the participants (44.6%) had normal BMI (18.5–24.9 kg m^{-2}), 25% were in overweight (25–29.9 kg m^{-2}), and 28.5% were obese (≥ 30 kg m^{-2}) (WHO, 2016). About 37.5% of the respondents were physically active and 29.8% were regular smokers (Table 1).

Table 1. Descriptive characteristics of the study group (n – number of respondents; % – proportion of respondents)

Parameter	Category	n	%
Main occupation	Sewing machine operator	49	86.0
	Co-ordinator	6	10.5
	Riveting machine operator	2	3.5
Work experience (years)	< 5	47	82.5
	1–5	7	12.3
	< 1	3	5.3
Workload (hours per week) average 40,3± 1,2	40	53	93.0
	43	1	1.8
	45	3	5.3
BMI (kg m^{-2}) average 26,8 ± 6,5	Underweight	1	1.8
	Normal weight	25	44.6
	Overweight	14	25.0
	Obesity I–III grade	16	28.5

The results showed, that very often 73.7% of sewing machine operators are working in sitting position and about two third of them are standing and walking seldom. A half of them lifted loads more than 25 kg seldom and 42.1% were exposed to lifting of loads sometimes (Fig. 1).

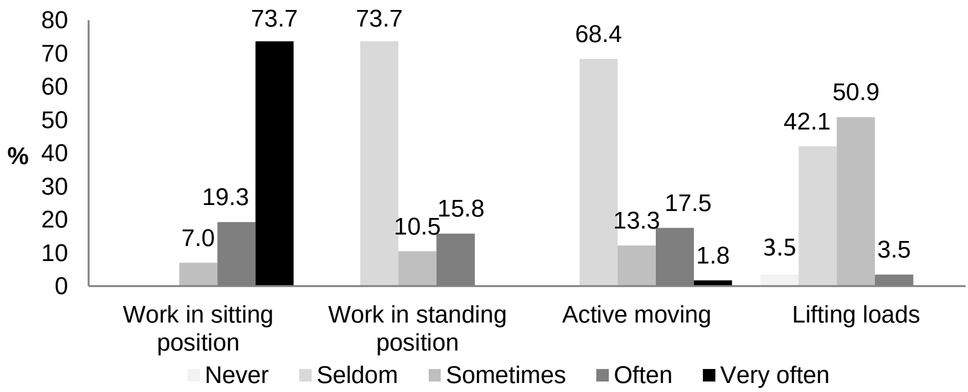


Figure 1. Evaluation of activities at work among sewing machine operators (%, proportion of respondents).

Almost all the workers affirmed that they are working under the pressure to complete tasks by a fixed time or complete a target number of articles that the team are expected to finish in the day. Most of them have reported continuous repetitive movements of wrist/hands and bending and straightening of elbows. Ninety two percent of respondents didn't use regular breaks during the work day (Fig. 2).

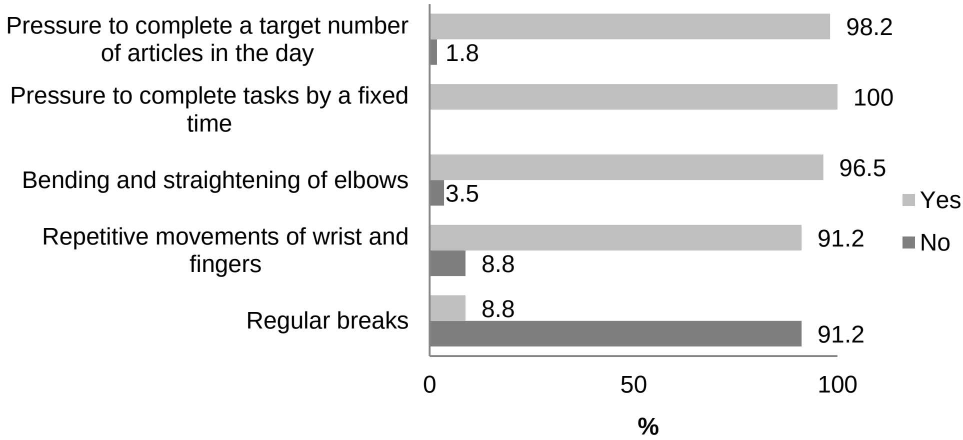


Figure 2. Evaluation of mental strain at work, repetitive movements and regular breaks among sewing machine operators (%, proportion of respondents).

In almost all of the cases (93%) poor autonomy over working schedule and breaks were reported. Also, 75.4% have reported that they have no chance to decide over work content and work activities and about half of them (47.4%) hadn't any choice in deciding what and how to do the work. More than half of the respondents have mentioned that sometimes support is available from the managers and less than half (40.4%) get advises from the supervisors quite often. About half of workers mentioned support sometimes from the colleagues (Table 2).

Table 2. Autonomy at work and support of colleagues and managers (%, proportion of respondents; (n), number of respondents)

Risk factor	Often	Sometimes	Seldom	Never
No choice in deciding how and when to do the work	24.6 (14)	14.0 (8)	14.0 (8)	47.4 (27)
Poor autonomy over work content and activities	12.3 (7)	8.8 (5)	3.5 (2)	75.4 (43)
Poor autonomy over working schedule and breaks	-	3.5 (2)	3.5 (2)	93.0 (53)
Help and support from the colleagues	33.3 (19)	49.1 (28)	8.8 (5)	8.8 (5)
Help and support from the managers	40.4 (23)	54.4 (31)	3.5 (2)	1.8 (1)

High prevalence of lower back pain (66.7%), neck (61.4%) and wrist/hand pain (50.9%) in the past 12 months and neck pain (45.6%) in the past month have observed. The right side was more painful, compared to the left one (Table 3).

Table 3. The prevalence of MSDs in the past 12 months and the past month on the right or left side of body or both (%, proportion of respondents)

Pain region	In the past 12 months				In the past month			
	Total	Right	Left	Both	Total	Right	Left	Both
Shoulders	42.1	14.0	17.5	8.8	26.3	10.5	10.5	3.5
Elbow	22.8	14.0	5.3	3.5	15.8	7.0	5.3	3.5
Wrist/hand	50.9	19.3	17.5	14.0	33.3	14.0	10.5	8.8
Knees	14.0	7.0	1.8	5.3	8.8	5.3	3.5	-
Neck	61.4				45.6			
Lower back	66.7				33.3			

Pain in more than three body sites was reported by 52.6% of respondents in the past 12 months and by 24.5% in the past month. Few pain-free respondents have seen in this study. No any pain was reported by 8.8% in the past 12 months and by 17.5% in the past month (Table 4).

Table 4. The number of body sites of musculoskeletal pain among sewing machine operators in the past 12 months and the past month (%, proportion of respondents; (n), number of respondents)

The number of pain sites	In the past 12 months	In the past month
0	8.8 (5)	17.5 (10)
1	14.0 (8)	38.6 (22)
2	22.8 (13)	19.3 (11)
3	29.8 (17)	14.0 (8)
4	14.0 (8)	10.5 (6)
5	7.0 (4)	-
6	3.5 (2)	-

The duration of pain from one to six days was reported more often in the lower back (42.1%), neck (31.6%) and wrist/hand (28.1%). The duration of pain from one to four weeks was measured more often in the neck (19.3%) longer than one month in the lower back (14.0%) (Table 5).

Table 5. Duration of pain and sick leave by the body regions among sewing machine operators (%, proportion of respondents; (n), number of respondents)

Pain region	Duration of pain			Sick leave			
	1–6 days	1–4 weeks	1–12 months	0 days	1–5 days	6–30 days	> 30 days
Lower back	42.1 (24)	10.5 (6)	14.0 (8)	84.2 (48)	5.3 (3)	8.8 (5)	
Neck	31.6 (18)	19.3 (11)	10.5 (6)	38.6 (22)	31.6 (18)	19.3 (11)	10.5 (6)
Shoulder	24.6 (14)	10.5 (6)	7.0 (4)	86.0 (49)	1.8 (1)	7.0 (4)	-
Elbow	12.3 (7)	5.3 (3)	3.5 (2)	87.7 (50)	1.8 (1)	1.8 (1)	-
Wrist/hand	28.1 (16)	14.0 (8)	8.8 (5)	93.0 (53)	-	1.8 (1)	1.8 (1)
Knee	7.0 (4)	1.8 (1)	5.3 (3)	-	-	-	-

In the most cases the workers didn't take the days off because of MSDs. Because of neck pain about one third of the respondents missed workdays from one to five days and 19.3% 6–30 days and 10.5% had sick leave more than 30 days. Surprisingly, a few respondents missed workdays because of lower back pain.

The correlation analysis showed direct relationship between BMI and lower back pain ($p = 0.05$). Positive correlation was detected also between smoking and wrist/hand pain ($p = 0.003$). Significant relationships between bending and straightening of elbow and pain in the neck ($p = 0.05$) and wrist/hand ($p = 0.05$) were observed. Positive correlations between autonomy on work content, tasks schedule, and rest breaks and pain in the lower back ($p = 0.02$) and elbow ($p = 0.01$). Lack of regular breaks didn't correlate to MSDs.

DISCUSSION

The sewing machine operators include into the risk group, with high probability for MSDs in neck/shoulder, upper and lower back and wrist/hand regions (Schibye et al., 1995). This study of work related risk factors and prevalence of MSDs among sewing machine operators was ordered by the enterprise management who were very interested in improvement of working conditions to prevent MSDs among the workers. Often the sewing machine operators are sitting closely behind the tables not always ergonomically designed and using technology that compel an awkward position (for example riveting). During the most of workday the bending and straightening of hands, wrists and fingers cause inflammatory and degenerative changes in the tendons, joints and muscles, resulting in pain and functional impairment (Schibye et al., 1995; EU-OSHA, 2007a; EU-OSHA, 2007b; Sealetsa & Thatcher, 2011; Männaste & Merisalu, 2016). A number of studies have shown that work related MSDs mainly affecting the neck, shoulders, elbows, forearms, wrists and hands of sewing machine operators (Schibye et al., 1995; Buckle & Devereux, 2002; EU-OSHA, 2007a; Deyyas & Tafese, 2014; Lu et al., 2015). In our study, there is additional information about the prevalence of MSDs among the sewing machine operators that the lower back pain was on the first place (Männaste & Merisalu, 2016). The direct relation between physiological, psychological, physical and individual risk factors and MSDs has been found in the earlier studies (Buckle & Devereux, 2002; Lu et al., 2015). In the present study the most of respondents had pain at least in one body region and more than half in three and more body sites in the past 12 months. Some of the authors have found the relationship between MSDs, physical overstrain and job satisfaction (Wang et al., 2007).

Although the majority reported poor autonomy at work, surprisingly the higher autonomy in work content, tasks schedule and resting breaks was positively correlated with lower back and elbow pain. Contrary, the earlier studies have shown negative association between poor autonomy and MSDs (Melzer & Iguti, 2010). Apparently the higher choice in deciding what and how to do the work is strongly forcing the workers, causing overstain and more often MSDs. At the same time few of the sewing machine operators misses workdays because of illness and short duration of sick leave about one week was reported. The earlier research on garment workers has demonstrated, that when the breaks were too short, the higher prevalence of pain in the neck and shoulders was observed (Afonso et al., 2014). The Chinese researchers are detected, that the optimal number of breaks and diverse work tasks enable to prevent MSDs among sewing machine operators (Lu et al., 2015).

The present study clearly demonstrate the need for better job control, because even when a higher autonomy the sewing machine operators are working too hard to complete the tasks by a fixed time to achieve the better results. High work pace plays here an important role.

In the present study positive correlation between BMI and lower back pain confirmed that there is a higher risk for MSDs among the workers with overweight (Lu et al., 2015; WHO, 2016; Männaste & Merisalu, 2016). It has been shown that steady work in sitting position during a whole workday is related to high risk on overweight (Buckle & Devereux, 2002; EU-OSHA, 2007a). So, the variation of work tasks in different positions and work rotation could be diminish risk of overweight and prevent MSDs among sewing machine operators (Wang et al., 2007; Lu et al., 2015).

Also, the smoking conceives a risk on musculoskeletal problems. Additionally to toxic effect of smoking on a whole body, the higher prevalence of MSDs has seen in our study – the more often wrist/hand pain was detected among the regular smokers. It has been recommended to stop smoking that to prevent MSDs (Abate et al., 2013).
Different ergonomic intervention activities and physio- and psychotherapy procedures could be useful to prevent MSDs and sick leave among sewing machine operators (Buckle & Devereux, 2002).

CONCLUSIONS

The results of study showed, that sewing machine operators include in the risk group with high prevalence of MSDs. Almost all the respondents (91.2%) reported pain at least in one body region in the past 12 months and most often in lower back, neck and wrist/hand. A relatively short duration of lower back pain (1–6 days) was reported by 42.1% of respondents and sick leave from one to five days was mentioned by 31.6% because of neck pain.

Monotonous work in constraint sitting position with repetitive movements and poor autonomy were observed as work specific risk factors for all the sewing machine operators. Most of the participants reported few breaks and work under pressure to complete tasks by a fixed time.

Statistically significant relationships between work related and individual risk factors have seen. Positive correlations between bending and straightening of elbow and pain in the neck and wrist/hand were observed. The regular smokers had higher prevalence of wrist/hand pain. Overweight and autonomy correlated positively with lower back pain. But support by colleagues and supervisors could be give positive effect on teamwork to better manage work overload.

In conclusion, it is very important to pay more attention on workplace ergonomics to correct a sitting posture and adapt the movements of elbow and wrist/hand among sewing machine operators. The best physical exercise programs, and optimal breaks and effective rehabilitation activities could be included into the work schedule of sewing machine operators. Further longitudinal studies are needful to investigate the effect of intervention programs on MSD prevalence among sewing machine operators.

ACKNOWLEDGEMENTS. The research team is much obliged to the sewing company management for help and guidelines in carrying out the study among the sewing machine operators.

REFERENCES

Abate, M., Vanni, D., Pantalone, A. & Salini, V. 2013. Cigarette smoking and musculoskeletal disorders. *Muscles, Ligaments and Tendons Journal* **3**(2), 63–69.

Afonso, L., Pinho, M.E. & Arezes, P.M. 2014. Risk factors associated with musculoskeletal symptoms in footwear sewing workers. *Occupational Safety and Hygiene II* pp. 597–602.

Baecke, J.A.H., Burema, J. & Frijters, J.E.R. 1982. A short questionnaire for the measurement of habitual physical activity in epidemiological studies. *The American Journal of Clinical Nutrition* **36**, 936–942.

Buckle, P.W. & Devereux, J.J. 2002. The nature of work-related neck and upper limb musculoskeletal disorders. *Applied Ergonomics* **33**(3), 207–217.

Coggon, D., Ntani, G., Palmer, K.T. et al. 2012. The CUPID (Cultural and Psychosocial Influences on Disability) study: methods of data collection and characteristics of study sample. *PLoS One* **7**(10), 1–22.

Deyyas, W.K. & Tafese, A. 2014. Environmental and organizational factors associated with elbow/forearm and hand/wrist disorder among sewing machine operators of garment industry in Ethiopia. *Journal of Environmental and Public Health* 2014:732731, pp 1–8.

EU-OSHA. 71/ET. Facts. European Agency for Safety and Health at Work. 2007a. Work related musculoskeletal disorders (in Estonian). *https://osha.europa.eu/et/tools-and-publications/publications/factsheets/71.* Accessed 24.3.2016.

EU-OSHA. 3/EN. European Agency for Safety and Health at Work. 2007b. Work-related musculoskeletal disorders: Back to work raport. Luxembourg, pp. 1–100.

Han, T.S., Schouten, J.S., Lean, M.E. & J.C. Seidell, M.E. 1997. The prevalence of low back pain and associations with body fatness, fat distribution and height. *International Journal of Obesity and Related Metabolic Disorders* **2**1, 600–607.

HSE. Health and Safety Executive. 2015. *Work-related musculoskeletal disorder (WRMSDs) statistics*. Great Britain, 20 pp. http://www.hse.gov.uk/statistics/causdis/musculoskeletal/msd.pdf

Kuorinka, I., Jonsson, B., Kilbom, A., Vinterberg, H., Biering-Sorensen, F., Andersson, G. & Jorgensen, K. 1987. Standardised Nordic questionnaires for the analysis of musculoskeletal symptoms. *Applied Ergonomics* **18**(3), 233–237.

Lu, L., Chen, S.G., Tang, S.C, Wang, S., He, L.H., Guo, Z.H., Li, J.Y., Yu, S.F. & Wang, Z.X. 2015. How work organization affects the prevalence of WMSDs. A case-control study. *Biomed Environ Sci.* **28**(9), 627–633.

Männaste, M. & Merisalu, E. 2016. Nature of work and incidence of musculoskeletal pain among sewing machine operators. *The10th Master students conference & 1st International Master students conference "Human and Engineering"* (in Estonian). Tartu, pp. 129–135.

Melzer, A.C.S. & Iguti, A.M. 2010. Working conditions and musculoskeletal pain among Brazilian pottery workers. *Cad Saúde Pública* **26**(3), 492–502.

Sealetsa, O.J. & Thatcher, A. 2011. Ergonomics issues among sewing machine operators in the textile manufacturing industry in Botswana. *Work* **38**, 279–289.

Summers, K., Jinnet, K. & Bevan, S. 2015. Musculoskeletal disorders, workforce health and productivity in the United States. *The Work Foundation.* London, pp 40.

Schibye, B., Skov, T., Ekner, D., Christiansen, J.U. & Sjøgaard, G. 1995. Musculoskeletal symptoms among sewing machine operators. *Scandinavian Journal of Work, Environment & Health* **21**(6), 427–434.

Health Board. Incidence of occupational diseases and work related diseases in 2014 (in Estonian). Tallinn, 2014. *http://terviseamet.ee/tervishoid/toeoetervishoid/aruanded.html* Accessed 24.3.2016.

Wang, P.C., Rempel, D.M., Harrison, R.J., Chan J. & Ritz, B.R. 2007. Work-organizational and personal factors associated with upper body musculoskeletal disorders among sewing machine operators. *Occupational and Environmental Medicine* **6**(4), 806–813.

WHO. World Health Organization Europe. 2016. *Body Mass Index – BMI*. http://www.euro.who.int/en/health-topics/disease-prevention/nutrition/a-healthy-lifestyle/body-mass-index-bmi

Agronomy Research **14**(4), 1427–1434, 2016

Influence of Mechanical Pre–treatment on Fermentable Sugar Production from Lignocellulosic Biomass

L. Mezule*, M. Strods and B. Dalecka

Riga Technical University, Faculty of Civil Engineering, Research Centre for Civil Engineering, Water Research Laboratory, Kipsalas 6a–263, LV-1048 Riga, Latvia
*Correspondence: linda.mezule@rtu.lv

Abstract. Mechanical pre-treatment of lignocellulosic biomass has been extensively applied in biofuel production despite its high energy requirements. To balance the consumed energy with the energy produced, careful selection and evaluation of pre-treatment parameters, equipment and desired outcome is needed. The study aims to determine optimal hay and barley straw biomass particle size in view of sugar yields, energy consumption and treatment time. The results show that there is no significant difference ($p > 0.05$) in sugar yields from hay biomass with particle sizes 0.25 mm, 1 mm and 10 mm. Energy requirements for the production of 1 kg of sugar from hay range from 1.8–10.7 MJ. At the same time barley straw proved to be inappropriate for sugar extraction due to low sugar yields (below 40 mg g^{-1} dry mass) and high energy consumption (18.5–76.2 MJ to produce 1 kg sugar). Thus, after the careful selection of biomass, mechanical pre-treatment followed by enzymatic hydrolysis can be an effective technique in biofuel production from biomass.

Key words: lignocellulosic biomass, pre-treatment, fermentable sugars, milling.

INTRODUCTION

Lignocellulosic biomass is regarded as a sustainable renewable resource to produce biofuels, e.g., bioethanol or biobutanol. A major portion of this biomass contains cellulose, hemicellulose and lignin. Cellulose and hemicellulose, in turn, can be converted to fermentable sugars. At the same time, lignin forms a protective covering and impedes the hydrolysis of cellulose and hemicellulose. Therefore, biomass pre-treatment is required for the depolymerisation of lignin prior to the conversion of cellulose and hemicellulose into fermentable sugars (Chaturvedi & Verma, 2013). Many combinations of various technologies have been proposed for the pre-treatment of lignocellulosic materials to produce biofuels. These methods can be divided into chemical (acid, alkaline), biological, oxidative and physical (mechanical) methods (Kumar et al., 2009). So that these technologies could be used outside laboratory and research environments, they must be effective as well as simple, user-friendly and economically sustainable. One of the simplest approaches is mechanical size reduction that has many advantages, like facilitating an increase in total accessible surface area, reduction in cellulose crystallinity (Barakat et al., 2014) and no formation of toxic by-products (Agbor et al., 2011). Cutting or crushing, coarse milling, chipping, shredding and grinding are among the most often reported size reduction approaches (Barakat et al., 2014).

The selection of the most appropriate mechanical pre-treatment method is associated with the economical parameters of the equipment, since it has been reported that pre-treatment is generally the most energy consuming step in biofuel production (Mosier et al., 2005). Sometimes energy consumption is even higher than the theoretical energy content available in the biomass (Kumar et al., 2009), thus making some techniques inefficient. Nevertheless, a large number of studies have been performed over the years to find the most appropriate mechanical pre-treatment conditions and equipment (Shi et al., 2009; Barakat et al., 2014) as there is a need for technological simplicity that must have an overall effect on production yields. It has been demonstrated that size reduction increases sugar (Pedersen & Meyer, 2009; Mezule et al., 2015) or biofuel (Menind & Normak, 2010) yields and is closely linked with energy requirements (Cadoche & López, 1989). At the same time, data on linking sugar yields with energy requirements is limited or the connection has not been demonstrated for biomass available at temperate climates (Da Silva et al., 2010) where inedible lignocellulosic biomass can be found in vast amounts. Recently, landowners have been even required to remove biomass cultures from the fields to receive financial support (Zalite et al., 2014; Rural Support Service of the Republic of Latvia, 2015), thus making the resource an unwanted waste.

The aim of this study is to determine optimal hay and barley straw biomass particle size in view of sugar yields, energy consumption and treatment time. For the evaluation biomass was milled in a commercial cutting mill with exchangeable sieves that was selected owing to its ability to produce variable biomass fractions and the potential for large-scale application. Detailed fractionation of the biomass was not performed due to the low probability of fractionation by the potential end user—the industry.

MATERIALS AND METHODS

Feedstock preparation

Hay (Dry weight (DW) 92.8 ± 1.3%) and barley straw (DW 94.2 ± 0.7%) harvested in 2015 in Latvia were used as the test material. Previously reported chemical compositions of the biomass were adopted for this study (35–45% cellulose, 30–50% hemicellulose and 8–20% lignin for barley straw (Chen et al., 2007) and 25–40% cellulose, 35–50% hemicellulose and 10–30% lignin for hay (Kumar et al., 2009). The material was milled at a mechanical cutting mill (Retsch SM100, Haan, Germany) with 1.5 kW drive and parallel section rotor with a peripheral speed of 9.4–11.4 ms^{-1}. For all individual tests 400 g of biomass was used. Particle size was controlled with the help of sieve size and type (0.25 mm and 1 mm trapezoid holes, 10 mm square holes). After each milling the sieves were carefully cleaned to exclude any transfer of biomass. Practical electrical energy consumption (E_p, kWh) was measured with a 3–phase indicator (Orno OR–WE–505, Mikolow, Poland). Theoretical energy (E_t, kWh) was calculated according to Eq. 1:

$$E_t = \mathrm{P} \times \mathrm{t} \quad (1)$$

where: P – drive power (kW); t – milling time, h.

After the milling all samples were collected to separate containers, carefully closed to avoid moisture and stored for further processing. All experiments were prepared in triplicate.

Dry weight content was analysed with the moisture analyser Kern DBS (Kern & Sohn GmbH, Germany).

Enzymatic hydrolysis

Prior hydrolysis 3% w/v of the collected milled 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 room temperature a laboratory-prepared enzyme (0.2 FPU ml^{-1}, Mezule et. al, 2015) was added to the diluted substrates and incubated on an orbital at 30 °C. Samples for sugar analyses were collected after dilution with buffer, prior enzyme addition and after 24 and 48 h of incubation. At least 2 samples from each test were collected for reducing sugar measurements.

Reducing sugar analysis

Total reducing sugar concentration was measured with the dinitrosalicylic acid (DNS) method (Ghose, 1987). In brief, all samples were centrifuged at 6,600 g for 5 min (MiniSpin Plus, Eppendorf). Then 0.1 ml of the supernatant was mixed with 0.1 ml of 0.05 M sodium citrate buffer and 0.6 ml of DNS (3,5-dinitrosalicylic acid, Sigma, Germany). For blank control, distilled water was used instead of the sample. Then all samples were boiled for 5 min and transferred to cold water. Further 4 ml of distilled water was added. Absorption was measured with spectrophotometer at 540 nm (Camspec M501, UK). To obtain absolute concentrations, a standard curve against glucose was prepared.

Data analysis

MS Excel 2007 t-test (two tailed distribution) and ANOVA single parameter tool (significance level ≤ 0.05) were used for the analysis of variance of data from various sample setups.

RESULTS AND DISCUSSION

The mechanical pre-treatment of biomass to reduce its size and facilitate hydrolysis has been widely used despite its high energy requirements (Barakat et al., 2014). To create a balance between sugar yields and energy consumption various factors like size and equipment must be evaluated. In this research biomass pre-treatment was performed with a commercial cutting mill with exchangeable sieves. Particles were milled by passing them through a sieve where they were reduced by the high-speed mechanical impacts and shearing inside the grinding chamber (Silva et al., 2012).

The obtained fractions were below 0.25 mm, 1 mm and 10 mm (Fig. 1, samples 1–3 respectively) in size. Milling time decreased with the increasing sieve size and the same amount of biomass was obtained twice the faster ($p < 0.05$) with the 10 mm sieve compared to 0.25 or 1 mm, irrespective of biomass source. At the same time, the processing of barley straw required a 18–44% longer milling time than hay. Regular blocking of the mill was observed for barley straw irrespective of the sieve size.

Processing difficulties connected to barley straw could be attributed to different initial density and moisture content, which afterwards decreased the material's flowability (Tumuluru et al., 2014). Nevertheless, visual observations showed that samples milled with 10 mm sieve contained distinct biomass pieces that could explain fractions producing low sugar yields (Mezule et al., 2015). Both 0.25 mm and 1 mm size samples had homogeneous biomass fractions without any distinct particles. Samples of 0.25 mm fractions were almost powder-like and created dust easily (during milling 10–50% of the material was lost). Thus, dust masks were required for operators and the powder was a potential health hazard. Fractions of 1 mm did not show such properties.

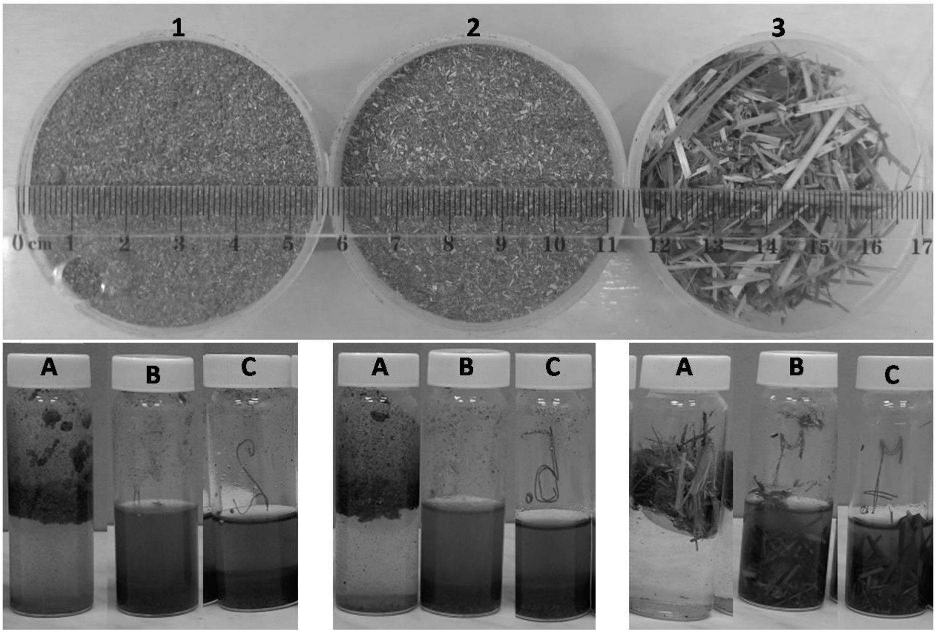


Figure 1. Hay biomass fractions after milling with 0.25 mm (1), 1 mm (2) and 10 mm (3) sieves (upper picture) and subsequent biomass sample after wetting (A), after 5 min of boiling (B) and after 24 h of hydrolysis (C).

After wetting (addition of 3% w/v buffer), 10 mm samples did not show any colouration of the buffer (Fig. 1., 3A). Slight coloration was observed only after boiling. However, it did not reach the level of samples milled with 0.25 and 1 mm sieves, which showed good wetting properties and distinct coloration after adding buffer. They also adopted a more brownish colour after boiling that could be explained with the more extensive formation of water soluble lignocellulose substances.

Analyses of fermentable sugar concentration during the production process did not show any significant differences ($p > 0.05$) between the hay samples milled with different sieves (Fig. 2). About 20 mg g^{-1} sugar was released already after milling, (including in the samples with 10 mm fractions), an additional 24–29% were released after boiling, indicating that boiling, which was initially used only for the neutralisation of indigenous microflora (Mezule et al., 2012), also supports the degradation of complex structures and sugar release. A slight variation in hay-sample sugar content was observed only after 48 h of hydrolysis when the sugar content in 0.25 mm size samples was 8–11% higher than in 1 and 10 mm samples ($p > 0.05$). Since longer hydrolysis time did not produce a significant increase in sugar concentration ($p > 0.05$), only 24 h hydrolysis data were used for further evaluation (low economic benefit in prolonged incubation).

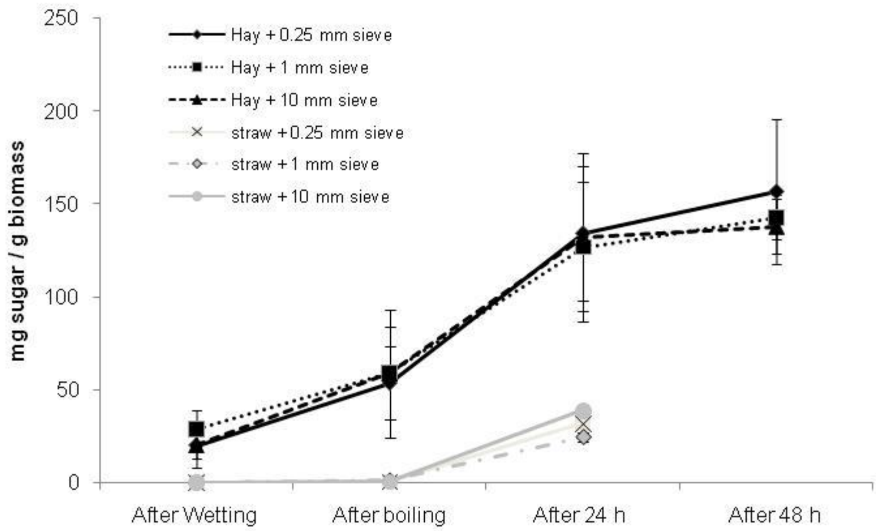


Figure 2. The amount of fermentable sugars produced from hay and barley straw biomass milled with 0.25, 1 and 10 mm sieves after wetting, boiling, 24 and 48 h of hydrolysis. Each standard deviation represents an average from at least 3 individual sample measurements.

Higher sugar yields were obtained from hay compared to barley straw. The amount extracted from barley straw after 24 h was 70% lower than from hay and was statistically different ($p < 0.05$) for the various sizes (Fig. 2). Nevertheless, these differences were attributed to deviations from the 24–39 mg g^{-1} sugar content and did not correlate with biomass size, and this contradicts with other studies on the processing of straw (Pedersen & Meyer, 2009). Furthermore, no or minor release of sugars was observed after sample wetting and boiling. The low release of sugars could be explained not only with the high crystallinity and low hydrolysability of barley straw (Vandenbossche et al., 2014) but also with the higher amount of *p*-hydroxycinnamates (abundant in monocots—barley straw), which have been shown to have a negative correlation with enzymatic digestibility if no chemical pre-treatment is applied (Li et al., 2012). Thus, barley straw might be inappropriate for biofuel production with the pre-treatment/hydrolysis method used in this study.

Analyses of energy requirements for the production of fermentable sugars showed that generally much more energy is required to process straw (Table 1) compared to hay. To produce 1 kg of sugar from hay, milling required 1.8–10.7 MJ depending on biomass size, however, for barley straw it required 18.5–76.2 MJ, thus further supporting the observations on the inapplicability of this resource for energy production.

Table 1. The amount of energy consumed and fermentable sugar produced per kg of hay or barley straw biomass (24 h of hydrolysis)

Sample	Sieve size, mm	Energy consumed, MJ kg^{-1}	Sugar produced, kg kg^{-1}
Hay	0.25	1.44	0.13
	1	0.49	0.13
	10	0.24	0.13
Barley straw	0.25	2.43	0.03
	1	0.99	0.02
	10	0.72	0.04

Research on mechanical pre-treatment generally involves the preparation of very fine particles (Barakat et al., 2014) and, subsequently, high consumption of energy (Da Silva et al., 2010). However, this research showed that hay fractions below 10 mm produce reasonable quantities of reducing sugars and there was no need to prepare powder-like fractions below the size of 0.25 mm, thus widening the variety of equipment that may be used for biomass pre-treatment. Energy consumption was not only influenced by particle size but also by biomass type. Seemingly similar biomass materials required significantly different ($p < 0.05$) amounts of energy, creating a problem when all-year, all-type biomass conversion technologies are planned. Similarly, pre-processing biomass to eliminate unproductive material would produce additional costs.

Nevertheless, the selected equipment still required a lower amount of energy compared to theoretical or reported values (Da Silva et al., 2010), allowing the application of even harder materials, e.g., hardwood, in biofuel production (Cadoche & López, 1989).

CONCLUSIONS

The results showed that particle size has no significant influence ($p > 0.05$) on sugar yields when fractions with the size of 0.25 mm, 1 mm and 10 mm are used. Nevertheless, the general observation that smaller biomass size generates more sugar proved to be correct in this study. Barley straw cannot be used as a biofuel substrate if mechanical pre-treatment is combined with enzymatic hydrolysis for sugar production because the potential yields were low and energy needed only for pre-treatment ranged from 18.5–76.2 MJ kg^{-1} of the sugar produced. At the same time it was possible to produce 1 kg of sugar from hay by using only 1.8 MJ for milling. In order to use barley straw as a renewable resource for energy production other pre-treatment/hydrolysis methods should be evaluated.

This study demonstrated that mechanical milling can be an effective, simple and sustainable approach, if the most appropriate treatment conditions, equipment and biomass type are used. However, the biomass type used must be thoroughly considered before production.

ACKNOWLEDGEMENTS. This work has been supported by the Latvian National Research Programme No. 2014.10-4/VPP-1/27 Energy efficient and low-carbon solutions for a secure, sustainable and climate variability reducing energy supply (LATENERGI) 2014–2017.

REFERENCES

Agbor, V.B., Cicek, N., Sparling, R., Berlin, A. & Levin, D.B. 2011. Biomass pretreatment: Fundamentals toward application. *Biotechnology Advances* **29**, 675–685.

Barakat, A., Mayer, C., Solhy, A., Arancon, R.A.D., De Vries, H. & Luque, R. 2014. Mechanical pretreatments of lignocellulosic biomass: towards facile and environmentally sound technologies for biofuels production. *RSC Advances. Royal Society of Chemistry* **4**, 48109–48127.

Cadoche, L. & López, G.D. 1989. Assessment of size reduction as a preliminary step in the production of ethanol from lignocellulosic waster. *Biological Wastes* **30**, 153–157.

Chaturvedi, V. & Verma, P. 2013. An overview of key pretreatment processes employed for bioconversion of lignocellulosic biomass into biofuels and value added products. *Biotechnology* **3**, 415–431.

Chen, Ye., Sharma-Shivappa, R.R., Keshwani, D. & Chen, C. 2007. Potential of agricultural residues and hay for bioethanol production. *Applied Biochemistry and Biotechnology Part A: Enzyme Engineering and Biotechnology* **142**, 276–290.

Da Silva, A.S., Inoue, H., Endo, T., Yano, S. & Bon, E.P.S. 2010. Milling pretreatment of sugarcane bagasse and straw for enzymatic hydrolysis and ethanol fermentation. *Bioresource Technology* **101**, 7402–7409.

Ghose, T.K. 1987. Measurement of cellulose activities.*Pure& Appl. Chem.***59**, 257–268.

Kumar, P., Barrett, D.M., Delwiche, M.J. & Stroeve, P. 2009. Methods for Pretreatment of Lignocellulosic Biomass for Efficient Hydrolysis and Biofuel Production.*Ind. Eng. Chem.Res.* **48**, 3713–3729.

Li, M., Foster, C., Kelkar, S., Pu, Y., Holmes, D., Ragauskas, A., Saffron, C. & Hodge, D.B. 2012. Structural characterisation of alkaline hydrogen peroxide pretreated grassess exhibiting diverse lignin phenotypes. *Biotechnology for Biofuels* **5**, 38.

Menind, A. & Normak, A. 2010. Study on Grinding Biomass as Pre–treatment for Biogasification. *Agranomy Research* **8**, 155–164.

Mezule, L., Dalecka, B. & Juhna, T. 2015. Fermentable Sugar Production from Lignocellulosic waste.*Chem. Eng. Trans.* **43**, 619–624.

Mezule, L., Tihomirova, K., Nescerecka, A. & Juhna, T. 2012. Biobutanol production from agricultural waste: A simple approach for pre-treatment and hydrolysis.*Latvian Journal of Chemistry* **4**, 407–414.

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**,673–686.

Pedersen, M. & Meyer, A.S. 2009. Influence of Substrate Particle Size and Wet Oxidation on Physical Surface Structures and Enzymatic Hydrolysis of Wheat Straw.*Biotechnol. Prog.* **25**, 399–408.

Rural Support Service of the Republic of Latvia. 2015. Grasslands must be not only cut, but also removed. *http://www.lad.gov.lv/lv/aktualitates-un-kalendars/aktualitates/zalajus-ne-tikai-janoplauj-bet-ari-janovac-536.* Accessed: 30.01.2016. (in Latvian).

Shi, F., Morrison, R., Cervellin, A., Burns, F. & Musa, F. 2009. Comparison of energy efficiency between ball mills and stirred mills in coarse grinding. *Minerals Engineering* **22**, 673–680.

Silva, G.G.D., Couturier, M., Berrin, J.G., Buléon, A. & Rouau, X. 2012. Effects of grinding processes on enzymatic degradation of wheat straw. *Bioresource Technology* **103**, 192–200.

Tumuluru, J.S., Tabil, L.G., Song, Y., Iroba, K.L. & Meda, V. 2014. Grinding energy and physical properties of chopped and hammer-milled barley, wheat, oat, and canola straws. *Biomass and Bioenergy* **60**, 58–67.

Vandenbossche, V., Brault, J., Vilarem, G., Hernández–Meléndez, O., Vivaldo–Lima, E., Hernández–Luna, M., Barzana, E., Duque, A., Manzanares, P., Ballesteros, M., Mata, J., Castellón, E. & Rigal, L.2014. A new lignocellulosic biomass deconstruction process combining thermo–mechano chemical action and bio–catalytic enzymatic hydrolysis in a twin–screw extruder.*Industrial Crops and Products* **4**, 258–266.

Zalite, K., Voormansik, K., Praks, J., Antropov, O. & Noorma, M. 2014. Towards detecting mowing of agricultural grasslands from multi–temporal COSMO–SkyMed data. In Geoscience and Remote Sensing Symposium (IGARSS), 2014 IEEE International, 5076–5079.

Agronomy Research **14**(4), 1435–1449, 2016

Comparison of musculoskeletal disorders development in Estonian office and garment industry workers

V. Pille*, K. Reinhold, P. Tint and J. Hartšenko

Tallinn University of Technology, Ehitajate 5, EE 19086 Tallinn, Estonia
*Correspondence: piia.tint@ttu.ee

Abstract. The aim of the paper was to investigate the structure of the factors influencing the development of the work-related musculoskeletal disorders (MSDs) in two different employee groups: office and garment industry workers. The work conditions in these two workplaces are different. The first group is mostly exposed to psychological distress and less to physiological risk factors. The second group is more affected by non-ergonomics factors. Several different research methods were used in the study: the work conditions were assessed using a flexible risk assessment method; the ergonomic risks were assessed with the ART-tool; the workers' musculoskeletal complaints were assessed using the Nordic Questionnaire; the intensity of pain was assessed by means of the Visual Analogue Scale (VAS). The number of investigated workers was 54 people from office and 49 from the garment industry. As a result, the garment workers' group had significantly more musculoskeletal complaints. Self-reported muscle pain and discomfort complaints showed that the office workers' left hand was less strained than the right one. It was confirmed by the studies determining the risk level using the ART tool at the workplace. The garment workers' both hands are usually strained at about the same level, only in the extreme conditions where the right hand is fulfilling special operations, the operating (right) hand is strained more. The results of the study make it possible to work out the means for prevention and rehabilitation of work-related musculoskeletal disorders.

Key words: work-related musculoskeletal disorders (WRMSD), office and garment industry workers, self-reported musculoskeletal disorders.

Abbreviations:
MSDs – musculoskeletal disorders,
WRMSDs – work-related musculoskeletal disorders,
OW – office workers,
GW – garment industry workers,
OCP – occupational disease patients,
VDU – visual display unit,
VAS – pain Visual Analogue Scale,
R – right; L – left,
N – number of workers.

INTRODUCTION

The majority of occupational diseases in Estonia are musculoskeletal disorders (MSDs) (National, 2015). They are mainly caused by long-time monotonous work or work in awkward postures. Both office and industrial workers are complaining of musculoskeletal disorders. Work-related musculoskeletal disorders (WRMSDs) of office workers are of shorter duration, especially specific hand diseases like carpal tunnel syndrome and epicondylitis (Leah, 2011; Mattoli et al., 2015). Manual workers, including garment workers, have a higher risk of developing an occupational disease. They are exposed to highly repetitive movements, awkward postures of hand, wrist, elbow, shoulder and neck. Usually, work intensity is high (Wang et al., 2009; Hagberg et al., 2012).

The occupational illnesses develop by stages. At the first stage, the rehabilitation is effective and the worker can return to work after a few weeks of treatment. At the next stage, treatment is possible, but it takes more time and sometimes the worker has to change the character of work in order not to be disabled in the future. In the case of occupational diseases, complaints and musculoskeletal changes are usually irreversible, but it is possible to use some rehabilitation methods to alleviate the sufferings of patients (Gawke et al., 2012; Pille et al., 2015). The MSDs are the common work-related diseases at the European level (Schneider et al., 2010). 25% of the workers in 27 of EU member countries complained of upper back pain and 23% of workers had neck, shoulder and hand complaints in 2007. Musculoskeletal disorders are the most common work-related diseases in the US and Australia, affecting millions of workers (Zheltoukhova et al, 2012; Summers et al., 2015). Middlesworth (2015) has estimated that MSDs are the single largest category of workplace injuries and are responsible for almost 30% of all worker's compensation costs in the US. At the same time, the work intensity and the information amount is increasing and it is followed by psychological stress of workers. The project's 'Fit for Work Europe' Estonian part was completed in 2011. The results showed that the health and ability to work of 50% of the Estonian workers are affected by MSDs. In 2009 the ability to work was limited due to long-lasting hand, leg, back or neck troubles in 59% of Estonian workers aged between 15 and 64 (Zheltoukhova et al., 2011).

Research conducted in different parts of the world has reported the problem of upper limb disorders among various occupations (Yassi, 1997; Bernaards et al., 2008; Borle et al., 2012). There are numerous names for the term work related upper limb disorders such as work-related musculoskeletal disorders, repetitive strain injuries, cumulative trauma disorders and occupational overuse syndrome (Yassi, 1997).

The factors influencing the development of MSDs

There is a very large number of investigations of MSDs available in scientific literature. One group of the high incidence of WRMSDs are workers in the garment industry (Pun et al., 2004). Many studies indicated that female sewing machine operators as well as several other groups of women who are performing monotonous, highly repetitive tasks have a high occurrence of musculoskeletal complaints (Kaergaard & Anderson, 2000). The epidemiologic study divides the risk factors into two groups: A: socio-demographic factors (used for collection of detailed information on the history of disease), such as age, gender, ethnicity, level of education, type of job, and income; B: information on upper limb disorders, which assessed the musculoskeletal problems in some body regions (neck, shoulders, elbows, hands/wrists). A number of epidemiological studies regarding work-related satisfaction, monotonous work with MSDs, role of job control, low social support, low job satisfaction, as well as monotonous work with MSDs, and the role of psycho-social factors and stress in these disorders have received increased attention (van den Heuvel et al., 2005; Oha et al., 2010; Park & Jang, 2010). The upper limb disorders are a subgroup of MSDs and are ailments, which have an effect on the neck, shoulders, elbows, hands and arms (Leah, 2011).

Workers are exposed to psychosocial, occupational, personal risk factors, which are connected with the developing of MSDs. Bongers et al. (1993) divided the psychosocial factors into two groups: demand and control (monotonous work, time pressure, high concentration, high responsibilities, high work load, few opportunities to take breaks, lack of clarity, low control and little autonomy) and social support (poor social support from colleagues, poor social support from superiors). Skov et al. (1996) classified the psycho-social factors into four categories: demand (job demands, especially items like high demands for concentration and speed in the work; perception of competition), control (control over the content of the job, control over time aspects of the work, items like deciding working hours, holidays), support (social contact and support from colleagues, support from superiors, psychosocial work environment, (uncertainty of employment prospects (being concerned that one may become unemployed, transferred to another job, etc.), conflicts with colleagues, work role ambiguity, unclearly defined demands in the work, work role conflict, conflicting demands in the work, variation in the work).

At the present time 2–D and 3–D biomechanical models for controlling the MSDs have been worked out (Garg & Kapellusch, 2009). The application of the strain index, and threshold limit value have been first presented. The future developments of improved biomechanical applications are presented: improved estimates of tissue tolerance, estimating stress: complex jobs estimating stresses: job rotation, estimating stresses: use of multiple criteria to analyse jobs, improved instrumentation for data collection. Better instrumentation is needed for collecting and analysing data in industry, as well as better understanding of tissue tolerance under different loading conditions.

In today's economic context the input via productivity of highly skilled employees is a crucial asset in manufacturing. Employee performance and productivity are influenced by a number of factors including satisfaction, health, safety comfort and welfare (Kaare Kõrbe & Otto, 2014).

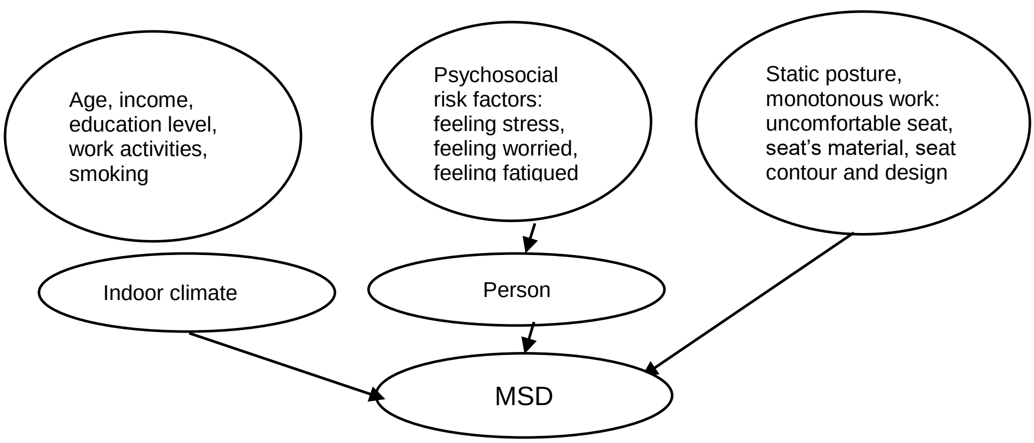


Figure 1. Development of musculoskeletal disorders.

The aim of the study was to investigate the risk factors contained in the work environment (the indoor air temperature) and how the workers complain about their health disorders resulting from continuous work in a forced position or in static posture (office and garment workers).

The novelty of the study lies in the complexity of the investigated risk factors in the workplace and the clarification of the strength of the same workers' health disorders.

MATERIAL AND METHODS

The prevention of MSDs begins with the assessment of risks in the work environment as the basic data.

1. The microclimate measurements in office-rooms and in the garment industry are based on ISO, EN and EVS standards: ISO 7726 'Thermal environments – Instruments and methods for measuring physical quantities'; EN 15251 'Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics'. The measuring equipment used for microclimate was TESTO 435.

The standard EVS-EN 15251:2007 gives the room temperature in three categories of the buildings: in office rooms the 1st category from 21–25.5 degrees; the 2nd category from 20 to 26.0 degrees and the third category from 18 to 27.0 degrees, in department scores 1st category from 17.5 to 24.0 degrees, the 2nd category from 16.0 to 25.0 degrees, and the third category from 15.0 to25.0 categories. The manufacturing space (e.g. garment industry) is not regulated with EVs-EN 15251.

2. The development of MSDs in both investigated activities is very much dependent of the ergonomics of the workplaces. In the current study, the risk level of office-workers and sewers was assessed using the ART tool (HSE, 2007). In 2007, the Health and Safety Executive (HSE) presented the prototype of a tool for risk assessment of repetitive tasks of the upper limbs. The technical content of the ART tool draws upon earlier work to develop the occupational repetitive actions methods (Colombini et al., 2002) and Quick Exposure Check (David et al., 2008). As a result, the ART tool examines twelve risk factors that have been grouped into four stages: (1) frequency and repetition of movements; (2) force; (3) awkward postures (of the neck, back, shoulder/arm, wrist and hand); (4) additional factors (which include the aspect of task duration, recovery, perceived work pace and other object and work environment factors). The result is the sum of the four stages: stages *A*, *B*, *C* and *D* (Eq. 1). These stages are divided into sub-stages: *A*1, *A*2, *B*, C1, *C*2, *C*3, *C*4, *C*5, *D*1, *D*2, *D*3. The body postures (in graphical mode) and conditions (by time) are given.

$$Task\ score = A1 + A2 + B + C1 + C2 + C3 + C4 + C5 + D1 + D2 + D3, \quad (1)$$

where: $A1$ – arm movements; $A2$ – repetition; B – force; $C1$ – head/neck posture; $C2$ – back posture; $C3$ – arm posture; $C4$ – wrist posture; $C5$ – hand/finger grip; $D1$ – breaks; $D2$ – work pace; $D3$ − other factors.

If you assess both arms, the scores for the left arm and right arm should be kept separate and not combined.

The calculation of the exposure score (risk level) is achieved when the task score is multiplied by the duration multiplier.

$$Exposure\ score\ (Risk\ level) = Task\ score\ x\ D4, \qquad (2)$$

where: $Task\ score -$ calculated by the formula 1; $D4 -$ Duration multiplier depends on the duration of the activity.

Task scores and exposure help prioritise tasks that need most urgent attention and help check the effectiveness of any improvements.

The system for interpreting the exposure score is proposed in Table 1.

Table 1. Risk levels depending from the scores

Exposure score	Proposed risk level	Action needed
0–11	low	Consider individual circumstances
12–21	medium	Further investigation required
22 or more	high	Further investigation required urgently

3. The assessment of musculoskeletal pain.

The workers' musculoskeletal complaints were assessed based on the Nordic Questionnaire (Kuorinka et al., 1987). The intensity of pain was assessed using the Visual Analogue Scale (VAS, a scale from one to ten). The workers filled the questionnaire forms.

4. The statistical analysis

The mean and standard deviation (SD) were calculated in the course of the measurements. The student t test was used. The statistical significance of the t test was p = 0.05.

103 workers were investigated (office-workers: 54; garment industry workers: 49). The industrial workers were from one enterprise; investigated office workers were from three different workplaces (Table 2). The study groups were chosen basing on the previous studies (Pille et al., 2014) which have concluded that the MSDs development in office workers have different character than in garment industry workers.

Table 2. The characterization of workers groups investigated

	Office workers group	Garment workers group
Subjects	54	49
Age (years)	40.6 (SD 12,14)	44.8 (SD 9,9)
BMI (kg m^{-2})	23.4 (SD 2.51)	24.7 (SD 2.75)
Working time (hours)	7.1 (SD 1.7)	8.0 (SD 1.3)
Seniority (years)	8.8 (SD 8.4)	13.2 (SD 9.0)

Fig. 2 depicts an office workplace where there is no direct contact with natural light or outdoor air. These conditions are not allowed by the standard EVS-EN 15251. Fig. 3 depicts a workplace in an atrium-type building, where natural lighting is not the best. The windows can be opened, the room is opposite the atrium, so in very hot summer days, and the conditions are good. In winter, it is not possible to use natural light as the opposite workrooms inside the atrium are very close and this disturbs the scientific work in the room shown in Fig. 3.

Figure 2. Office room without natural lighting.

Figure 3. Office room in atrium-type building.

The workplaces depicted in Fig. 4 (gore machine) and Fig. 5 (universal sewing machine) are from the garment industry. Working with the core machine, the right hand of the worker is moving up and down hundreds of times during the workday. The right hand is under big stress. The factory has been looking for better work solutions for a long time, but there is no other machine available. Working by the universal sewing machine, the worker is working in the forced position for 8 hours a day (excluding the rest periods, 10 minutes per hour, and the lunch break). The static posture over a long period of time is a clear risk factor for developing MSDs in the neck, upper or lower back.

Figure 4. Workstation (gore machine) with sewing continuous one-sided dynamic movement.

Figure 5. Workstation (universal machine) with continuous static spine curve.

RESULTS

The characterization of the study groups

Two study groups were selected: office workers and garment workers. Employees in both groups worked in seating position. Garment workers are more influenced by static hand postures and repetitive movements. People who had chronic inflammatory disease of the joints, used nonsteroid anti-inflammatory drugs or BMI >30 kg m^{-2} were excluded from the study. The patients with occupational disease, the chronic arthritis's patients etc. were excluded.

Assessment of the work conditions in the workplace

The air temperature, velocity and humidity in the investigated offices and garment industry rooms are given in Table 3.

Table 3. The assessment of indoor climate at workplaces

Company	Risk level	Air temperature, °C, U* = 0.6 °C	Air velocity M s^{-1} U* = 0.01m s^{-1}	Air humidity, % U* = 2.0%
The limit	< 4	20–26 °C	< 0.3 m s^{-1}	30–60%
Office-room (Fig. 2)	1–2	22–22.4	0.1	34–42
Atrium-type office-room (Fig. 3)	2–3	22.0–22.8	0	22–26
Gore machine (Fig. 4)	2	19–22	0.03	40–50
Universal sewing machine (Fig. 5)	2	18–22	0.1–0.3	36–48

(Abbreviation: *U – uncertainty of measurements, k = 2).

The seasons studied, were summer and winter. The conditions are different. The only justified risk in summer is usually the air humidity. If the air temperature is > 30 °C (which happens very seldom, for one to two weeks), then the effective ventilation has to be switched on. Connected with the very strong ventilation, the problem is that airflow may blow upon people and cause colds. If the windows are opened during very hot days and drafts are formed, then the same result is possible. The bad ergonomics is the same risk factor both in summer and in winter.

In winter in office rooms, the risk factor is low humidity of the air (< 20%), that may cause dryness of mucous membranes. Other risk factors are badly organized lighting and office workers' insufficient knowledge of the lighting requirements during computer work. Not only the monitor has to be lighted, but also the backlighting has to be used. This demand is not always fulfilled in the rooms where IT specialists are working. They like to work in the dark (without general lighting). The air temperature in the investigated office rooms was good (22–23 °C).

The office workers were not aware of the scientific design principles of workplace ergonomics, but they were interested in having a good chair or an adjustable table if the person was short or tall.

In the garment industry, the air temperature is good both in winter and in summer (18–22 °C). The indoor climate conditions in winter change regarding humidity, seeing that during the heating period, humidity is usually below the norm (< 40%).

Assessment of the ergonomic situation in workplaces

The assessment of the workplaces in offices and in the garment industry was carried out on site in co-operation with the workers working in these workplaces (Figs 2–5). The assessment was carried out using the ART tool (Table 4). It is expected that the workers doing general office work and in the garment industry are engaged for 8 hours per day, while computer workers at high schools (Fig. 3) work for 10 hours per day (they work on at home).

Table 4. Assessment of monotonous work and/or in static posture by means of the ART tool (presented in Table 1) in offices and garment industry

Work-place	Lef/right (L/R)	*A*1/*A*2	*B*	*C*1/*C*2	*C*3/ *C*4	*C*5/*D*1	*D*2/*D*3	*D*4	Risk** level
Fig. 2	L	1/2	4	1/1	0/1	0/1	1/2	1	14–medium
	R	3/3	4	1/1	0/1	0/1	1/2	1	18–medium
Fig. 3	L	1/2	4	1/1	0/1	0/0	1/2	1.2	15.6*–medium
	R	3/3	4	1/1	0/1	0/0	1/2	1.2	19.2*–medium
Fig. 4	L	6/3	6	1/1	1/1	4/4	2/2	1	24**–high
	R	6/6	12	2/2	2/2	4/4	2/2	1	41**–high
Fig. 5	L	3/3	6	1/1	2/2	2/6	2/2	1	30 –high
	R	3/3	6	1/1	2/2	2/6	2/2	1	30 –high

Risk level: 0–11= low risk; 12–21: medium risk; 22 or more: high risk level;
*Right hand: RL= (3+3+4+1+1+0+1+0+0+1+2) x 1.2=19.2; risk level: medium;
*Left hand: RL= (1+2+4+1+1+0+1+0+0+1+2) x 1.2=15.6; risk level: medium;
**Right hand: RL= (6+6+12+2+2+1+2+2+4+2+2) x 1=41; risk level: high;
**Left hand: RL= (3+3+6+1+1+1+1+2+4+2+2) x 1=24; risk level: medium.

The results of the assessment (Table 4) show that office workers' risk level is medium (14–19.2); while garment workers' ergonomic risk is on a high level (24–41). There is a difference in the risk level of the left and right hand for the office-workers. There is no difference in the risk level of a garment worker, who works with two hands at the same physical level (universal sewing machine). The highest risk for developing the MSDs was stated for the worker's (gore machine) right hand, i.e. 41 points (Table 4).

The health complaints of office and garment workers

The data characterizing the age, working hours and seniority, is presented in Table 2. The health complaints of office workers (OW) and garment workers (GW) are presented in Table 5, and the pain duration in Table 6.

The workers, who declared the presence of pain, assessed the following durations of pain: 1–7 days, 8–30 days, more than 30 days, every day. The results show that the pain in the muscles of office workers (OW) is less frequent and the duration of pain is shorter. Garment industry (GR) workers have more frequently pain in their muscles and it lasts longer.

We can see from Table 5, that the right hand muscles are more painful in office workers (OW). Only two of the office workers (OW = 54) had pain in the left wrist (VAS scale = 3–4 (10 max)). The other 11 office workers had pain in the right wrist (VAS scale, mean = 3.9). The pain occurrence in the garment workers (GW)' both hands was similar and the pain intensity was 5.7 in 10-point scale.

The difference between the office and garment workers' painful regions also lies in the neck area. The neck is more damaged in garment industry workers (71.3%) and less in computer workers (55.6%). The low back pain data have the same numbers.

Pain duration is the longest in the neck region (Table 6), both in the office and the garment industry workers. Office workers have less long-term pains that last over 30 days and they do not have daily pains. Remarkable group of workers are people who have severe pain, which means 5 points in VAS scale and pains duration is over 30 days over or continuous. Workers with this kind of complaints should have been treated actively, because chronic myalgia syndrome may lead to chronic musculoskeletal disease, occupation disease and cause permanent incapacity. It is necessary to check the job management.

Table 5. Health complaints according to the Nordic Questionnaire and VAS: pain strength

Anatomical region		Office workers' Group, OW	Garment workers' Group, GW	p-value
Pain occurrence during the past 12 months				
Neck N (%)		30 (55.6%) SD 0.5	35 (71.4%) SD 0.4	0.06
Shoulder N (%)		23 (42.6%)	33 (67.3%)	
	Right	20 (37%) SD 0.5	30 (61.2%) SD 0.5	0.00*
	Left	16 (29.6%) SD 0.5	24 (48.9%) SD 0.5	0.03*
Elbow N (%)		5 (9.26%)	19 (38.8%)	
	Right	4 (7.41%) SD 0.3	11 (22.4%) SD 0.4	0.03*
	Left	2 (3.7%) SD 0.2	14 (28.6%) SD 0.5	0.00*
Wrist/hand N (%)		12 (22.2%)	26 (53.1%)	
	Right	11 (20.4%) SD 0.4	25 (51.0%) SD 0.5	0.00*
	Left	2 (3.70%) SD 0.2	24 (48.9%) SD 0.5	0.00*
Back N (%)		21 (38.9%) SD 0.5	29 (59.1%) SD 0.5	0.01*
Pain intensity (VAS)				
Neck		4.1 (SD 1.8)	5.0 (SD 2.0)	0.03*
Shoulders		3.3 (SD 1.4)	6.0 (SD 1.7)	0.00*
Elbows		3.8 (SD 1.6)	5.3 (SD 2.0)	0.13
Wrist/hand		3.9 (SD 1.8)	5.7 (SD 2.0)	0.01*
Back		4.4 (SD 2.1)	6.1 (SD 1.8)	0.00*

*p <0.05 = significant difference between workers' groups.

Table 6. Pain duration

Worker group/ pain region	Pain duration				Total
	1–7 days	8–30 days	More than 30 days, but not every day	Every day	
W* neck	21	8	2	0	31
OW shoulder	13	2	5	0	23
OW elbow	2	2	0	0	4
OW wrist/hand	7	4	0	0	11
OW low back	12	2	4	0	18
Total	55	18	11	0	87
GR neck	10	4	13	7	34
GR shoulder	7	6	8	7	28
GR elbow	2	4	9	2	17
GR wrist/hand	7	7	9	5	28
GR low back	4	8	8	9	29
Total	30	29	47	30	136

*OW –office workers group, GR –garment workers group.

Different hazardous factors (indoor climate, psychosocial factors, static posture etc.) are influencing the workers (Figs 1, 2). If improvement methods in the working environment are implemented, the level of stress of workers could be decreased.

Workers feeling pain in several regions of the body were directed to therapy. The medical surveillance in the investigated firms was very good. In both investigated groups (office and garment workers), the therapy helped workers and most of the workers were rehabilitated in a week time.

In the schematic drawing (Fig. 6), the development of MSDs is presented. The presented factors could be taken as a basis for elaborating a prevention and rehabilitations model and for performance of work ability and quality of life of people. At the first stage of health disorders (1st stage of MSDs), the subjective data on fatigue and pain in overloaded muscles was noticed by the workers; at the 2nd stage of MSDs, the pain was over 5 points by the VAS scale and muscle fatigue was more intense. The objective symptoms are more pronounced and can be diagnosed for clinical syndromes. The ability to work has decreased. At the last stage, if the rehabilitation has not begun in time, the illness might continue developing until the patient is disabled.

The model for the prevention and rehabilitation of MSDs has to include:

1) Risk analysis data (the level and effectiveness of lighting, indoor climate, ergonomics etc.) in a workplace;

2) Health status data of workers using the questionnaires (work ability index –WAI; the Nordic questionnaire for MSD s, psychological tests).

3) The results of measurements of muscle strain (myotonometry).

There is a good correlation between the ergonomic risk level (determined by ART-tool) and the pain regions (R = 0.9), but the correlation between the temperature in the workroom and the pain groups of workers was not high (R = 0.4). The microclimate conditions in garment industry are usually normal, therefore we cannot consider the room temperature as the risk factor in garment industry, but it good be the risk factor during outdoor activities, like driving an agriculture machine or at construction work etc.

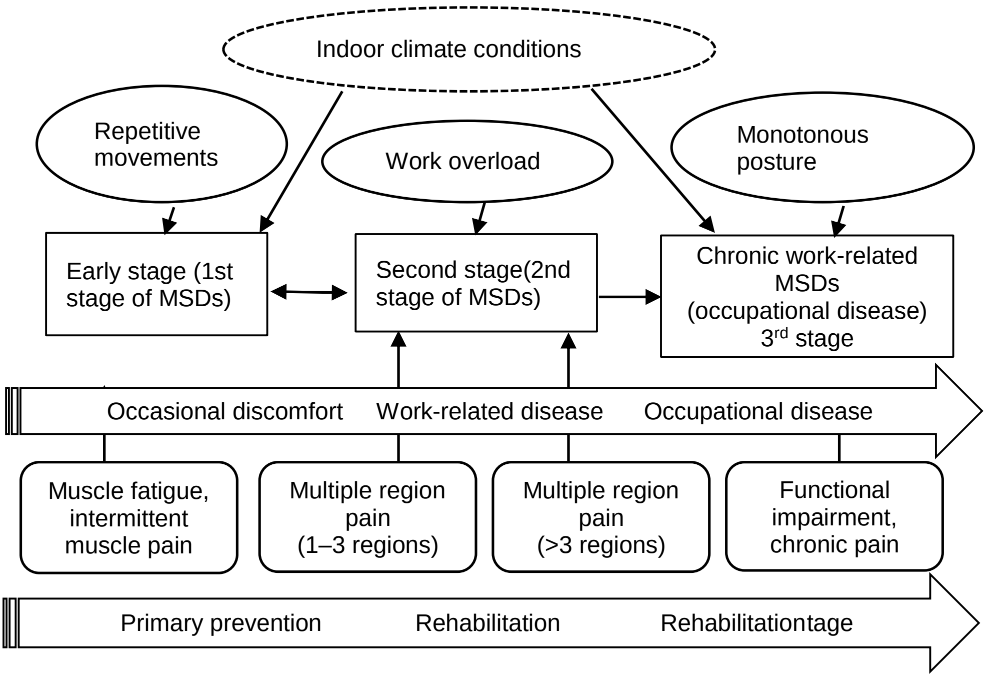


Figure 6. The factors influencing the development of MSDs as an occupational disease.

These data are the basis for the developing of the model and a subsequent IT program for designing computer-equipped and industrial workplaces for different age groups in order to prevent decreased work ability and development of an occupational disease. These recommendations could be followed by the occupational health and family doctors in their treatment work.

DISCUSSION

The novelty of the present study lies in the statement that the right hand of office workers is more painful than the left one (as proved by the questionnaires) due to a greater load affecting the right hand. Garment workers' both hands are painful to the same extent. The other authors' papers dedicated to garment workers' MSDs show the same tendency.

Although neck pain is mentioned as the most prevalent musculoskeletal complaint of office workers (Blagsted et al., 2008), pain symptoms in other body regions are reported as well (Juul-Kristensen et al., 2008). The number of workers studied by Andersen et al. (2010) was 544. The areas of pain were as follows: neck 53% of the people studied, lower back 43%, R shoulder 36%, upper back 33%, knees 20 %, R hand 22%, L shoulder 24%, feet 18%, R elbow 16%, hips 15%, L hand 10% and L elbow 10%. Pain intensity was rather unvaried: 4.18…4.93 on the scale of 0 to 9.

Neck pain is very common among office workers (Sihawong, et al., 2010). Approximately 43% to 69% of the office workers experienced neck pain in the preceding 12 months. A survey of MSDs among visual display unit (VDU) users in a bank showed the prevalence of complaints in various body parts as follows: neck 31.4%, shoulder 16.5%, hand and wrist 14.9% and arm 6.6%. Frequent users of VDU had significantly more musculoskeletal problems in the neck and shoulder regions than infrequent users (Yu & Wong, 1996). Modification of the workstation design and improvement of work organization should be able to reduce the prevalence of these disorders.

The corresponding results (OW) obtained by the authors of this paper were 55.6% in the neck, 42.6% in the shoulders, 38.9% in the back, 5.96% in the elbows and 22.2% in the wrist (the percentage of people suffering from pain of all the people studied). Pain intensity was from 3.3 to 4.4 in the present study (Table 5).

The results of the assessment (Table 3) show that office workers' risk level is medium (14–19.2); while garment workers' ergonomic risk is on a high level (24–41).

We have to conclude that the results derived from this study are similar to or higher when compared to the other authors. New data are derived from a comprehensive study of wrist pains.

In the garment workers' group (230 people, Reinhold et al., 2008) the incidence of pain in different areas of the body were rather variable: the pain in the shoulders was felt by 27% of the workers studied, lower back pain by 46%, pain in the neck area by 21%, headache and brain fatigue by 15%, carpal channel syndrome –moderate stadium by 18%, back pain in the pectoral region by 8%, fatigue of hands and disturbances in the sensitiveness by 16%, pain in hip by 2%, pain in the leg muscles by 7%, knee pains by 6%, pain in thigh muscles by 2% and back pain by 8% of the workers.

Wang et al., (2009) report about pain in the neck/shoulder region (12.9% of garment workers), in hands/wrists (6.9%) and in arms/forearms (3.7%). The most frequent physical signs observed in the neck/shoulder region were rotator cuff tendonitis (7.3%), somatic pain syndrome (6.9%), radicular pain syndrome (6.0%) and thoracic outlet syndrome (4.6%).

Herbert et al. (2001) observed the areas and frequency of pain among garment workers as follows: neck in 47% of the people studied, R shoulder 66%, L shoulder 36%, L elbow 26%, R elbow 29%, R forearm 29%, L forearm 24%, R wrist 25%, L wrist 19%, R hand 42% and L hand 36%.

Thus the data are variable, but the problem is actual and several researchers are looking for ways of decreasing the risk factors in the garment workers' work environment and also for the best means of rehabilitation.

The results of the present study of garment workers correspond to the previous data regarding back pain (59.1%). The frequency of pain occurrence in the neck area (71.4% of all GW), in the shoulders (67.3% of all GW), wrist/hand region (53.1% of all GW) is higher when compared to the study of Reinhold et al. (2008).

In the study of Friedrich et al. (2000), the proportion of sewing industry workers suffering from neck, upper back and lower back pain was much higher: 52.4%, 54.8% and 72.8% respectively of all the workers studied, which is in better conformity with the results of the present study.

The work is repetitive both for workers (in the garment industry and in offices), but the movements, made by the right hand, are different. The probability of developing the carpal-syndrome disease is higher for office workers who use the mouse. Number of musculoskeletal disorders has risen, caused by the work with computers; therefore, the rehabilitation methods are very important. The authors of the present study suggest the following: the complex treatments of these syndromes include active and passive methods of physiotherapy. The active part is organized by the physiotherapist. Systematic application of physical education, exercise therapy improves the functional capacity of the organism to physical stress. The role of the physical therapist in the occupational health team is to ensure that an optimum work environment exists for the prevention of injury and for the rehabilitation of work-related impairment, activity limitation, and participation restrictions. There are also physical therapies which influence the tissues metabolic activity and have positive influence on the repairing process. These are massage, physical agents' therapies and water immersion therapy. The most important is the workplace ergonomic design (Figs 4–5) to prevent the health damages.

The microclimate measurements are in the accordance with our previous measurements Reinhold et al. (2008) & Tint et al. (2012).

Thus, the intensity of pain and the frequency of its occurrence in certain areas of the body are closely linked to the risk factors in the work environment. They have to be determined on the individual level.

CONCLUSIONS

The studied office and garment workers' groups had a significant difference in the presence of shoulder, elbow and wrist pains. There was no great difference in the incidence of neck pain; back pain was also observed quite often in both groups. The office workers had characteristically short-term muscle pains, usually lasting from one to 7 days. The average duration of pain in the garment workers' group was 8 to 30 days, in fewer cases over 30 days. From the results it can be concluded that the studied industrial workers were not sufficiently protected against physiological risks. Continuing to work in the same working conditions may lead to chronic MSDs, and the development of permanent incapacity might occur. The threat to office workers does not seem to be so high, but considering the high incidence of neck and back pain, it is necessary to monitor workplace ergonomics, the intensity of work and other indicators of working conditions. However, it is certainly important for the workers themselves to ensure adequate physical activity, since both studied groups had a sedentary job, and static muscle strain dominated the muscles throughout the body. It can be pointed out that for the occupational health personnel it is important to collect detailed work anamnesis and complaints, and let the workers themselves to fill out the complaints in the muscle mapping questionnaire. Based on articles listed in the *References* part of the present paper, it is desirable that the employees participate in suitable rehabilitation programs.

The results of the risk assessment of the workplaces in office and garment industry (using ART-tool) are corresponding to the data derived from the questioning of the persons in the current study (VAS-scale and Nordic Questionnaire).

The amount and intensity of the work environment risk factors are in correlation with the development of musculoskeletal complaints. The time during which the workers have been subjected to the non-ergonomic risk factors in the workplace is in correlation with the development of musculoskeletal disorders. There are different stages of the disease which can be clearly detected.

Future research: preventive programs/models will have to be worked out on the basis of the structure of risk factors in the workplace and the complaints of workers, considering the measurement results of musculoskeletal pain and muscle strain. The design of workplaces will have to be based on the individual features of workers. The prevention methods for different age groups for computer and industrial workers will have to be investigated.

REFERENCES

Andersen, L.L., Christensen, K.B., Holtermann, A., Poulsen, O.M., Sjogaard, G., Pedersen, M.T. & Hansen, E.A. 2010. Effect of physical exercise interventions on musculoskeletal pain in all body regions among office workers: a one-year randomized controlled trial. *Manual Therapy*, **15**, 100–104.

Bernaards, C.M., Ariens, G.A., Simons, M., Knol, D.L. & Hildebrandt, V.H. 2008. Improving work style behavior in computer workers with neck and upper limb symptoms. *Journal of Occupational Rehabilitation* **18**(1), 87–101.

Blagsted, A.K., Sogaard, K., Hansen, E.A., Hannerz, H. &. Sjogaard, G. 2008. One–year randomized controlled trial with different physical-activity programs to reduce musculoskeletal symptoms in the neck and shoulders among office workers. *Scandinavian Journal of Work and Environmental Health* **34,** 55–56.

Bongers, P.M., de Winter, C.R., Kompier, M.A. & Hildebrandt, V.H. 1993. Psychological factors at work and musculoskeletal disease. *Scandinavian Journal of Work Environment and Health* **19**, 297–312.

Borle, A., Gunjal, S., Jadhao, A., Ughade, S. & Humne, A. 2012. Musculoskeletal morbidities among bus drivers in city of Central India. *Age (Years)*, **46**(06.69), 28–57.

Colombini, T., Occhipinti, E. & Grieco, A.2002. Risk assessment and management of repetitive movements and exertions of upper limbs: job analysis. In: *OCRA risk indices, prevention strategies and design principles.* Elsevier Science Ltd, London.

David, G., Woods, V., Li, G. & Buckle, P. 2008. The development of the Quick Exposure Check (QEC) for assessing exposure to risk factors for work-related musculoskeletal disorders. *Applied Ergonomics* **39**, 57–69.

Friedrich, M., Cermak, T. & Heller, I. 2000. Spinal troubles in sewage workers: epidemiological data and work disability due to low back pain. *International Archives of Environmental Health* **73**(4), 245–254.

Gawke, J.C., Marjan, J., Gorgievski, M.J. & van der Linder, D. 2012. Office work and complaints of the arms, neck and shoulders: The role of job characteristics, muscular tension and need for recovery. *Journal of Occupational Health* **54**, 323–330.

Garg, A. & Kapellusch, M.2009. Applications of biomechanics for prevention of work–related musculoskeletal disorders. *Ergonomics* **52**(1), 36–59.

Hagberg, M., Violante, F.S., Bonfiglioli, R., Descantha, A., Gold, J., Evanoff, B & Sluiter, J.K. 2012. Prevention of musculoskeletal disorders in workers: classification and health surveillance – statements of the Scientific Committee on Musculoskeletal Disorders of the international Commission on Occupational Health. *BMS Musculoskeletal Disorders* **13**, 109, 6 pp.

Herbert, R., Dropkin, J., Warren, N., Sivin, N., Doucette, J., Kellogg, L., Bardin, J., Kass, D. & Zoloth, S. 2001. Impact of a joint labor-managemnt ergonomics program on upper extremity musculoskeletal symptoms among garment workers. *Applied Ergonomics* **32**, 453–460.

HSE (Health and Safety Executive). 2007. Assessment of Repetitive Tasks (ART) tool http://www.hse.gov.uk/msd/uld/art/

Juul-Kristensen, B., Kadefors, R., Hansen, K., Bystrom, P., Sandsjo, L. & Sjogaard, C. 2006. Clinical signs and physical function in neck and upper extremities among elderly female computer users: the NEW study. *European .Journal of Applied Physiology* **96**, 136–145.

Kaare Kõrbe, K. & Otto, T. 2014. Smart health care monitoring technologies to improve employee performance in manufacturing. *Procedia Engineering* **100**, 826–833.

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

Kuorinka, I., Jonsson, B., Kilbom, A., Vinterberg, H., Biering-Sorensen, F., Andersson, G. & Jorgensen, K. 1987. Standardised Nordic questionnaires for the analysis of musculoskeletal symptoms. *Applied Ergonomics* **18**(3), 233–237.

Leah, C. 2011. *Exercises to reduce musculoskeletal discomfort for people doing a range of static and repetitive work*. Norwich, England: HSE Books.

Mattoli, S, Violante, F.S. & Bonfiglioli, R. 2015. Upper-extremity and neck disorders associated with keyboard and mouse use. *Handbook of Clinical Neurology* **131**, 427–33.

Middlesworth, M. 2015. *The definition and causes of musculoskeletal disorders (MSDs).* http://ergo-plus.com/musculoskeletal-disorders-msd/

National Labour Inspectorate. 2015. *Annual Report 2014*. www.ti.ee

Oha, K., Viljasoo, V. & Merisalu, E. 2010. Prevalence of musculoskeletal disorders, assessment of parametres of muscle tone and health status among office workers. *Agronomy Research* **8**(Special issue 1), 192–200.

Park, J.K. & Jang, S.H. 2010. Association between upper extremity musculoskeletal disorders and psychosocial factors at work: A review on the Job DCS Model's perspective. *Safety and Health at work* **1**(1), 17–42.

Pille, V., Tuulik, V.-R., Saarik, S., Tint, P., Vare, T. & Sepper, R. 2015. Work-related musculoskeletal symptoms in industrial workers and the effect of balneotherapy. *Agronomy Research* **13**(3), 820–828.

Pille, V., Tuulik, V.-R., Tint, P., Tuulik, V. & Hazak, A. 2014. Office and industrial workers complaints detection and prevention of professional upper limb overuse. *Riga Technical University Scientific Papers. Safety and Technogenic Management*, **6**, 23–27.
Pun, J.C., Burgel, B.L., Chan, J. & Lashuay, N. 2004. Education of garment workers. Prevention of work related musculoskeletal disorders. *AAOHN Journal* **52**, 338–343.
Reinhold K., Tint, P., Tuulik, V. & Saarik, S. 2008. Innovations at workplace: improvement of ergonomics. Engineering Economics **60**(5), 85–94.
Skov, T., Bong, V. & Orhede, E. 1996. Psychosocial and physical risk factors for musculoskeletal disorders of the neck, shoulders, and lower back in salespeople. *Occupational and Environmental Medicine* **53**, 351–356.
Schneider, E., Irastorza, X. & Copsey, S. 2010. *OSH in figures: work-related musculoskeletal disorders in the EU-facts and figures*. European risk observatory report. European Agency for Safety and Health at Work.
Sihawong, R., Janwantanakul, P., Sitthipomvorakul, E. & Pensri, P. 2010. Exercise therapy for office workers with nonspecific neck pain: a systematic review. *Journal of Manipulative and Physiological Therapeutics* **34**(1), 62–71.
Summers, K., Jinnett, K & Bevan, S. 2015. *Musculoskeletal disorders, workforce health and productivity in the United States.* The Work Foundation. Part of Lancaster University. 41 pp.
Tint, P., Traumann, A., Pille, V., Tuulik-Leisi, V.-R. & Tuulik, V. 2012. Computer users‘ health risks caused by the simultaneous influence of inadequate indoor climate. *Agronomy Research, Biosystems Engineering Special Issue* 261–268.
Van den Heuvel, S.G., van der beck, A.J., Blatter, B.M., Hoogendoom, W.E. & Bongers, P.M. 2005. Psychosocial work characteristics in relation to neck and upper limb symptoms. *Pain* **114**(1), 47–53.
Wang, P.-C., Rempel, D.M., Hurwitz, E.L., Harrison, R.J., Janowitz, I. & Ritz, B.R. 2009. Self-reported pain and physical signs for musculoskeletal disorders in the upper body region among Los Angeles garment workers. *Work* **34**, 79–87.
Yassi, A. 1997. Repetitive strain injuries. *The Lancet*, **349**(9056), 943–947.
Yu, I.T.S. & Wong, T.W. 1996. Musculoskeletal problems among VDU workers in a Hong Kong bank. *Occupational Medicine* **46**(4), 275–280.
Zheltoukhova, K. & Bevan, S. 2011. *Töövõimeline Eesti? Luu-ja lihaskonna vaevused ja Eesti tööturg.* Eesti Haigekassa (in Estonian).
Zheltoukhova, K., Bevan, S. & Reich, A. 2012. *Fit for work? Musculoskeletal disorders and the Australian labour market.*

Agronomy Research **14**(4), 1450–1466, 2016

Ground flora in plantations of three years old short rotation willow coppice

I. Pučka[1,3], D. Lazdiņa[2] and I. Bebre[2,3]

[1]Daugavpils University, Parades street 1, LV-5401 Daugavpils, Latvia
[2]Latvian State Forest Research Institute 'Silava', Rigas street 111, LV-2169 Salaspils, Latvia
[3]Latvia University of Agriculture, Liela street 2, LV-3001 Jelgava, Latvia
[*]Correspondence: irena.pucka@du.lv

Abstract. Short rotation willow coppice plantations are widely used for biomass production over the world. However, their effect on local biodiversity has not been fully elucidated. Ground flora cover of willow plantations are functionally diverse and contains high richness of plant species. The vegetation structure depends on soil type, previous land use, management practices (for example herbicide and fertilizer use) and frequency of harvesting. Investigation of ground vegetation and soil analyze were conducted in seven willow SRC plantations in Central Latvia, Skrīveri municipality. The objective of this study was to evaluate the influence of light availability, plantation age, and soil properties on ground vegetation species composition in three years old short rotation willow coppice. Plantations consist of various willow clones, planted in rows. Weed control was carried out during the first year of plantation establishment.
The qualitative and quantitative proportion of species, including species percentage cover and the mean Ellenberg indicator values were calculated. In total, 64 vascular plant species and two tree species were found in the willow coppice ground vegetation layer. Perennial plants dominate in ground vegetation (constitutes 81% of the identified species). For most species, percentage cover was 10–20% within each plot, but percentage cover of *Achillea millefolium* L., *Elytrigia repens* (L.) Nevski and *Agrostis gigantea* Roth was more than 40% in some plots.

Key words: Ellenberg indicator values, ground flora, weed species, willows, plantations.

INTRODUCTION

Short rotation coppice (SRC) plantations on agricultural lands are appropriate for biomass and bioenergy production. However, their effects on local biodiversity have not been fully elucidated (Baum et al., 2012). SRC plantation have been shown to contains high plant species richness and functional diversity (Cunningham et al., 2006; Verheyen et al., 2014), although the plant composition depends largely on the specific growth conditions (Baum et al., 2012), previous land use, management practices and time since establishments (Ledin, 1998; Sage, 1998; Fry & Slater, 2009). The influence of the previous vegetation decreases with plantation age (Stjernquist, 1994; Baum, 2012). In addition to planation age, irradiance and soil nutrient contents influence ground vegetation cover and composition in plantations (Baum et al., 2014). However, some studies indicate that willow biomass can be produced without fertilizer additions during the first rotation (Quaye & Volk, 2013). With increasing age, decrease irradiance reaching through the ground and suppresses growth of the ground vegetation (Wieh, 2009; Baum et al., 2014).

More diverse ground flora and a higher proportion of long-lived perennials characterize plantations established on former grassland instead of former arable land (Cunningham et al., 2006; Baum et al., 2012). Annual plants that germinate from the seed bank dominated immediately after the establishment of plantations, but over the time, there is an increase in the proportion of invasive and long-lived perennials (Fry & Slater, 2009).

Some researchers also argue that the vegetation communities closer to the edge of plantation are strongly influenced by the plant species from the surrounding landscape (Verheyen et al., 2014) accordingly ground vegetation cover and number of species are higher at the edges than in the inside of plantations (Cunningham et al., 2004; Cunningham et al., 2006). However, the edge effect has not been studied during this research.

It also should be mentioned that many perennial species characteristic for SRC plantations are typical for disturbed areas and anthropogenic environments. The vegetation cover consisting of a few species with high share, including predominantly grass species. Most species reported in SRC plantations are common, but rare plant species have be identified in young plantations (Baum, 2012).

There are several environmental factors influencing plant growth and geographic distribution in SRC, for example sunlight – essential for any crop, soil structure, composition, fertility, pH, water content etc. (Caslin et al., 2010). Species composition in plantations depends heavily on light intensity. Light intensity is higher in youngest plantations before full canopy closer (Baum et al., 2009; Baum, 2012) and also depends on the planted tree species. Light demanding species which includes a large proportion of annual species, usually colonize plantations in the early stage, with increasing plantation age there is a replacement with more shade-tolerant, perennial species (Cunningham et al., 2004; Cunningham et al., 2006; Archaux et al., 2010). Investigations of Sage & Tucker (1998) have shown that during the growing season photoactive radiation is reduced by between 98% and 88% within uncut willow plantation, thereby may have an impact on successful growth of the plant species within plantations. As radiation and temperature decrease with increasing canopy coverage, ruderal and pioneer species are replaced with woodland species (Baum et al., 2009) and annual species to perennial species (Cunningham et al., 2004; Cunningham et al., 2006). Usually, short-lived species being replaced by long-lived species in the vegetation succession process (Baum et al., 2009).

Weed species have been found to affect the development of plantation crops by competing for moisture, nutrients and light (Sage, 1998; Aguilar et al., 2003). Therefore perennial weeds, with developed root system have to be removed completely before planting willows (Verwijst et al., 2013). Missed or failed weed control or lack of soil preparation can lead to plantation extintion in the first growing season. However once established willow shoots inhibit the growth of weeds and ground cover consists of shade-tolerant species in spaces between rows (Lazdiņa & Lazdiņš, 2011). For example, *Salix dasyclados* has a dense crown and broad leaves providing shade and reducing ground vegetation (weed) competition (Lazdiņa & Lazdiņš, 2011). Weed management is therefore needed only during the establishment of the plantation (Wieh, 2009).

The changes in ground flora could have impacts on ecosystem processes and services. The increased ground cover may also help to reduce soil erosion and improve water quality (Rowe et al., 2009). Vegetation diversity could be beneficial for soil organism diversity, and may affect decomposition rates (Hattenschwiler et al., 2005) and may positively effects primary production (Hooper et al., 2005; Duffy et al., 2007). Ground vegetation of plantations can improve the soil structure, landscape value and provide a habitat for the natural agents of pest control (Sage, 1995; Cunningham et al., 2006).

As is well known, willow plantations are an important renewable energy resource. Willow growth and development may be affected by various factors, several of which are described above. The aim of this study is to inventory ground flora in willow short rotation coppice. Species of ground vegetation level were determined, species occurrence due to different ecological requirements (Ellenberg values), soil parametres as well as previous land use and of the plantation management activities were assessed during the research.

MATERIALS AND METHODS

Location and brief territory description

Ground vegetation surveys were conducted on four study sites located in central part of Latvia, Skrīveri municipality (56.691438, 25.133457). Short rotation willow coppice plantations were planted in 2012. Flora cover estimated in all plot 20 x 24 m as whole and graded to persents of the coverage.

Plantations were established using mixtures of genus *Salix* clones (Sven, Klara, Inger, Gudrun, Lisa, Tora, Stina, Biminalis, Swerini, Burjatica, Purpurea, Tordis). Cuttings had been planted in double row system 1.5 x 0.75 x 1.5 m (Table 1). Those are comercial and candidate clones for commercial use. They need similar growth conditions. This *Salix* varieties are field-tested and have high disease and insect resistance are suitable for growing in different soils (Lazdiņa et al., 2014; Salix Energy, 2016).

In plantation was carried out weeding and line spacing mowing in the first year and only mowing in the second year. Separate plots of willow plantations were fertilized with ashes and sewage, but flora investigations were carried out in plots without fertilisers. Nearby plots were fertilized in strips (Table 1). Information about fertilizers used and fertilization regimes as well soil analysis results are published by Bārdule et al. (2013). Control plots (control–K and control–D) were selected for ground flora analysis. Names of sample plots formed using field block numbers (1–4). Control D plots – it was planned to use the digestate as fertiliser, but fertilizer was no applicated because of lacking of material) (1K; 1D; 2K, 2D, 3K, 3D, 4D).

Different forecrops were grown in sample plots before willow plantation establishment: rape (*Brassica napus* L. s.l.), timothy (*Phleum pratense* L.), perennial ryegrass (*Lolium perenne* L.), meadow fescue (*Festuca pratensis* Huds.), red clover (*Trifolium pratense* L.), common barley (*Hordeum vulgare* L. s.l.), buckwheat (*Fagopyrum esculentum* Moench) and Italian rye-grass (*Lolium multiflorum* Lam.).

Table 1. Location scheme of *Salix* clones in plantation

	1 – 'block'				2 – 'block'				3 – 'block'				4 – 'block'			
	Control - K	*ash*	*sludge*	*Control - D*	*Control -K*	*sludge*	*Control - D*	*ash*	*Control - K*	*Control - D*	*ash*	*Sludge*	Control - K	Control - D	*sludge*	*ash*
2,20 m between double rows of each clone	Sv	Sv	Sv	Sv	Sv	Sv	Sv	Sv	Sv	Sv	Sv	Sv	Different species and trees from our road sides	Sv	Sv	Sv
	K	K	K	K	K	K	K	K	K	K	K	K		K	K	K
	I	I	I	I	I	I	I	I	I	I	I	I		I	I	I
	G	G	G	G	G	G	G	G	G	G	G	G		G	G	G
	L	L	L	L	L	L	L	L	L	L	L	L		L	L	L
	T	T	T	T	T	T	T	T	T	T	T	T		T	T	T
	St	St	St	St	St	St	St	St	St	St	St	St		St	St	St
	Bi	Bi	Bi	Bi	Bi	Bi	Bi	Bi	Bi	Bi	Bi	Bi		Bi	Bi	Bi
	Sw	Sw	Sw	Sw	Sw	Sw	Sw	Sw	Sw	Sw	Sw	Sw		Sw	Sw	Sw
	B	B	B	B	B	B	B	B	B	B	B	B		B	B	B
	P	P	P	P	P	P	P	P	P	P	P	P		To	To	To
20 m	20 m	20 m	20 m	20 m	20 m	20 m	20 m	20 m	20 m	20 m	20 m	20 m	20 m	20 m	20 m	20 m
Fore-crops	Rape 2007 Timothy 2008–2010 (104 m)				Perennial ryegrass 2007–2010 (56 m)			Meadow fescue 2007–2010 (56 m)			Red clover 2007–2009 Common barley 2010 (48 m)		Red clover 2007–2008 Fallow land 2009. Buckwheat 2010. (42 m)		Timothy 2007–2008 Fallow land 2009 Italian rye-grass 2010 (52 m)	

Abbreviations: Sv – Sven; K – Klara; I – Inger; G – Gudrun; L – Lisa; T – Tora; St – Stina; Bi – Biminalis; Sw – Swerini; B – Burjatica; P – Purpurea; To – Tordis.

.

Ground-vegetation studies

Ground-level vegetation share in each sample plot were visually assessed using values 1, 2, 3 and 4. Braun-Blanquet method where not used, because flora were conted in all the plot not in small sampling places 1x1m. Later for grading are adapted to %, respectively 0–10%, 11–20%, 20–40% and above 60%.

Soil measurements

Soil samples were collected at different depths of 0–20, 20–40, 40–60, 60–80 cm. Soil samples were prepared for analyses according to LVS ISO 11464 Standard (LVS ISO 11464, 2006). Soil pH was measured following LVS ISO 10390 standard (LVS ISO 10390, 2006) using a glass electrode in a 1:5 suspension of soil in water (pH in H_20), in 0.01 mol^{-1} calcium chloride solution (pH in $CaCl_2$), total nitrogen ($N_{tot.}$) according to LVS ISO 11261 – Modified Kjeldahl method – (LVS ISO 11261, 2002).

Statistical Data Processing

The arithmetic mean of of Ellenberg indicator values (Ellenberg et al., 1992) for nitrogen (N), soil reaction (R), moisture (F), light (L), continentality (C) and temperature (T) of all plots were calculated. According to values plants were ordered along a nine point scale: closer value to nine, it is more connected to this indicator.

The qualitative and quantitative proportion of species, including species percentage cover was calculated. The classification of species by life expectancy was done according to Priedītis (2015).

Statistical analysis of obtained data realized using Microsoft Excel 2010, SPSS 22 software tools. Phytosociological descriptions of ground-level vegetation plant communities of seven sampling plots were stored in the TURBOVEG data base (Hennekens, 1995). The further analysis and data grouping was carried out using the Two-way indicator species analysis (TWINSPAN). Ecological analysis of vegetation in each sample plot was done using detrended correspondence analysis (DCA) and program PC ORD 4.0. The numerical significance values of ecological gradients and the relationship between axes were obtained in PC ORD program using tool (Correlations with second matrix –∑2), correlation coefficients obtained (Table 3). Ellenberg indicator values were used as main gradients.

RESULTS AND DISCUSSION

In total, 64 vascular plant species and two tree species (*Betula pendula* Roth and *Populus sp*.) were found during the analysis of vegetation in willow coppice ground vegetation layer

The most frequently identified species were *Agrostis gigantea* Roth (black bent), *Artemisia vulgaris* L. (mugwort), *Cirsium arvense* (L.) Scop. (creeping thistle), *Epilobium montanum* L. (broad-leaved willowherb), *Hypericum perforatum* L. (perforate St John's-wort), *Matricaria perforata* Mérat (scentless mayweed), *Mentha arvensis* L. (corn mint), *Vicia cracca* L. (tufted vetch) and *Betula pendula* Roth (silver birch), found on all seven plots. *Elytrigia repens* (L.) Nevski (common couch), *Hieracium spp*. (hawkweeds), *Myosotis sylvatica* Ehrh. e1 Hoffm. (wood forget-me-not), *Phleum pratense* L. (timothy), *Sonchus arvensis* L. (perennial sow-thistle), *Taraxacum officinale* F.H.Wigg. s.l. (common dandelion), *Trifolium hybridum* L. (alsike clover), *Trifolium pratense* L. (red clover) and *Tussilago farfara* L. (colt's-foot) at six sites. 39% of species found at only one or two sites (26 species) (Table 2).

Table 2. A list of vegetation species observed in the short rotation willow coppice during research. Species division by life span, frequency and cover in sample plots

Species name	Life span	Species cover in sample plots							
		1K	1D	2K	2D	3K	3D	4D	The incidence (number of plots)
Achillea millefolium L.	perennial	2	*	3	4	2	3	*	5
Agrostis gigantea Roth	perennial	1	2	3	3	3	3	2	7
Agrostis stolonifera L.	perennial	*	*	*	3	1	3	1	4
Agrostis tenuis Sibth.	perennial	2	*	1	2	*	*	*	3
Alchemilla vulgaris L. s.l.	perennial	*	1	*	*	*	*	*	1
Anthriscus sylvestris (L.) Hoffm.	perennial	1	*	*	*	*	*	*	1
Artemisia vulgaris L.	perennial	2	1	1	2	2	2	2	7
Betula pendula Roth	tree	1	1	1	1	1	1	2	7
Calamagrostis epigeios (L.) Roth	perennial	1	*	*	*	*	*	*	1
Campanula patula L.	perennial	*	*	1	1	1	1	*	4
Centaurea diffusa Lam.	annual	*	*	*	*	2	*	*	1
Cerastium holosteoides Fr.	perennial	*	*	1	1	3	1	*	4
Cirsium arvense (L.) Scop.	perennial	1	1	1	2	4	2	2	7
Convolvulus arvensis L.	perennial	1	*	*	*	1	*	*	2
Elytrigia repens (L.) Nevski	perennial	4	4	3	*	2	4	1	6
Epilobium montanum L.	perennial	1	1	1	1	2	1	1	7
Equisetum arvense L.	perennial	2	2	4	*	2	2	*	5
Erigeron acris L.	perennial	*	*	*	*	2	*	*	1
Erigeron annuus (L.) Pers.	biennial	*	*	*	2	*	1	*	2
Erigeron canadensis L.	annual	1	*	*	*	*	*	1	2
Festuca arundinacea Schreb.	biennial	*	*	*	*	1	*	*	1
Galeopsis bifida Boenn.	annual	1	1	1	1	1	*	*	5
Gnaphalium sylvaticum L.	perennial	*	*	1	1	*	1	1	4
Hieracium spp.	perennial	1	1	1	*	2	3	1	6
Hypericum perforatum L.	perennial	1	1	1	3	1	1	2	7

Table 2 (continued)

Juncus conglomeratus L.	perennial	*	*	1	*	*	*	*	1
Juncus effusus L.	perennial	*	*	*	2	1	*	2	3
Lapsana communis L.	annual	*	*	*	2	1	1	1	4
Leucanthemum vulgare Lam.	perennial	*	*	1	1	1	1	3	5
Lotus corniculatus L. s.str.	perennial	*	*	*	1	*	*	*	1
Luzula multiflora (Ehrh.) Lej.	perennial	*	1	1	*	*	*	*	2
Matricaria perforata Mérat	annual	1	1	1	1	1	1	1	7
Medicago lupulina L.	perennial	*	*	*	*	*	1	3	2
Melampyrum nemorosum L.	annual	*	*	*	*	*	*	1	1
Melandrium album (Mill.) Garcke	perennial	*	1	*	*	*	1	1	3
Melilotus albus Medik.	biennial	*	*	*	*	*	1	1	2
Mentha arvensis L.	biennial	1	2	2	2	1	1	1	7
Myosotis sylvatica Ehrh. e1 Hoffm.	perennial	1	1	1	*	1	1	1	6
Phleum pratense L.	perennial	4	4	3	*	1	1	4	6
Plantago lanceolata L.	perennial	*	*	*	*	1	1	1	3
Plantago major L.	perennial	1	*	*	1	*	1	*	3
Populus sp.	tree	*	*	*	*	1	*	*	1
Potentilla anserina L.	perennial	*	2	4	2	*	*	*	3
Potentilla erecta (L.) Raeusch.	perennial	*	*	*	*	1	*	*	1
Potentilla reptans L.	perennial	*	*	2	*	2	4	1	4
Prunella vulgaris L.	perennial	1	*	*	*	*	*	*	1
Ranunculus acris L.	perennial	1	*	*	*	1	1	*	3
Raphanus raphanistrum L.	annual	*	1	*	*	*	*	1	2
Rumex acetosa L.	perennial	*	*	2	2	1	1	2	5
Rumex confertus Willd.	perennial	*	*	*	*	*	*	1	1
Rumex thyrsiflorus Fingerh.	perennial	*	*	*	*	1	*	*	1
Senecio jacobaea L.	perennial	*	*	*	*	*	*	1	1
Solidago canadensis L. s.l.	perennial	*	*	*	1	*	1	1	3
Sonchus arvensis L.	perennial	2	3	2	*	3	2	2	6

Table 2 (continued)

Stachys palustris L.	perennial	1	*	*	*	*	*	*	1
Stellaria graminea L.	perennial	*	1	3	2	1	1	*	5
Taraxacum officinale F.H.Wigg. s.l.	perennial	*	2	2	2	2	2	1	6
Trifolium hybridum L.	perennial	*	1	1	1	2	1	2	6
Trifolium medium L.	perennial	*	*	*	*	*	*	1	1
Trifolium pratense L.	perennial	1	1	*	1	2	1	2	6
Trifolium repens L.	perennial	1	2	2	*	2	2	*	5
Tussilago farfara L.	perennial	1	2	1	4	2	*	2	6
Urtica dioica L.	perennial	*	*	*	1	*	*	*	1
Valeriana officinalis L.	perennial	1	*	*	*	1	1	2	4
Vicia cracca L.	perennial	1	1	4	2	1	1	2	7
Viola arvensis Murray	annual	*	*	*	1	*	*	*	1

* species was not established in sample plot.

Data obtained during research show that perennials are particularly dominant in willow plantation ground flora level with 81.3% proportion of the total number of vascular plant species in plantations, annuals – seven species (10.9%), biennials – five species (7.8%) (Fig. 1). Total species number per plot varied from 27 to 41.

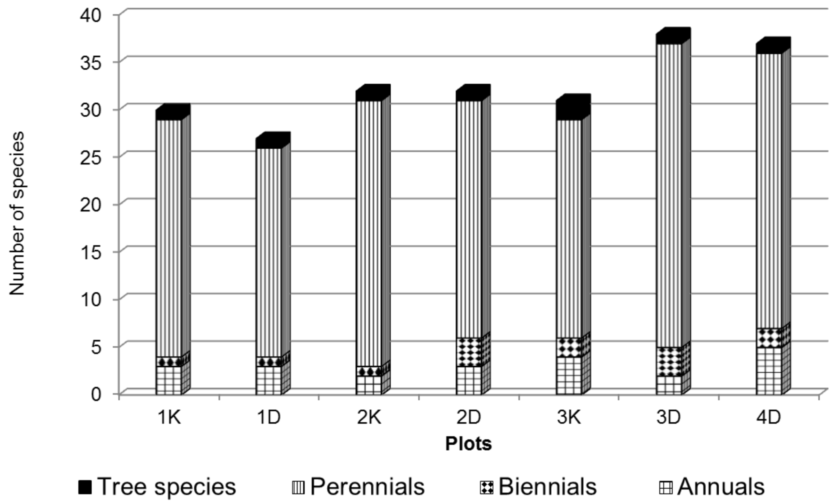


Figure 1. Ground-level vegetation groups by life span.

Similar studies in Sweden show that *Taraxacum officinale, Betula pendula, Dactylis glomerata* (orchard grass) and *Geum urbanum* (wood avens) are very common plants in willow plantations (Baum et al., 2013). However, in plots located in Skrīveri *D. glomerata and G. urbanum* were not detected at all. Ligh and soil nutrients The main factors could be key factors for *G. Urbanum* distribution. Mean Ellenberg indicator value for light in sample plots is 7, but this plant are shade tollerant (Ellenberg indicator value for light = 4), and also associated with nutrient-rich soils (Ellenberg indicator value = 7), but average in plots is 5.4. It were former arable land no abandoned grasland which is ussualy turned to SRC plantations to minimize agricultural activities necesary for some product growing up.

On average, for most species (48.5%), cover takes up to 10% per sample plots. Species average cover within one plot also is similar and takes about 15–20%. Percentage cover of *Achillea millefolium* L. (yarrow), *Elytrigia repens* (L.) Nevski and *Agrostis gigantea* Roth in average takes more than 40% in some plots.

Invasive species

According to list of invasive species in Latvia (Anon, 2014), two potentially invasive (*Erigeron canadensis* L., *Myosotis sylvatica* Ehrh. e1 Hoffm.) and three invasive species (*Populus* species, *Rumex confertus* Willd. and *Solidago canadensis* L. s.l.) were found. However, the total covers of these plants in plots were only about 10% and characterized by a small number of invaded plots (*Populus sp.* and *R.confertus* – one, *E.canadensis* – two, *S.canadensis* – three and *M. sylvatica* – six). It is need to take into account fact that *Populus* species are characterized as fast-growing plants and species coverage may increase in the coming years. Relatively wide range of distribution of *M. sylvatica* could relate with plant ecology – tolerate a variety of soils, full sun to full shade and prefers rich-moist soils. Numbers of plants are limited because during management they are going to cut down before seed production, probably seeds were bringing by animals from abandoned fields.

Occurrence of weed species

Several weed species typical for vegetation of Latvia were also found in plots (weed species evaluation based on State Plant Protection Service database about weed species in Latvia) (State Plant Protection Service, 2016). Weed species, which found in all plots: *Artemisia vulgaris* L., *Cirsium arvense* (L.) Scop., *Matricaria perforata* Mérat, *Mentha arvensis* L. and *Vicia cracca* L.

Urtica dioica L. (common nettle) is relatively widespread weed in Latvia, recorded only in one plot with average cover about 10%, in contrast in Rowe et al., (2011) reported high abundance of *U. dioica* in a study off mature willow SRC in the United Kingdom, but this plant was not most abundant weed in surrounding land-use. The level of plant covers increase with distance into the cultivated area (Rowe et al., 2011). Insufficient soil moisture and nitrogen content probably determine the prevalence of species. According to Taylor (2009) *U.dioica* occurs on almost all soil types, although it prefers moist or damp soils, and also has been described as a nitrophile or nitrophyte found in highly rich fertile conditions (Taylor, 2009).

Occurrence of *Artemisia vulgaris* may indicate about decrease in agricultural activity, but increase in the number of *Mentha arvensis* about changes in the composition of agrobiocenosis and about proliferation of weeds resistant to herbicides, for example *Matricaria perforata* (Priede, 2011; Lapiņš & Oboļeviča, 2014).

Albertsson J. (2014) found in his study that from the establishment until the end of the first harvest, annual weed species gradually replaced with the perennials. Another essential feature: more than 60% of the ground was covered by creeping thistle (*C. arvense*). *C. arvense* can reduced growth of plantation crops at the end of the first year by > 90% (Clay & Dixon, 1997). Weed control is necessary when installing willows from cuttings. Its takes time while willow cuttings becomes competitive against weeds (Verwijst et al., 2013).

Taking into account a fact that some weed species and also invasive species with relatively rapid and sometimes even aggressive distribution were found, they can also create a threat to plantations. For example *S.canadensis*, which has spread widely in recent years in Latvia. Seeds are essential for long-distance dispersal and infestation of large territories. *S. canadensis* also spread quickly and is well adapted to a wide range of habitats (Weber, 2000; Priede, 2008). It can take a lot of money to implement limiting measures.

Weed prevalence may affect the future growth of the willow clones and output of biomass yield. Depending on territory, weeds reduced stem biomass yield by between 68 and 94% after the first harvest cycle and also increased plant mortality (Albertsson, 2014). The low plant density restricts the possibility of willow to oppress weeds during the first season (Labrecque et al., 1994). If weeds are not controlled well, they will exceed and suppress the willow plants more than the willow suppresses the weeds (Albertsson, 2014). In order to facilitate decision making about control measures, weeds can be classified according to their life cycle (Lundkvist & Verwijst, 2011).

Ellenberg indicator values:

Identified plant species demands for environmental parameters are summarized in Fig. 2.

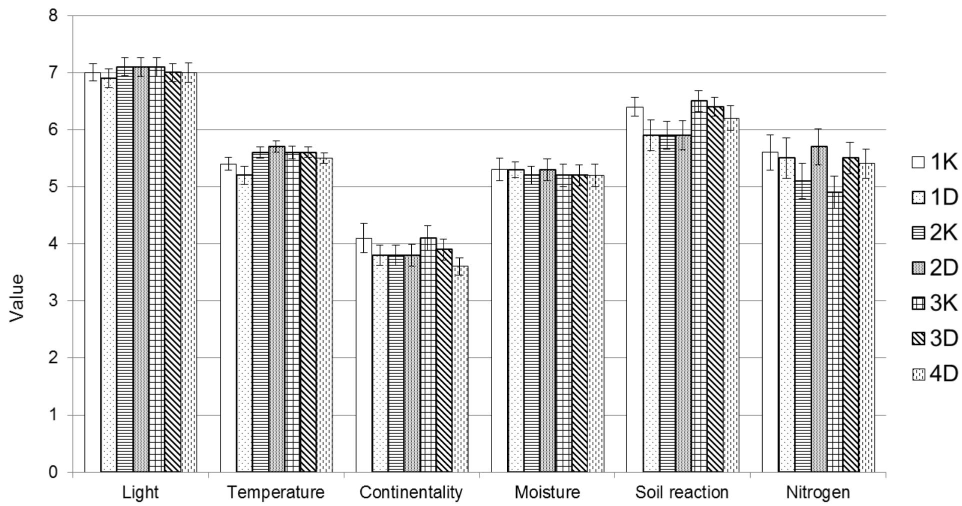


Figure 2. Mean Ellenberg indicator values with standart error bars in sample plots.

Mean Ellenberg indicator values represents that all species found in seven sample plots have high requirements to **light**. Average value of all plots 7.1 – typical for species which are more appropriate to grow in full or half- light conditions. According to Birmele et al. (2015) light-demanding plant species were dominating SRC plantations at all vegetation research time (2010–2013). Nevertheless their proportion showed a steady deterioration, but the proportion of semi-shade species raised and some shade-tolerant species occurred (Birmele et al., 2015).

Three from observed species have maximum requirements for the light - *Centaurea diffusa* Lam. and *Melilotus albus* Medik. (grows in groups on roadsides and along railways; in dry, sandy wastes in Latvia), *Erigeron acris* L. (in Latvia: different dry habitats). *M.albus* also is typical in dry weedy plant communities. Found only one species *Melampyrum nemorosum* L., with optimal growth conditions in middle shade. Analyzing the spread in Latvia, plant mainly found in dry forests and forest edges, shrubs and roadsides (Priedītis, 2015).

The average **temperature** values (5.5) shows that most species are moderately warm climate species. Two species (*Centaurea diffusa* and *Rumex thyrsiflorus* Fingerh) – warm climate species, one (*Alchemilla vulgaris* L. s.l.) – species characterized for cool climate. *C. diffusa and R. thyrsiflorus* typical to Latvia biotopes (dry and sunny meadows, sunny slopes of riverbanks and along railways) shows not only this plant requirements for the light, but also for the high temperature.

Continentality (average value 4) – species typical for suboceanic climate, which conform to the location of the Latvia.

Requirements for moisture – xeromesophytes (average value 5.1). Six species which haracterized as plants growing in moist and wet conditions (values 7–8) – *Agrostis stolonifera* L., *Festuca arundinacea* Schreb., *Juncus conglomeratus* L., *Juncus effusus* L. and *Mentha arvensis* L. *Juncus sp*. occur a wide range of habitats, usually moist, but not wet. Four species – *Achillea millefolium*, *Centaurea diffusa*, *Melilotus albus* and *Rumex thyrsiflorus* **-** drought tolerant plants.

Average soil reaction value (6.2) corresponds to plants growing in neutral soils. Four species – *Centaurea diffusa*, *Erigeron acris*, *Medicago lupulina* L., *Tussilago farfara* L. – prefer alkaline soils and *Juncus effusus* L. – acidic soils.

Ellenberg indicator values for **soil nitrogen** concentration show data distribution. Average value 5.1 – indicator of sites of intermediate fertility. Twelve species are within group - more or less infertile sites and five species – with nitrogen extremely rich soils. *U.dioica* have the maximum value of indicator values (9) and was found only in one site (2D). Perhaps it depends on soil conditions, because plant prefers slightly acidic to alkaline soil, moist and rich in nutrients (Ellenberg et al., 1992).

Vascular plants in sample plots are differentiated by ecological conditions. The distribution within the ordination space is explained by DCA Axis 1 with eigenvalue 0.89, DCA Axis 2 with eigenvalue 0.26 and DCA Axis 3 with eigenvalues 0.19.

Between calculated average Ellenberg indicator values moisture and temperature are the major gradients grouping plots into groups (Table 3).

Table 3. Correlation between DCA axes and Ellenberg values

Parameter	DCA Axis 1	DCA Axis 2	DCA Axis 3
Light (L)	-0.74	-0.41	0.38
Temperature (T)	-0.89	-0.20	0.31
Continentality (C)	0.26	-0.51	-0.21
Moisture (M)	0.74	-0.61	0.59
Soil reaction (R)	-0.11	0.18	-0.59
Nutrients (N)	0.40	0.31	0.46

Most of species also are located in the direction of the temperature gradient (Fig. 3).

Taking into account species composition in sample plots and its location between axes, there are differences between sample plots. For example, plot 1D differ with species lower requirements for light and temperature, plot 1K – species with lower temperature requirements.

Optimal or even increased species demand for light and temperature shown in plots 3D, 2D, 3K. The following results can be explained by the fact that the plantation was created only two vegetation seasons ago. Thus, there is no competition between planting material and ground flora for ecological factors (mainly light and water) yet. This is well illustrated by the location of plots 1K and 1D – species listed in these plots have the lowest temperature requirement (Ellenberg indicator values) (Ellenberg et al., 1992).

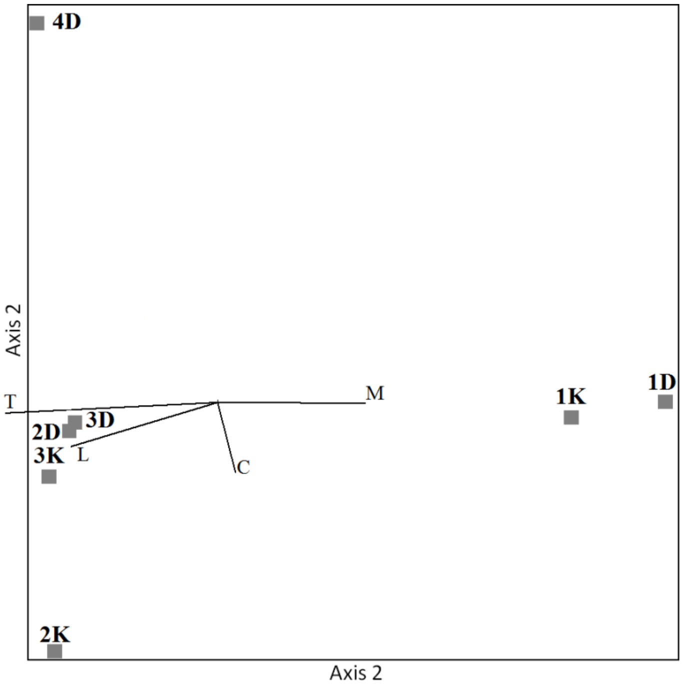


Figure 3. DCA ordination of releves. Sample plots 1K – 4D. T – temperature, L – light, C – continentality, M–moisture.

Soil analyses

In total seven sample plots were investigated and soil parameters were measured (Table 4).

Table 4. The soil parameters of analyzed sample plots of willow short rotation coppice (2011)

	Sample plot						
	1K	1D	2K	2D	3K	3D	4K
pH ($CaCl_2$)	5.9	7.0	6.5	4.5	4.6	5.6	5.1
mg N_{total} * kg	0.8	1.5	3.2	0.6	0.4	0.7	0.3
mg P_{total} *kg	124.6	97.1	88.8	53.8	82.0	59.3	53.1

The pH values ranges from 4.6 to 7.0. The highest pH values were found at 1D and 2K plots, respectively 7.0 and 6.5. The most suitable soils for willows are soils with pH 5.5–7.5 and will provide satisfactory coppice growth. In alkaline soils willows grow more slowly and are more vulnerable to disease (Lazdiņs et al., 2005; Caslin et al., 2015). So it can be concluded, plots 2D and 3K (with acidic soils) not very appropriate for development of willow clones. In addition, the largest number of weed species was counted in these plots, which may further limit the development of willow clones.

Table 4 shows higher concentrations of phosphorus in the plot 1K (124.6 mg kg^{-1}) and also high concentration in plot 1D (97.1 mg kg^{-1}). Phosphorus is an important element in plant growth. The highest concentration of total nitrogen was detected in plot 2K (3.2 mg kg^{-1}). The cultivation of fast-growing trees could reduce nitrate concentrations in the soil solution, because nitrogen is consumed by trees and other ground vegetation. Short rotation plants have ability to use nutrients from deeper soil layers (Līpenīte & Kārkliņš, 2011). Obtained results show that the content of N_{total} decreases towards the deeper soil layers.

Differences in soil conditions on which willow species are being grown for energy purposes, are reflected in weed species diversity (Wrobel et al., 2012).

At the same time the willow clones are expressed response to nutrient supply and the amount of available sunlight (Lazdiņa et al., 2014).

A statistically significant correlation was not found between soil chemical parameters and calculated average Ellenberg indicator values and of soil parameters: reaction and nutrients.

CONCLUSIONS

1. It is difficult to talk about changes in herbaceous species number and proportion in ground-level vegetation in the coming years in this study. Flora assessment should be done for several years (during the first four years since installation) in these plantations. This would allow predicting species, which will spread more intensive and also assess their effects on planted willow clones, as similar studies of other scientists demonstrate.
2. It is considering that plantations of willows on agricultural land can provide higher biodiversity compared with fields of cereals or monoculture plantings, however additional studies of vegetation also should be carried out in cereals other agricultural fields.
3. Perennial plants dominate in plantations, and some species were detected in all plots. This may indicate that, distribution of certain plants develop and stabilize over time and adapt to the specific growing conditions of plantation.
4. On the one hand, presence of invasive and weed species increase the total species diversity in plantation, but on the other hand, may also reflect the negative changes in composition of flora, which may lead to the homogenization of flora.
5. Analysis of Ellenberg values shows, that light and temperature loving plants are dominating in the plantation at the moment of research. However, these parameters likely will change, with increase in plantation age and willow size and may increase the number of shade tolerant plants until current cutting.

REFERENCES

Aguilar, V., Staver, C. & Milberg, P. 2003. Weed vegetation response to chemical and manual selective ground cover management in a shaded coffee plantation. *European Weed Research Society Weed Research* **43**, 68–75.

Albertsson, J. 2014. Impact and Control of Weeds in Biomass Willow Clones. Doctoral thesis. http://pub.epsilon.slu.se/11583/1/albertsson_j_141008.pdf Accessed 12.1.2016

Anon, 2014. A list of alien species in Latvia. http://biodiv.lvgma.gov.lv/cooperation/invaz/i-netam_invazivie.xls Accessed 15.12.2015

Archaux, F., Chevalier, R. & Berthelot, A. 2010. Towards practices favourable to plant diversity in hybrid poplar plantations. *Forest Ecology and Management* **259**, 2410–2417.

Baum, S., 2012. Phytodiversity in short rotation coppice plantations. Dissertation, 99 p.

Baum, S., Bolte, A. & Weih, M. 2012. Short Rotation Coppice (SRC) Plantations Provide Additional Habitats for Vascular Plant Species in Agricultural Mosaic Landscapes. *Bioenergy* research **5**, 573–583.

Baum, S., Bolte, A. & Weih, M. 2014. Short rotation coppice (SRC) plantations can enhance phytodiversity in agricultural landscapes. In: *Book of Abstracts 2nd International Symposium on Energy Challenges and Mechanics*, Aberdeen, Scotland.
Baum, S., Weih, M. & Bolte, A. 2013. Floristic diversity in Short Rotation Coppice (SRC) plantations: Comparison between soil seed bank and recent vegetation. *Applied Agricultural and Forestry Research* **3**(63), 221–228.
Baum, S., Weih, M., Busch, G., Kroiher, F. & Bolte, A. 2009. The impact of Short Rotation Coppice plantations on phytodiversity. *Landbauforschung – vTI Agriculture and Forestry Research* **3**(59), 163–170.
Bārdule, A., Rancane, S., Gutmane, I., Berzins, P., Stesele, V., Lazdiņa, D. & Bārdulis, A. 2013. The effect of fertiliser type on hybrid aspen increment and seed yield of perennial grass cultivated in the agroforestry system. *Agronomy Research* **11**(1), 13 – 24.
Birmele, J., Kopp, G., Brodbeck, F., Konold, W. & Sauter, U.H. 2015. Successional changes of phytodiversity on a short rotation coppice plantation in Oberschwaben, Germany. *Frontiers in plant science* **6**, 124:1–124:8.
Caslin, B., Finnan, J. & McCracken, A. 2010. Short rotation coppice willow best practice guideline, Belfast, 66 pp.
Caslin, B., Finnan, J., Johnston, C., McCracken, A. & Walsh, L. (eds.) 2015. Short rotation. Coppice willow. Best practice guidelines. https://www.agriculture.gov.ie/media/migration/ruralenvironment/environment/bioenergy scheme/TeagascCoppiceWillowGuidelines260315.pdff Accessed 20.11.2015. Accessed 20.11.2015.
Clay, D.V. & Dixon, F.L. 1997. Effect of ground-cover vegetation on the growth of poplar and willow short-rotation coppice. *Aspects of Applied Biology* **49**, 53–60.
Cunningham, M.D., Bishop, J.D. & McKay, H.V. 2004. Arbre monitoring – ecology of short rotation coppice. Four year study involving wildlife monitoring of commercial SRC plantations planted on arable land and arable control plots. URN NUMBER 04/961
Cunningham, M.D., Bishop, J.D., Watola, G., McKay, H.V. & Sage, R.B. 2006. The effects on flora and fauna of converting grassland to Short Rotation Coppice. http://webarchive.nationalarchives.gov.uk/+/http:/www.berr.gov.uk/files/file30621.pdf Accessed 15.11.2015
Duffy, E.J., Cardinale, B.J., France, K.E., McIntyre, P.B., Thebault, E. & Loreau, M. 2007. The functional role of biodiversity in ecosystems: incorporating trophic complexity. *Ecology Letters* **10**, 522–538.
Ellenberg, H., Ruprecht, D., Volkmar, W., Willy, W. & Dirk, P. 1992. Zeigerwerte von Pflanzen in Mitteleuropa. *Scripta Geobotanica* **18**, 258 pp.
Fry, D. & Slater, F. 2009. The biodiversity of short rotation willow coppice in the Welsh landscape, 162 pp.
Hattenschwiler, S., Tiunov, A.V. & Scheu, S. 2005. Biodiversity and litter decomposition in terrestrial ecosystems. *Annual Review of Ecology and Systematics* **36**, 91–218.
Hooper, D.U., Chapin, F.S., Ewel, J.J., Hector, A., Inchausti, P. & Lavorel, S., 2005. Effects of biodiversity on ecosystem functioning: a consensus of current knowlegde. *Ecological Monographs* **75**, 3–35.
Labrecque, M., Teodorescu, T.I., Babeux, P., Cogliastro, A. & Daigle, S. 1994. Impact of herbaceous competition and drainage conditions on the early productivity of willows under short-rotation intensive culture. *Canadian Journal of Forest Research* **24**(3), 493–501.
Lapiņš, D. & Oboļeviča, D. 2014. Research of weed species number and composition in cereals. http://biodiv.lvgma.gov.lv/cooperation/lauksaimn/fol815176 Accessed 7.12.2015. (in Latvian).
Lazdiņa, D. & Lazdiņs, A. 2011. Short rotation willow plantations and its use. 36 pp. (in Latvian)

Lazdiņa, D., Bārdule, A., Rancāne, S., Stesele, V., Dzene, I., Kaļeiņikovs, P. & Sisenis, L. 2014. Comparison of fertilizer impact on commercial willow clones development in the first rotation. *Scientific seminar proceedings*: Harvest Festival 'Vecauce–2014': Agricultural research in the new period. 32–35 (in Latvian)

Lazdiņš, A., Kāposts, V., Kariņš, Z., Lazdiņa, D., Strazdiņš, U. & Larsson, S. 2005. Willow plantations. Installation and management guide. 'Silava' 72 pp. (in Latvian)

Ledin, S. 1998. Environmental consequences when growing short rotation forests in Sweden. *Biomass and Bioenergy* **15**(1), 49–55.

Līpenīte, I. & Kārkliņš, A. 2011. Soil quality within the context of land use changes. II. Soil physical and agrochemical properties. *Proceedings of the Latvia University of Agriculture*. LLU, **26**(321), 18–32. (in Latvian). CABI Abstracts.

Lundkvist, A. & Verwijst, T. 2011. Weed biology and weed management in organic farming. In: Nokkoul, R. (ed.) *Research in Organic Farming*, 157–186.

Priede, A. 2008. Invasive Non-Native Solidago Species in Latvia: Expansion History and Current Distribution. Proceedings of the Latvian Academy of Sciences. Section B. *Natural, Exact, and Applied Sciences* **62**(1–2), 78–83.

Priede, A. 2011. Dynamics of weed flora. http://biodiv.lvgma.gov.lv/cooperation/invaz/sugas_nezales_lv.doc/download/lv/1/SUGAS_Nezales_LV.doc Accessed 7.12.2015.

Priedītis, N. 2015. Encyclopedia 'Latvian Nature' http://www.latvijasdaba.lv/augi/ (in Latvian) Accessed 10.11.2015

Quaye, A.K. & Volk, T.A. 2013. Biomass production and soil nutrients in organic and inorganic fertilized willow biomass production systems. *Biomass and Bioenergy* **57**, 113–125.

Rowe, R.L., Hanley, M.E., Goulson, D., Clarke, D.J., Doncaster, C.P. & Taylor, G. 2011. Potential benefits of commercial willow Short Rotation Coppice (SRC) for farm-scale plant and invertebrate communities in the agri-environment. *Biomass and bioenergy* **35**, 325–336.

Rowe, R.L., Street, N.R. & Taylor, G. 2009. Identifying potential environmental impacts of large-scale deployment of dedicated bioenergy crops in the UK. *Renewable and Sustainable Energy Reviews* **13**(1), 271–290.

Sage, R.B. 1995. Factors affecting wild plant communities occupying short rotation coppice crops on farmland in the UK and Eire. *Brighton Crop Protection Conference*, Weeds 5, 985–990.

Sage, R.B. 1998. Short rotation coppice for energy: towards ecological guidelines. *Biomass and Bioenergy* **15**, 39–47.

Sage, R.B. & Tucker, K. 1998. Integrated crop management of SRC plantation to maximise crop value, wildlife benefits and other added value opportunities. DTI publication.

Salix energy. 2016. SRC willow varieties http://www.salixenergi.se/uploads/Varieties_UK.pdf Accessed 5.4.2016

State Plant Protection Service. 2016. Harmful organisms. http://www.vaad.gov.lv/sakums/registri/augu-aizsardziba/kaitigie-organismi.aspx Accessed 12.1.2016

Stjernquist, I. 1994. An integrated environmental-analysis of short-rotation forests as a biomass resource. *Biomass and Bioenergy* **6**, 3–10.

Taylor, K. 2009. Biological flora of the British Isles: Urtica dioica L. *Journal of Ecology* **97**(6), 1436–1458.

Technical Committee 2002. Soil quality – Determination of total nitrogen – Modified Kjeldahl method, Latvian standard, 8 pp.

Technical Committee 2005. Soil quality – Pretreatment of samples for physico-chemical analysis, Latvian standard, 11pp.

Technical Committee 2006. Soil quality – Determination of pH, Latvian standard, 7 pp.

Verheyen, C., Buggenhout, M., Vangansbeke, P., De Dobbelaere, A.,Verdonckt, P. & Bonte, D. 2014. Potential of Short Rotation Coppice plantations to reinforce functional biodiversity in agricultural landscapes. *Biomass and bioenergy* **67**, 435–442.
Verwijst, T., Lundkvist, A., Edelfeldt, S. & Albertsson, J. 2013. Development of Sustainable Willow Short Rotation Forestry in Northern Europe. http://cdn.intechopen.com/pdfs-wm/44392.pdff Accessed 20.11.2015.
Weber, E. 2000. Biological flora of Central Europe: Solidago altissima L. *Flora* **195**, 123–134.
Weih, M. 2009. Willow short rotation coppice commercially grown on agricultural land in Sweden – possibilities for improvement of biodiversity and landscape design. International Energy Agency (IEA) Bioenergy, task 30, Technical review No.4, Uupsala, pp 40.
Wrobel, M., Gregorczyk, A. & Wróbel, J. 2012. The Effect of Chemical Soil Properties on Weed Infestation Structure in Willow (SalixL.) Short-Rotation Coppice. *Polish Journal of Environmental Studies* **21**(6), 1893–1899.

Agronomy Research **14**(4), 1467–1485, 2016

Canopy traits in rye, triticale and wheat under varying N supply

K. Sieling*, U. Böttcher and H. Kage

Christian-Albrechts-University Kiel, Institute of Crop Science and Plant Breeding, Hermann-Rodewald-Strasse 9, DE-24118 Kiel, Germany
*Correspondence: sieling@pflanzenbau.uni-kiel.de

Abstract. Information on growth of rye (*Secale cereale* L.) and triticale (*X Triticosecale* Wittmark) are scarce. In 2007/08 and 2008/09, winter rye, winter triticale and winter wheat (*Triticum aestivum* L.) were simultaneously grown in combination with 4 nitrogen (N) treatments (0/0, 40/40, 80/80 and 120/120 kg N ha^{-1}) at the Hohenschulen Experimental Farm in northern Germany allowing for a comparison of the resource capture and biomass accumulation during spring growth. Several canopy traits (e.g. green area index (GAI), specific leaf area (SLA), light use efficiency (LUE)) as well as N dilution curves of the whole shoots, leaves and stems were determined.

Triticale achieved highest GAI in throughout both growth periods. An extended growth period of wheat partly compensated for a lower GAI, thus the differences in the amount of intercepted photosynthetically active radiation (Q) between the crops remained small. In general, rye leaves were thinner (higher SLA) compared to wheat and triticale showing similar SLA, except at ear emergence in both years. Total above-ground dry matter accumulation at dough ripening was lowest in wheat mainly due to a lower LUE which in turn may be the result of a lower specific leaf area. The N dilution curves revealed a clear reduction of stem N concentration with increasing dry matter accumulation, whereas leaf N concentration only slightly decreased presumably in order to maintain optimal photosynthesis. The presented results enhance the understanding of the growth of rye and triticale and allow improving crop growth modeling of both crops.

Key words: Specific leaf area; light use efficiency; green area index; N dilution curve.

INTRODUCTION

In the European Union, wheat (*Triticum aestivum* L.) was grown on 26.1 Mio. ha compared to rye (*Secale cereale* L.) with 2.4 Mio. ha and triticale (*X Triticosecale* Wittmark) with 2.7 Mio. ha on average of 2012–2014. With 5.3 t ha^{-1} wheat clearly outyielded rye (3.67 t ha^{-1}) and triticale (4.21 t ha^{-1}) (FAO 2016). However, under less favorable growing conditions e.g. limited water availability in a Mediterranean environment, triticale may achieve higher grain yields than wheat, due to a longer spike formation phase or a greater early vigor leading to more grains per unit area (López-Castañeda & Richards 1994a; 1994b). In the last decade, the use of whole plant silage of winter rye and winter triticale as energy crops for biogas production increased (Amon et al., 2007; Gissén et al., 2014; Mayer et al., 2014).

In general, the key factor for plant growth is the absorption of the incoming radiation being a function of the total leaf area resp. the total green area. The ratio of leaf area to leaf mass i.e. the specific leaf area (SLA) – or its inverse, leaf mass per unit area

(LMA) (g m^{-2}) – thereby is often used in growth analysis because it is positively related to potential relative growth rate across species (Gunn et al., 1999; Poorter et al., 2009; Pérez-Harguindeguy et al., 2013). SLA tends to scale negatively with area-based light-saturated photosynthetic rate, but positively and linearly with mass-based light-saturated photosynthetic rate as well as with leaf nitrogen (N) concentration (Wright et al., 2005; Shipley, 2006; Lemaire et al. 2008; Poorter et al., 2009; Pérez-Harguindeguy et al., 2013).

Shortly after emergence, canopy SLA of winter wheat showed an initial increase, thus young plants producing large, but thin leaves to intercept as much irradiation as possible, followed by a levelling off (Hotsonyame & Hundt, 1998; van Delden et al., 2000). A meta-analysis on the causes and consequences of variation in leaf mass per area (=1/SLA) is presented by Poorter et al. (2009). According to Ratjen & Kage (2013) both drought and N shortage lead to a reduced SLA in wheat mainly due to reduced mutual shading under stress situation.

While for wheat a lot of information on canopy traits is available (e.g. Rawson et al., 1987; Hotsonyame & Hundt, 1998; Poorter et al., 2009; Qin et al, 2013), respective data for rye and triticale are scarce. Comparing spring rye, spring triticale and spring wheat, Sheng & Hunt (1991) found significant differences in total plant dry weight with rye showing consistently the highest total plant dry weight at several sampling dates during the growth period. Giunta et al. (2009) attributed the higher biomass accumulation of spring triticale to the higher amount of intercepted photosynthetically active radiation (PAR) compared to durum wheat under the Mediterranean conditions of Sardinia (Italy), mainly due to earlier build-up of the leaf area (López-Castañeda & Richards, 1994b). However, Estrada-Campuzano et al. (2012) and Motzo et al. (2013) observed a higher radiation use efficiency of triticale. Based on pot experiments Amanullah (2015) and Amanullah & Stewart (2015) reported that rye developed a higher leaf area per plant and a higher SLA than wheat at 30, 60 and 90 days after emergence.

Beside the radiation interception, N content of the plant plays an important role for the carbon assimilation. Justes et al. (1994) published a critical N dilution curve for winter wheat crops relating shoot N concentration to the corresponding above-ground dry matter based on a power function. However, some authors argued that leaf N concentration and also its vertical gradient within the plant have to be taken into account (e.g. Grindley, 1997; Moreau et al., 2012). Unfortunately, to our knowledge, N dilution curves do exist neither for rye nor for triticale.

Limited experimental data compare rye, triticale and wheat simultaneously in the same (field) experiment allowing to investigate their growth under similar conditions. Therefore, based on a 2 year field trial with different N treatments (0–240 kg N ha^{-1}), the objectives of this study were (i) to identify canopy traits (e.g. green area index (GAI), SLA) affecting dry matter (DM) accumulation of rye, triticale and wheat and (ii) to analyze differences in the crop behavior. It is hypothesized that the importance of the canopy traits differs with the crops.

MATERIALS AND METHODS

Site and soils

The field trial was carried out at the Hohenschulen Experimental Farm (northern Germany, 10.0° E, 54.3° N, 30 m a.s.l.) on a pseudogleyic sandy loam (Luvisol: 170 g kg^{-1} clay, pH 6.7, 13 g kg^{-1} Corg, 1.1 g kg^{-1} Norg in 0–30 cm). The climate of northern Germany can be described as humid temperate with a long-term mean annual temperature of about 8.4 °C. Total rainfall averages 800 mm annually, of this ca. 400 mm occur during the main growing season (April–September) (Table 1).

Table 1. Monthly rainfall (mm), mean air temperature (°C), and mean global radiation at Hohenschulen, Germany

	Total rainfall (mm)			Mean air temperature (°C)			Mean global radiation (MJ m^{-2} d^{-1})		
	2007/ 2008	2008/ 2009	long-term average	2007/ 2008	2008/ 2009	long-term average	2007/ 2008	2008/ 2009	long-term average
September	71	64	61	13.1	13.2	14.2	9.79	9.45	10.38
October	25	124	75	8.9	9.5	9.8	5.76	5.17	5.76
November	38	45	58	5.0	6.4	4.9	2.85	1.88	2.34
December	77	20	62	3.3	2.8	1.6	1.00	1.19	1.38
January	64	16	48	4.4	-0.1	1.2	1.37	1.97	1.82
February	40	25	50	4.7	0.5	2.0	3.90	3.52	3.81
March	62	45	44	4.3	4.1	3.4	8.06	6.66	8.54
April	41	7	44	7.6	10.4	8.0	14.11	17.65	14.79
May	19	52	62	13.7	11.7	11.9	23.18	20.36	17.96
June	42	104	69	15.7	13.2	14.8	21.58	19.89	19.72
July	69	101	100	17.6	17.3	16.9	18.70	18.16	18.77
August	131	69	59	16.7	17.8	17.9	12.15	16.04	14.41

Field trials

In 2007/08 and 2008/09, winter rye (cvs. Amato; Balistic in 2007/08 and Palazzo in 2008/09, all hybrids), winter triticale (cvs. Inpetto; Korpus) and winter wheat (cvs. Mulan; Winnetou) were grown in a field trial. Preceding crops were field beans in 2007 and oilseed rape in 2007/08. Each variety was combined with 4 N treatments: N1 – 0/0, N2 – 40/40, N3 – 80/80, N4 – 120/120 kg N ha^{-1}). The experimental design was a completely randomized block design with four replicates. The whole plot size was 12 m x 3 m, using a row width of 0.12 m. Sowing density was 240 and 200 kernels m^{-2} for rye, 270 and 230 kernels m^{-2} for triticale and 300 and 250 kernels m^{-2} for wheat in 2007/08 and 2008/009, respectively. Nitrogen (calcium ammonium nitrate, 27% N) was applied in split-dressings at the beginning of spring growth (growth stage 25 (GS according to Zadoks et al., 1974) and at stem elongation (GS 30/31) (details see Table 2). During the second N application in 2009, the attribution of the N treatments to the respective plots was not correct, resulting in N levels differing from the aimed ones.

The straw of all crops remained on the plots. In general, the trials were ploughed within one day before sowing. Crop management not involving the treatments (e. g. P and K supply, soil tillage, sowing dates, pesticide application) were applied according to local recommendations to achieve optimal yield.

Table 2. Dates of crop management and plant sampling

	2007/08			2008/09		
	Rye	Triticale	Wheat	Rye	Triticale	Wheat
Crop management						
Sowing	08 Oct	08 Oct	08 Oct	18 Sep	18 Sep	18 Sep
1st N application	20 Feb	20 Feb	20 Feb	18 Mar	18 Mar	18 Mar
2nd N application	08 Apr	08 Apr	08 Apr	16 Apr	16 Apr	16 Apr
Harvest	01 Aug	01 Aug	01 Aug	14 Aug	14 Aug	14 Aug
Plant sampling						
End of autumn growth	13 Nov	13 Nov	13 Nov	01 Dec	01 Dec	01 Dec
Start of spring growth	20 Feb	20 Feb	20 Feb	12 Mar	12 Mar	12 Mar
GS 30/31#	14 Apr	14 Apr	14 Apr	14 Apr	16 Apr	16 Apr
GS 55	20 May	28 May	02 Jun	04 May	18 May	25 May
GS 75	23 Jun	23 Jun	30 Jun	22 Jun	24 Jun	30 Jun

GS 30/31 – stem elongation; GS 55 ear emergence; GS 75 milk ripe.

Measurements, calculations, and statistical analysis

Starting in Mid-April, green area index (GAI) and the mean leaf angle (MTA) of all plots was determined non-destructively each week using a LAI 2000 (LiCor Inc., NE, USA). In addition, the extinction coefficient k was derived from the LAI2000 readings GAI and DIFN (diffuse non-interceptance):

$$k = -\ln(\mathrm{DIFN})/\mathrm{GAI} \qquad (1)$$

At the end of autumn growth, beginning of spring growth, stem elongation (GS 30/31), ear emergence (GS 55) and milk ripe (GS 75), plants from 2 x 50 cm drilling row (at GS 75: 5 x 50 cm) per plot were harvested (sampling dates see Table 2). In the N1, N2 and N4 treatment, above-ground dry matter (DM) was determined. Plants of the N3 treatment (80/80) were subdivided into a leaf fraction (leaf blades = leaf DM), a stem fraction (leaf sheaths and stem = stem DM), and an ear fraction (= ear DM; GS 55 and GS 75 only). From a sub-sample of the leaf fraction, leaf area (LAI) was determined using a LiCor 3100 leaf area meter (LiCor Inc., NE, USA). After drying and weighing, the fractions were ground and analyzed separately for the N concentration by using near infrared spectroscopy (NIRS). Total above-ground DM and total nitrogen content were calculated by adding the fractions, and, if appropriate, standardized to m^2. At maturity, to minimize border effects, a core of 6 m x 1.75 m of each plot was combine harvested and seed yield was corrected to t ha^{-1} at 86% DM based on the moisture content of a grain subsample.

The amount of photosynthetically active radiation intercepted by the crops (Q) was calculated on a daily basis from GAI and k which have been linearly interpolated between the dates of GAI measurements:

$$Q = \mathrm{PAR}\,(1-e^{(-k\mathrm{GAI})}) \qquad (2)$$

where PAR denotes the amount of incoming photosynthetically active radiation (measured by a weather station nearby), GAI the green area index and k the extinction coefficient derived from Eq. 1.

The light use efficiency (LUE) was estimated for each plot separately by relating the DM accumulation between the GS 30/31 and GS 75 to the corresponding cumulated radiation intercepted by the canopy (Q).

The fractionation of the plants from the N3 treatment allowed for deriving additional parameters. However, the last sampling date (GS 75) was excluded due to progressive leaf senescence. Separately for each plot, specific leaf area (SLA), leaf area ratio (LAR) and leaf mass ratio (LMR) were calculated as following

$$SLA = LAI/DM_{leaf} \tag{3}$$

$$LAR = LAI/DM_{shoot} \tag{4}$$

$$LMR = DM_{leaf}/DM_{shoot} \tag{5}$$

Please note that the destructively measured leaf area (LAI) was used.

This paper mainly focusses on the crop effects; therefore, the effects of the varieties are not presented and were considered as replications. All statistics were done for each year separately using the SAS procedures PROC MIXED with the block effect as random factor. Due to the inaccurate N fertilization in 2009, N fertilization has to be characterized as quantitative factor (as total fertilizer N amount) requiring a covariance analysis (parameters see Table 3). N dilution curves were fitted by PROC NLIN separately for each crop. Function parameters were compared by a modified *t*-test based on Zar (2009) (parameters see Table 5).

RESULTS

Dry matter at GS 75 and grain yield at maturity

In both years (2008, 2009 and all crops, N supply significantly ($P < 0.001$) increased above-ground dry matter (DM) at the milk ripe stage (growth stage (GS) 75) (Fig. 1); however, no effects occurred if N fertilization equaled or exceeded 160 kg N ha^{-1}. In 2008, winter rye outyielded winter triticale and winter wheat, but the differences were not significant ($P > 0.20$), whereas in 2009, rye and triticale DM were significantly higher than that of wheat, especially at lower N supply, but similar for all crops in the 240 kg N ha^{-1} treatment.

Grain yield at maturity ranged in the order rye > triticale > wheat at low N fertilization, while at N amounts higher than 200 kg N ha^{-1} triticale outyielded rye and wheat (Fig. 2). Wheat achieved in both years the lowest grain yields.

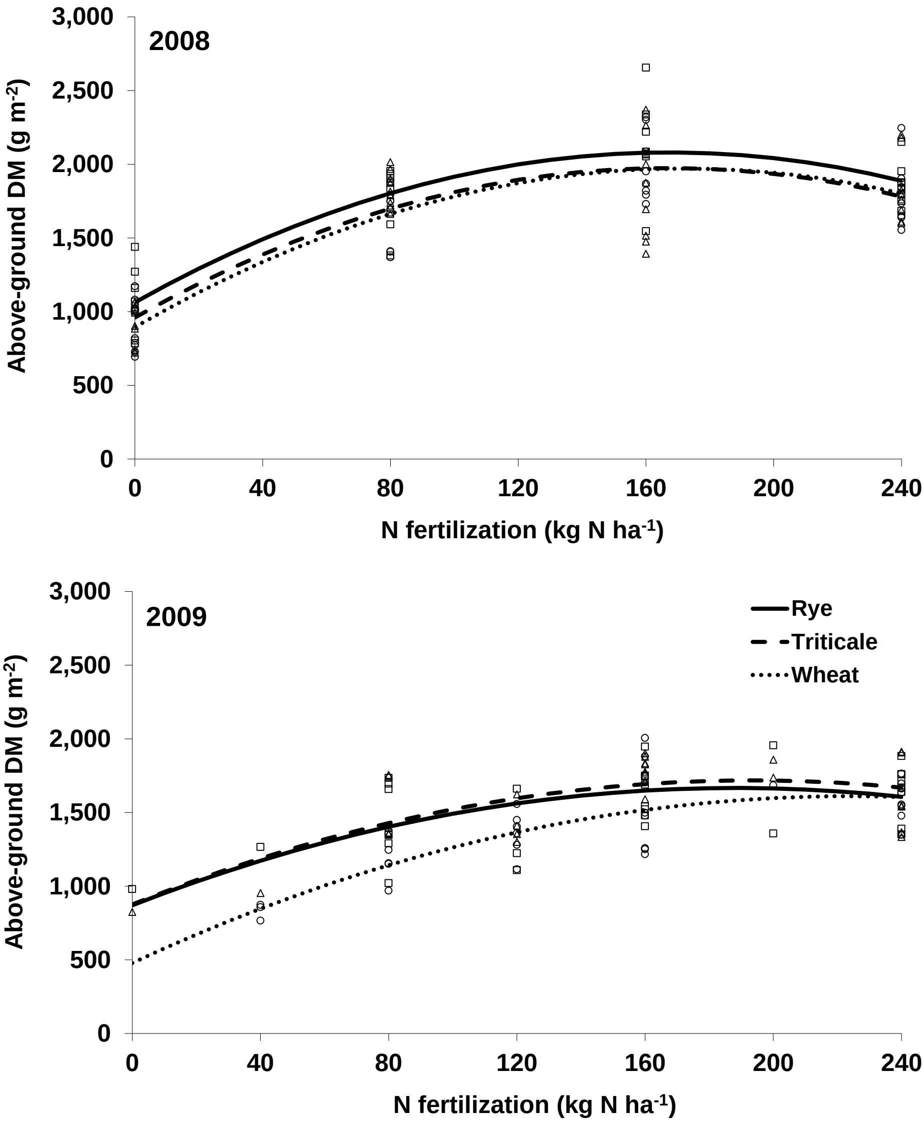
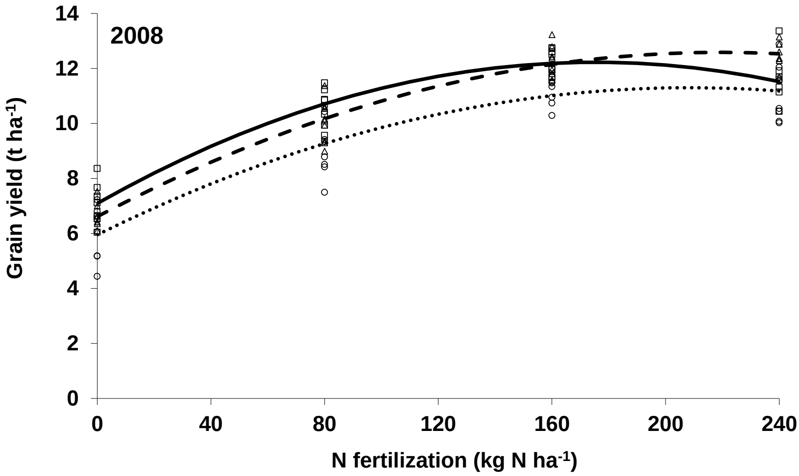


Figure 1. Effect of N fertilization on above-ground dry matter (DM; g m^{-2}) at GS 75 of rye (□), triticale (Δ) and wheat (○) in 2008 and 2009 (function parameters see Table 3).

Table 3. Parameters of the N response curves of rye, triticale and wheat in 2008 and 2009 ($Y = a + b*N + c*N^2$)

	2008					2009				
Crop	n	a	b	c	R^2	n	a	b	c	R^2
Above-ground dry matter at GS 75# ($g\ m^{-2}$) (Fig. 1)										
Rye		1,062.8	12.16				869.9	8.47		
Triticale	96	960.2	12.15	-0.03634	0.76***	87	875.8	8.70	-0.02249	0.54***
Wheat		895.2	12.50				478.9	10.09		
Grain yield ($t\ ha^{-1}$) (Fig. 2)										
Rye		7.32	0.0519				6.45	0.0455		
Triticale	91	6.48	0.0585	-0.00014	0.89***	87	5.12	0.0526	-0.00011	0.82***
Wheat		5.85	0.0553				4.10	0.0536		
Amount of intercepted photosynthetically active radiation between GS 30/31 and GS 75 ($MJ\ m^{-2}$) (Fig. 5)										
Rye		505.2	2.274				494.0	0.817		
Triticale	96	531.7	2.159	-0.00588	0.88***	96	519.7	0.742	-0.00082	0.57***
Wheat		505.9	2.441				466.4	1.043		
Light use efficiency between GS 30/31 and GS 75 ($g\ MJ^{-1}$) (Fig. 6)										
Rye		1.840					1.515			
Triticale	96	1.692	0.00998	-0.00003	0.43***	86	1.523	0.01102	-0.00003	0.34***
Wheat		1.676					1.248			

GS 30/31 – stem elongation; GS 55 ear emergence; GS 75 milk ripe.



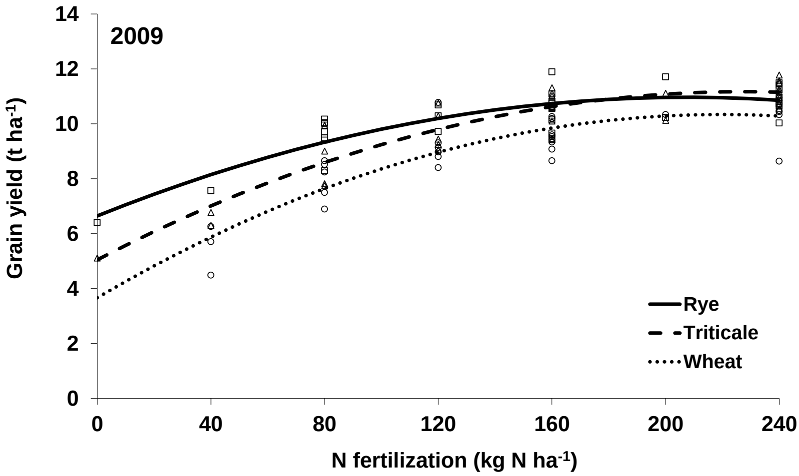


Figure 2. Effect of N fertilization on grain yield (t ha^{-1}) at maturity of rye (□), triticale (Δ) and wheat (○) in 2008 and 2009 (function parameters see Table 3).

Green area index, extinction coefficient, and mean leaf angle

In general, all crops achieved a lower green area index (GAI) in 2009 than in 2008 (Figs 3a, 4a). The course of GAI of the three crops during both growth periods revealed highest GAI in rye in April and May, but from Mid-May onwards triticale clearly outyielded rye and wheat, especially in 2008. Wheat GAI was lower or similar (end of May until Mid-July 2008) to that of rye. Even maximum GAI did not reach the level of rye or triticale. In general, N fertilization increased GAI. In 2008, the difference between the crops became larger with increasing N supply, while in 2009 GAI increase was similarly in all crops (not shown).

The extinction coefficient k varied within the growth period (Figs. 3b, 4b). While no consistent differences between rye and triticale occurred, k of wheat was lowest at most of the sampling dates. In contrast, leaves of the wheat plants showed the highest leaf angle (Figs 3c, 4c).

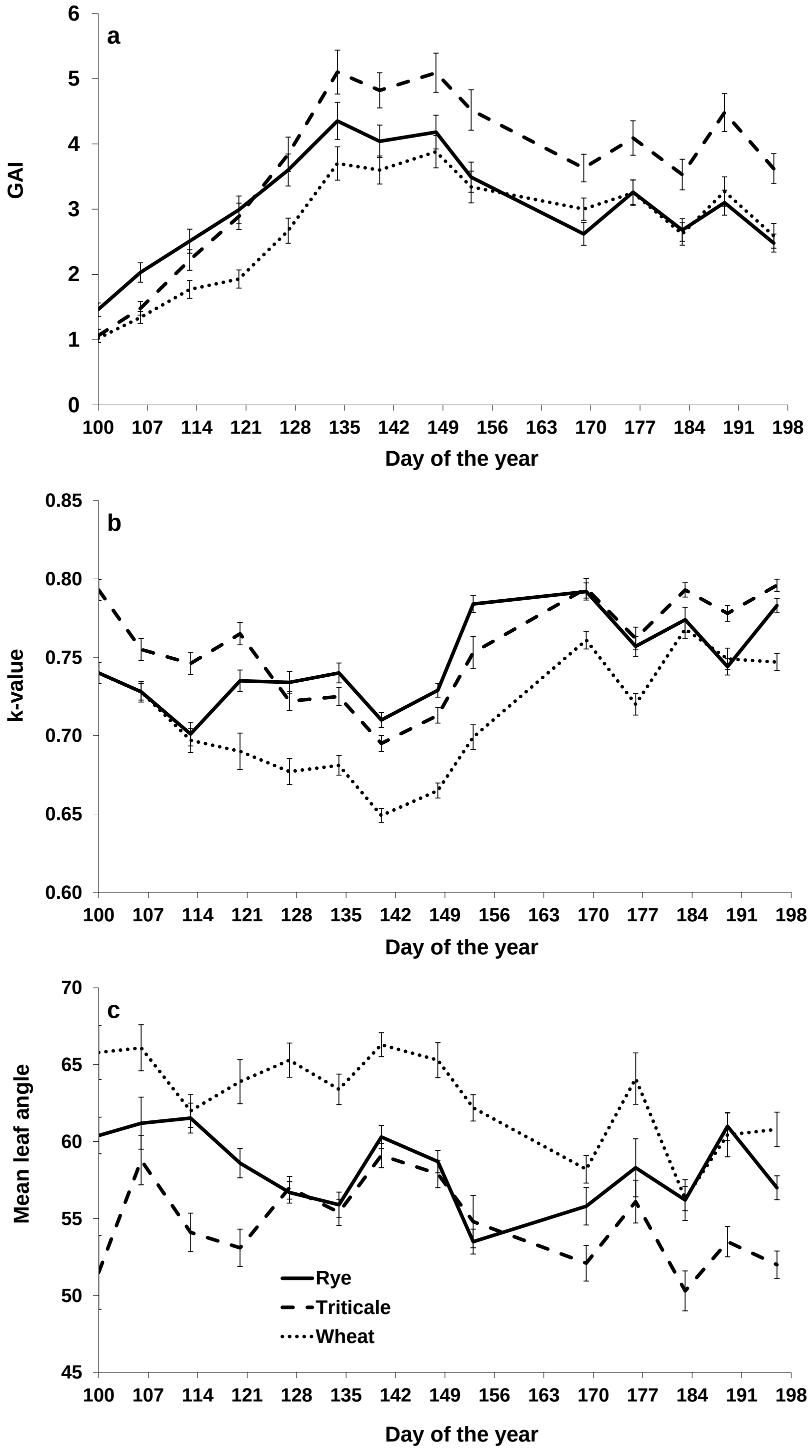


Figure 3. Course of green area index (GAI) (a), extinction coefficient k (b) and mean leaf angle (c) of rye, triticale and wheat in 2008 (N3 treatment).

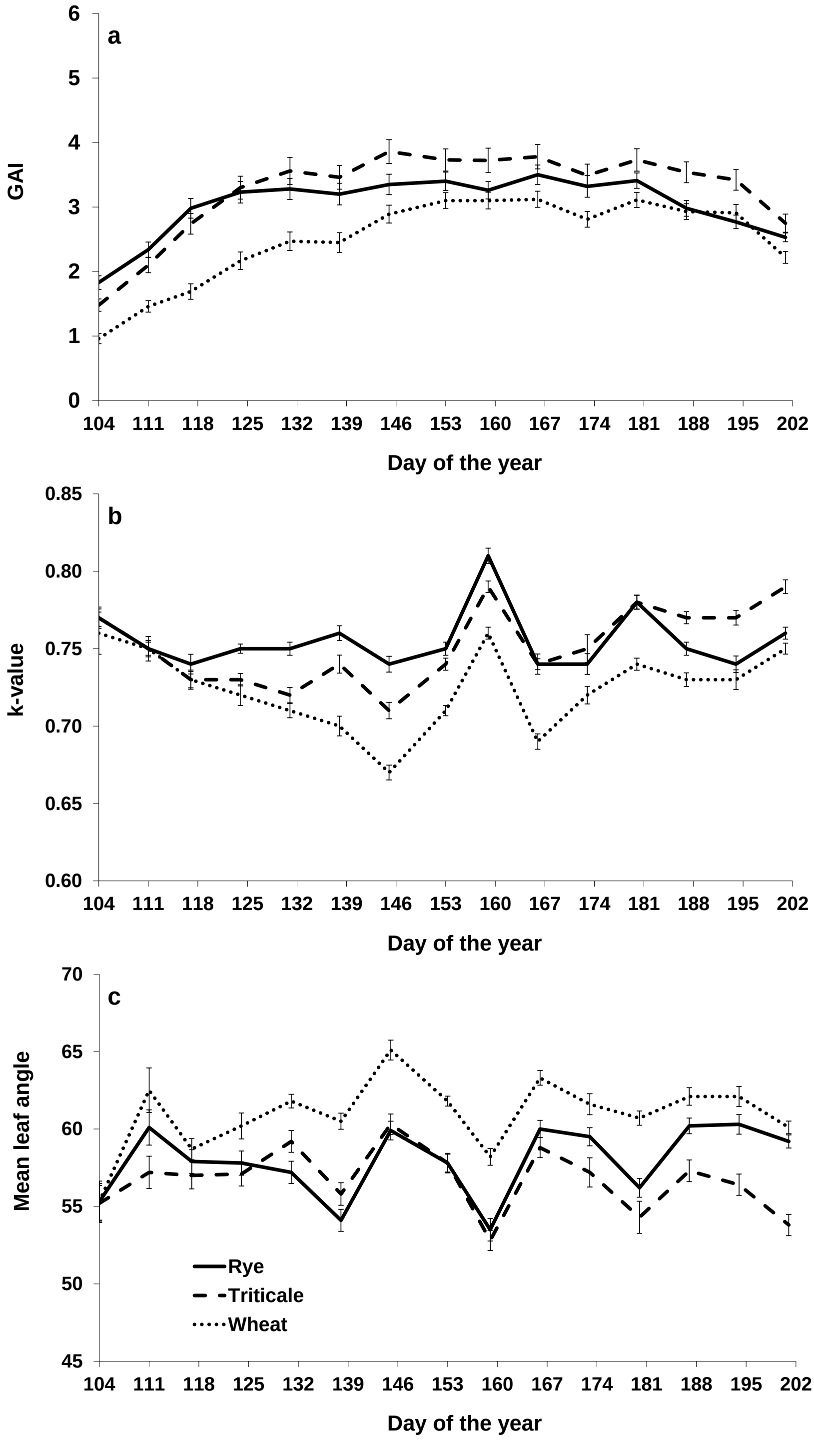


Figure 4. Course of green area index (GAI) (a), extinction coefficient k (b) and mean leaf angle (c) of rye, triticale and wheat in 2009 (N3 treatment).

Photosynthetically active radiation interception and light use efficiency

In 2008, the amount of photosynthetically active radiation (PAR) intercepted by the crops (Q) was higher than 2009 and its increase due to the N fertilization became smaller in all crops, whereas it was linear in 2009 (Fig. 5). In both years, triticale intercepted more PAR at low N levels than rye and wheat. In the 240 kg N ha^{-1} treatment, wheat outyielded rye and triticale which intercepted similar Q amounts during this period. The larger variation in 2009 was mainly due to canopy heterogeneities.

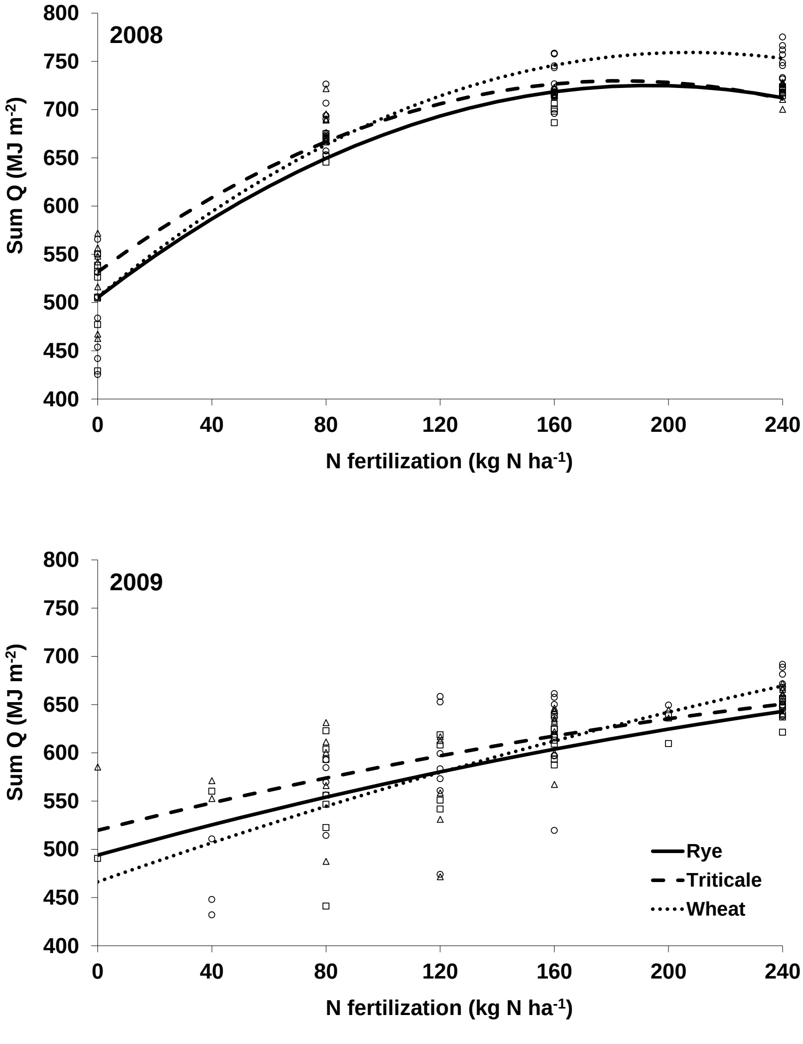


Figure 5. Effect of N fertilization on the amount of photosynthetically active radiation intercepted by the crops (Sum Q; MJ m^{-2}) between GS 30/31 and GS 75 of rye (□), triticale (Δ) and wheat (○) in 2008 and 2009 (function parameters see Table 3).

In order to estimate the light use efficiency (LUE), Q was estimated for the period between GS 30/31 and GS 75 and related to the corresponding DM increase. It should be noted that the duration of this period varied with the year and the crop. In both years, LUE increased with increasing N supply; however, only the plots receiving 0 or 40 kg N ha^{-1} significantly differed from the other N treatments (Fig. 6). While in 2008 no differences between the crops were observed, LUE of wheat was significantly lower compared to rye and triticale in 2009. In both years, N fertilization similarly affected LUE of all crops indicating no N x crop interaction.

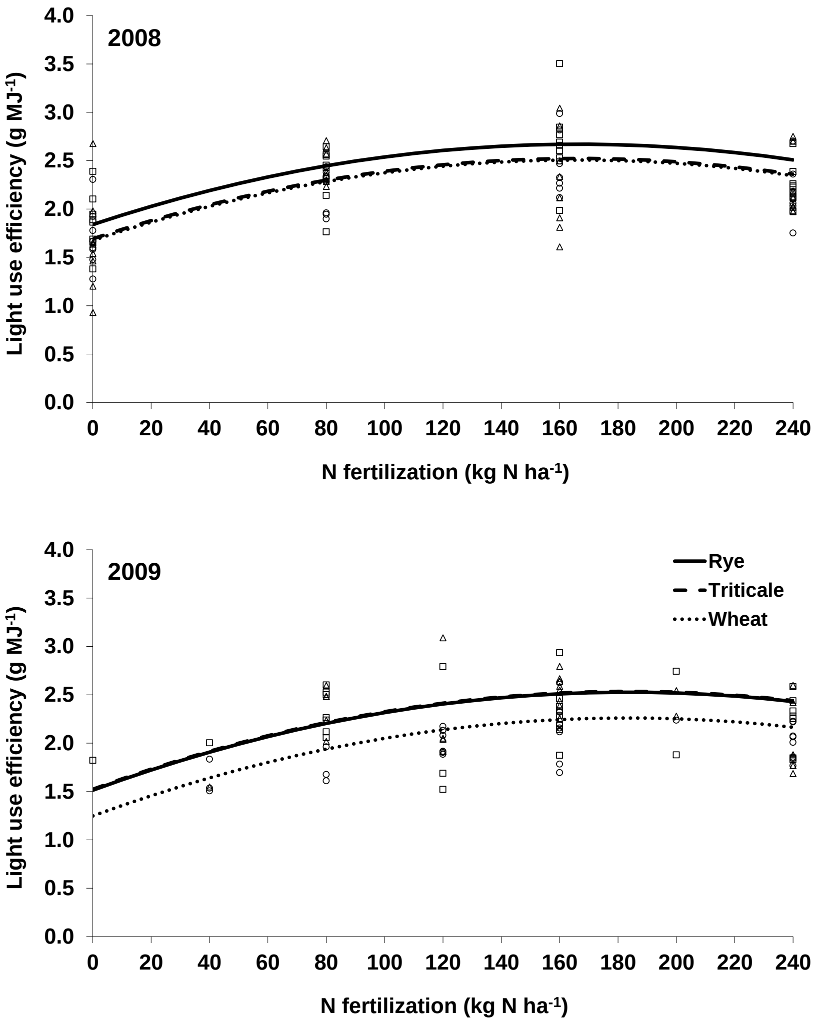


Figure 6. Effect of N fertilization on light use efficiency (g MJ^{-1}) of rye (□), triticale (Δ) and wheat (○) in 2008 and 2009 (function parameters see Table 3).

Leaf area ratio, specific leaf area and leaf mass ratio

The following presented parameters were derived from the plants being fractionated from the N3 treatment only. Therefore, no N effects can be analyzed.

At most of the sampling dates, rye achieved highest leaf area in relation to the total above-ground DM (leaf area ratio, LAR) except at ear emergence (Table 4). In contrast, wheat showed lowest LAR; however, without being significant from triticale.

Table 4. Selected canopy traits (specific leaf area, leaf area ratio, leaf mass ratio) of rye, triticale and wheat at different growth stages in 2008 and 2009

	2008			2009		
	Rye	Triticale	Wheat	Rye	Triticale	Wheat
Specific leaf area (SLA) (cm^2 g^{-1})						
End of autumn growth	156.7[a]	133.2[b]	142.9[ab]	168.9[a]	137.2[b]	149.0[ab]
Beginning of spring growth	222.9[a]	194.6[b]	192.3[b]	184.2[ns]	169.9[ns]	170.1[ns]
GS 30/31[#]	205.3[a]	146.0[b]	140.8[b]	220.0[a]	153.5[b]	153.2[b]
GS 55	227.5[a]	219.5[a]	171.6[b]	235.3[a]	199.6[b]	171.0[c]
Leaf area ratio (LAR) (m^2 kg^{-1})						
End of autumn growth	11.71[a]	10.15[b]	10.07[b]	10.26[ns]	8.58[ns]	8.43[ns]
Beginning of spring growth	14.71[a]	13.43[ab]	12.86[b]	10.53[ns]	10.81[ns]	10.16[ns]
GS 30/31	10.00[a]	8.99[b]	8.26[b]	10.87[a]	8.68[b]	7.92[b]
GS 55	3.33[b]	4.55[a]	2.68[c]	4.66[a]	4.87[a]	3.67[b]
Leaf mass ratio (LMR) (g g^{-1})						
End of autumn growth	0.728[ab]	0.743[a]	0.680[b]	0.608[ab]	0.625[a]	0.563[b]
Beginning of spring growth	0.659[ns]	0.688[ns]	0.665[ns]	0.572[b]	0.636[a]	0.596[b]
GS 30/31	0.482[c]	0.616[a]	0.582[b]	0.492[b]	0.567[a]	0.516[b]
GS 55	0.153[b]	0.217[a]	0.170[b]	0.199[b]	0.245[a]	0.216[b]

[‡]Different letters indicate significant differences at $P = 0.05$ between the crops within a year and a row;
GS 30/31 – stem elongation; GS 55 ear emergence; GS 75 milk ripe.

In 2008 and 2009, rye achieved the highest specific leaf area (SLA = leaf area per unit leaf DM) indicating thinner leaves compared to the other crops (Table 4). Triticale and wheat had similar SLA except at ear emergence (GS 55) when SLA of triticale markedly increased especially in 2008. Relating SLA to the destructively determined leaf area revealed a positive correlation of both parameters (Fig. 7). SLA increase was similar for all crops ($P > 0.10$), but at different levels.

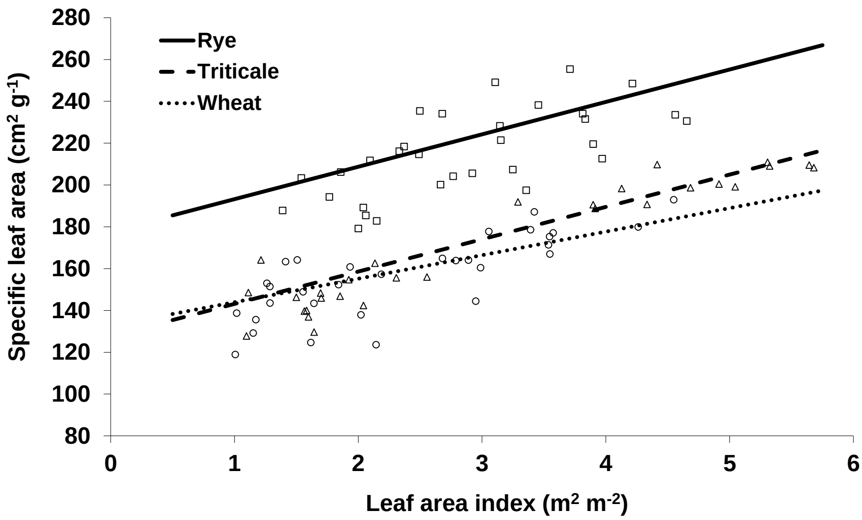


Figure 7. Relation between leaf area index (LAI) and specific leaf area (SLA = leaf area/leaf DM) of rye (□; SLA = 177.8 + 15.49*LAI), triticale (Δ; SLA = 127.7 + 15.45*LAI) and wheat (○; SLA = 132.66 + 11.25*LAI) (2008 and 2009).

Leaf mass ratio (LMR) increased during winter, especially in 2008, and then decreased (Table 4). Compared to rye and wheat, triticale produced more leaf DM in relation to the total shoot DM at all sampling dates in in both years, whereas the ratio of the LMR values for rye and wheat changed during the vegetation period with higher LMR values for wheat compared to rye during the later growth stages (Table 4).

N dilution curves

The N dilution curves of the shoot and the different parts stem, leaves and ear of all crops reveal a negative correlation between the N concentration and the corresponding DM from the N3 treatment (Fig. 8, curve parameters see Table 5); however, the decrease was more pronounced in the stem fraction and the total shoot DM, since shoot DM mainly consisted of stem DM, especially at later growth stages. Leaf N concentration only varied between 4 and 6%, whereas ear N concentration only slightly decreased. Due to advancing senescence, data from GS 75 was excluded from the estimation of the leaf curves, whereas the ear curves only based on data from GS 55 and GS 75. Rye had higher N concentrations in all plant parts, but the difference in shoot and stem N concentrations between the crops decreased during the growth period. The scattered data around 2 t ha^{-1} shoot DM resp. 1 t ha^{-1} stem DM mainly correspond to plants sampled at GS 30/31 in 2008.

Table 5. Parameters of the N dilution curves for the shoot (%N = 1/(a+b*DM), stem (%N = 1/(a+b*DM), leaf (%N = 1/(a+b*DM) and ear (%N = a+b*DM) fraction of rye, triticale and wheat (Figure 8; 2008 and 2009)

Crop	n	a	b	R^2
Shoot (End of autumn growth–GS 75[#])				
Rye	240	0.1705^{c}	0.0320^{ns}	0.95***
Triticale	240	0.1894^{a}	0.0330^{ns}	0.96***
Wheat	240	0.1826^{b}	0.0366^{ns}	0.94***
Stem (End of autumn growth–GS 75)				
Rye	80	0.1849^{c}	0.0812^{ns}	0.95***
Triticale	80	0.2141^{a}	0.0812^{ns}	0.95***
Wheat	80	0.2042^{b}	0.0995^{ns}	0.93***
Leaf (End of autumn growth–GS 55)				
Rye	64	0.1668^{c}	0.0396^{ns}	0.67***
Triticale	64	0.1831^{a}	0.0398^{ns}	0.81***
Wheat	64	0.1740^{b}	0.0478^{ns}	0.70***
Ear (GS 55–GS 75)				
Rye		2.26^{a}		
Triticale	72	2.05^{b}	-0.067	0.50***
Wheat		2.10^{b}		

[‡]Different letters indicate significant differences at $P = 0.05$ between the N treatments according to Zar (2009); ns – not significant;
GS 30/31 – stem elongation; GS 55 ear emergence; GS 75 milk ripe.

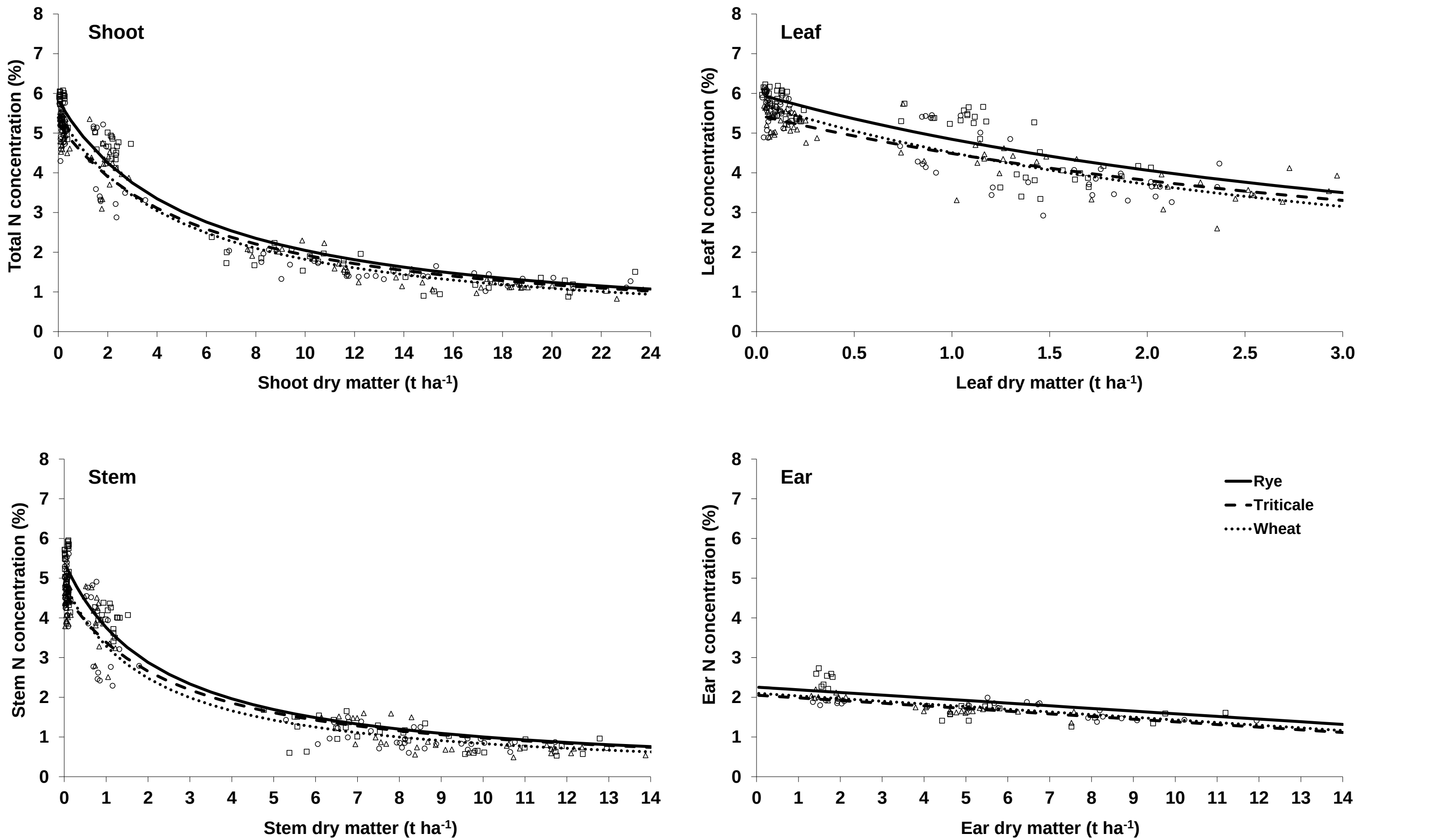


Figure 8. N dilution curves for shoot (end of autumn growth–GS 75), stem (end of autumn growth–GS 75), leaves (end of autumn growth–GS 55) and ear (GS55–GS 75) of rye (□), triticale (Δ) and wheat (○) (only N3 treatment; 2008 and 2009; function parameters see Table 5).

DISCUSSION

Several papers compared the yield formation of rye, triticale and (durum) wheat (e.g. López-Castañeda & Richards, 1994a; Motzo et al., 2015); however, no concurrent growth analysis of the three cereals exists. The presented field trial was designed to compare rye, triticale and wheat for their suitability feeding biogas plants to produce biomethane. For this purpose, a harvest as whole-plant silage during milk and dough ripening was aimed for. Since grain N concentration was of no importance, total N supply was split into 2 applications at the beginning of spring growth and at stem elongation, thus skipping the 3rd N application normally given at ear emergence. Therefore, the crop and N effect on final grain yield should not be overestimated. Nevertheless, the simultaneous cropping of rye, triticale and wheat allows for a comparison of the resource capture and biomass accumulation during spring growth of all three crops. The preceding crops differed in both years (faba beans vs. oilseed rape) probably affecting soil N dynamic; however, several other trials at the experimental site suggested similar preceding crop effects of legumes and oilseed rape on a subsequent winter wheat crop (e.g. Sieling & Christen, 2015).

It was somewhat surprising that DM yield at GS 75 and grain yield at maturity (Fig. 2) of wheat was lower than those of rye and triticale. The course of GAI revealed that wheat developed less green area for PAR interception and showed a lower extinction coefficient at most of the sampling dates throughout the growth period compared rye and triticale (Figs 3a, 3b, 4a, 4b). This can partly explained by the more erectophile leaf angle of wheat (Fig. 3c & 4c). In addition, even the maximum GAI of wheat remained below that of the other tested cereals. On the other hand, triticale produced highest GAI as revealed by Giunta et al. (2009). Although N supply clearly affects leaf formation (Sieling et al. 2016), GAI course is presented on average of the N treatments, since the paper mainly focusses on crop effects and no significant crop by N interactions were observed.

The lower extinction coefficient of wheat compared to triticale is in contrast to findings of Estrada-Campuzano et al. (2012) who observed wheat exhibiting a higher extinction coefficient than triticale. Since k varied throughout the growth period, a stage-specific k was estimated by linear interpolation between the respective sampling dates when calculating the amount of intercepted PAR. Therefore, using a constant k seems to be debatable. A more detailed analysis revealed only small N effects on the extinction coefficient which was in agreement with Estrada-Campuzano et al. (2012). Therefore, a similar k for all N treatments was used. Variation between measurement dates may be due to canopy heterogeneity as well as different weather conditions (cloudy vs. sunny).

N fertilization increased the amount of intercepted PAR (Q) mainly due to an increased GAI (data not shown). In addition, differences between the crops occurred with rye showing almost lowest amounts of Q, while triticale and wheat intercepted most PAR with low and high N supply, respectively. Giunta et al. (2009) reported of higher Q amounts for triticale compared to durum wheat at, however, one N level. Combining Q with the corresponding DM increase allows for the estimation the effective light use efficiency (LUE) (Fig. 6), thus possibly including biotic or abiotic stress (e.g. drought stress). LUE was reduced in the unfertilized plots in all crops being in agreement with Muurinen & Peltonen-Sainio (2006) and Sieling et al. (2016). Rye used Q more efficiently for above-ground DM accumulation than wheat in both years, while triticale behavior was similar to that of wheat in 2008. Sanchez et al. (2015) also reported of higher LUE for rye than for wheat. Compared triticale with (durum) wheat, Motzo et al. (2013) observed higher LUE for triticale due to a higher stomatal conductance during vegetative growth, whereas Winzeler et al. (1989) attributed the lower growth rate to a substantially lower leaf respiration for triticale and rye than for wheat, the difference being more pronounced at the cooler temperatures.

Specific leaf area (SLA) often is a key factor in growth analysis because SLA positively correlates with relative growth rate at early growth stages. In general, rye leaves were thinner (higher SLA) compared to wheat and triticale showing similar SLA, except at ear emergence in both years (Table 4). Winzeler et al. (1989) determined the specific leaf weight (= 1/SLA) being similar for rye and triticale, but higher for wheat. These thicker leaves went along with an increased leaf respiration (see above). In pot experiments, Amanullah (2015) and Amanullah & Stewart (2015) also observed that rye SLA outyielded wheat SLA at 30, 60 and 90 days after emergence. It should be noted that each pot contained 15 plants of which 5 plants were harvested at each sampling date; therefore, the situation will be different from a canopy in the field. In the presented data herein, triticale SLA clearly increased at ear emergence indicating that the leaves became thinner, probably indicating an intensified translocation of assimilates into the growing ear. In addition, as already observed in wheat and barley, SLA positively correlated with GAI (Fig. 7) presumably due to mutual shading (Rawson et al., 1987; Ratjen & Kage, 2013; Sieling et al., 2016).

The N dilution curve relates the N concentration of the shoot or of parts of it to the corresponding DM during vegetative growth. Justes et al. (1994) for wheat and Colnenne et al. (1998) for oilseed rape used a power equation (%N = a*W-b; W is total shoot biomass) to describe the relationship. Comparing additional approaches revealed lowest residual error if a rational equation (%N = 1/(a + b*W)) was used instead of a power function or a ln-function (%N = a + b*ln(W)) (not shown). The fractionation of the total shoot into stem, leaves and ear (if appropriate) allowed for estimating separate N dilution curves (Fig. 8). While leaf N only slightly decreased during spring growth, stem N was dramatically reduced. This can at least partly be explained by the fact that the plant tries to maintain a high leaf N concentration to ensure maximum photosynthesis whereas stem N mainly achieves structural functions. The larger variation around 2 t ha^{-1} shoot DM resp. 1 t ha^{-1} stem DM (Fig. 8) mainly corresponding sampling at GS 30/31 in 2008 may be explained by the fact that the 2nd N application occurred in that year 1 week before sampling. The plants took up fertilizer N which, however, was not yet converted into leaves. If the N1, N2 and N4 treatments were additionally taken into account, the variation of the data at that sampling date markedly increased (data not shown). In 2009, plant sampling was just before N application.

CONCLUSIONS

The simultaneous growth analysis of rye, triticale and wheat reveals that the lower DM yield of wheat at GS 75 mainly resulted from a lower light use efficiency, which in turn may be due to a lower specific leaf area. An extended growth period of wheat partly compensated for a lower GAI, thus the differences in the amount of intercepted PAR between the crops remained small. The higher leaf DM related to the total shoot DM (leaf mass ratio) did not outweigh the lower SLA. On the other hand, rye produced the thinnest leaves with the highest leaf N concentrations resulting in the highest light use efficiency.

The results presented here revealed small, but remarkable differences in the resource capture and above-ground biomass accumulation between the crops. They may allow improving crop growth models for rye and triticale, since respective data are scarce compared to wheat.

ACKNOWLEDGEMENTS. The authors thank Gunda Schnack for the plant sampling and Achim Seidel for collecting and handling the data.

REFERENCES

Amanullah. 2015. Specific leaf area and specific leaf weight in small grain crops wheat, rye, barley, and oats differ at various growth stages and NPK source. *J. Plant Nutr.* **38**, 1694–1708.

Amanullah & Stewart, B.A. 2015. Analysis of growth response of cool season cereals 'wheat vs. rye' grown in organic and inorganic soils. *Emir. J. Food Agric*. **27**, 430–440.

Amon, T., Amon, B., Kryvoruchko, V., Machmüller, A., Hopfner-Sixt, K., Bodiroza, V. Hrbek, R., Friedel, J., Pötsch, E., Wagentristl, H., Schreiner, M. & Zollitsch, W. 2007. Methane production through anaerobic digestion of various energy crops grown in sustainable crop rotations. *Biores. Techn.* **98**, 3204–3212.

Colnenne, C., Meynard, J.-M., Roche, R. & Reau, R. 2002. Effects of nitrogen deficiencies on autumnal growth of oilseed rape. *Eur. J. Agron.* **17**, 11–28.

Estrada-Campuzano, G., Slafer, G.A. & Miralles, D.J. 2012. Differences in yield, biomass and their components between triticale and wheat grown under contrasting water and nitrogen environments. *Field Crops Res.* **128**, 167–179.

FAO 2016. Statistics of harvested area and yield. http://faostat3.fao.org/home/E (07.03.2016).

Gissén, C., Prade, T., Kreuger, E., Achu Nges, I., Rosenqvist, H., Svensson, S.-E., Lantz, M., Mattsson, J.E., Börjesson, P. & Björnsson, L. 2014. Comparing energy crops for biogas production – Yields, energy input and costs in cultivation using digestate and mineral fertilisation. *Biomass Bioenergy* **64**, 199–210.

Giunta, F., Pruneddu, G. & Motzo, R. 2009. Radiation interception and biomass and nitrogen accumulation in different cereal and grain legume species. *Field Crops Res*. **110**, 76–84.

Grindlay, D.J.C. 1997. Towards an explanation of crop nitrogen demand based on the optimization of leaf nitrogen per unit leaf area. *J. Agric. Sci.* **128**, 377–396.

Gunn, S., Farrar, J.F., Collis, B.E. & Nason, M. 1999. Specific leaf area in barley: individual leaves versus whole plants. *New Phytol.* **143**, 45–51.

Hotsonyame, G.K. & Hundt, L.A. 1998. Seeding date, photoperiod and nitrogen effects on specific leaf area of field-grown wheat. *Can. J. Plant Sci.* **77**, 51–61.

Justes, E., Mary, B., Meynard, J.-M., Machet, J.-M. & Thelier-Huche, L. 1994. Determination of a critical nitrogen dilution curve for winter wheat crops. *Ann. Bot.* **74**, 397–407.

Lemaire, G., Jeuffroy, M.-H. & Gastal, F. 2008. Diagnosis tool for plant and crop N status in vegetative stage: Theory and practices for crop N management. *Eur. J. Agron.* **28**, 614–624.

López-Castañeda, C. & Richards, R.A. 1994a. Variation in temperate cereals in rainfed environments I. Grain yield, biomass and agronomic characteristics. *Field Crops Res.* **37**, 51–62.

López-Castañeda, C. & Richards, R.A. 1994b. Variation in temperate cereals in rainfed environments II. Phasic development and growth. *Field Crops Res.* **37**, 63–75.

Mayer, F., Gerin, P.A., Noo, A., Lemaigre, S., Stilmant, D., Schmit, T., Leclech, N., Ruelle, L., Gennen, J., von Francken-Welz, H., Foucart, G., Flammang, J., Weyland, M. &

Delfaosse, P. 2014. Assessment of energy crops alternative to maize for biogas production in the Greater Region. *Biores. Techn*. **166**, 358–367.
Moreau, D., Allrad, V., Gaju, O., Le Gouis, J., Foulkes, M.J. & Matre, P. 2012. Acclimation of leaf nitrogen to vertical light gradient at anthesis in wheat is a whole-plant process that scales with the size of the canopy. *Plant Physiol.* **160**, 1479–1490.
Motzo, R., Pruneddu, G. & Giunta, F. 2013. The role of stomatal conductance for water and radiation use efficiency of durum wheat and triticale in a Mediterranean environment. *Eur. J. Agron.* **44**, 87–97.
Muurinen, S. & Peltonen-Sainio, P. 2006. Radiation-use efficiency of modern and old spring cereal cultivars and its response to nitrogen in northern growing conditions. *Field Crops Res.* **96**, 363–373.
Pérez-Harguindeguy, N., Díaz, S., Garnier, E., Lavorel, S., Poorter, H., Jaureguiberry, P., Bret-Harte, M.S., Cornwell, W.K., Craine, J.M., Gurvich, D,E., Urcelay, C., Veneklaas, E.J., ReichI, P.B., Poorter, L., Wright, I.J., Ray, P., Enrico, L., Pausas, J.G., de Vos, A.C., Buchmann, N., Funes, G., Quétier, F., Hodgson, J.G., Thompson, K., Morgan, H.D., ter Steege, H., van der Heijden, M.G.A., Sack, L., Blonder, B., Poschlod, P., Vaieretti, M.V., Conti, G., Staver, A.C., Aquino, S. & Cornelissen, J.H.C. 2013. New handbook for standardised measurement of plant functional traits worldwide. *Aust. J. Bot.* **61**, 167–234.
Poorter, H., Niinemets, Ü., Poorter, L., Wright, I.J. & Villar, R. 2009. Causes and consequences of variation in leaf mass per area (LMA): a meta-analysis. *New Phytol.* **182**, 565–588.
Qin, X., Weiner, J., Qi, L., Xiong, Y. & Li, F. 2013. Allometric analysis of the effects of density on reproductive allocation and Harvest Index in 6 varieties of wheat (*Triticum*). *Field Crops Res*. **144**, 162–166.
Ratjen, A.M. & Kage, H. 2013. Is mutual shading a decisive factor for differences in overall canopy specific leaf area of winter wheat crops? *Field Crops Res*. **149**, 338–346.
Rawson, H.M., Gardner, P. A. & Long, M.J. 1987. Sources of variation in specific leaf area in wheat grown at high temperature. *Aust. J. Plant Physiol.* **14**, 287–289.
Sánchez, M.L., Pardo, N., Pérez, I.A. & García, M.A. 2015. GPP and maximum light use efficiency estimates using different approaches over a rotating biodiesel crop. *Agric. Forest Meteo*. **214–215**, 444–455.
Sheng, Q. & Hunt, L.A. 1991. Shoot and root dry weight and soilwater in wheat, triticale and rye. *Can. J. Plant Sci.* **71**, 41–49.
Shipley, B. 2006. Net assimilation rate, specific leaf area and leaf mass ratio: which is most closely correlated with relative growth rate? A meta-analysis. *Funct. Ecol.* **20**, 565–574.
Sieling, K. & Christen O. 2015. Crop rotation effects on yield of oilseed rape, wheat and barley and residual effects on the subsequent wheat. *Arch. Agron. Soil Sci.* **61**, 1531–1549.
Sieling, K., Böttcher, U. & Kage, H. 2016. Dry matter partitioning and canopy traits in wheat and barley under varying N supply. *Eur. J. Agron.* **74**, 1–8.
van Delden, A., Pecios, A. & Haverkort, A.J. 2000. Temperature response of early foliar expansion of potato and wheat. *Ann. Bot.* **86**, 355–369.
Winzeler, M., McCullough, D.E. & Hunt, L.A. 1989. Leaf gas exchange and plant growth of winter rye, triticale, and wheat under contrasting temperature regimes. *Crop Sci.* **29**, 1256–1260.
Wright, I.J., Peter, B., Reich, P.B., Cornelissen, J.H.C., Falster, D.S., Eric Garnier, E., Hikosaka, K., Lamont, B.B., Lee, W., Oleksyn, J., Osada, N., Poorter, H., Villar, R., Warton, D.I. & Westoby, M. 2005. Assessing the generality of global leaf trait relationships. *New Phytol.* **166**, 485–496.
Zadoks, J.C., Chang, T.T. & Konzak, C.F. 1974. A decimal code for growth stages of cereals. *Weed Res.* **14**, 415–421.
Zar, J.H. 2009. *Biostatistical Analysis*. 5th Edition, Prentice Hall, 960 pp.

Agronomy Research **14**(4), 1486–1493, 2016

The effect of fertilizer and growing season on tuber dry matter and nitrate content in potato

R. Simson[1,*], L. Tartlan[2], E. Nugis[1] and V. Eremeev[3]

[1]Estonian Crop Research Institute, Department of Plant Biotechnology, Aamisepa 1, EE48309 Jõgeva, Estonia
[2]Estonian Research Institute of Agriculture, Department of Plant Sciences, Teaduse 13, 75501 Saku, Estonia
[1]Estonian Crop Research Institute, Department of Agrotechnology, Aamisepa 1, EE48309 Jõgeva, Estonia
[3]Estonian University of Life Sciences, Department of Field Crop and Grassland Husbandry, Kreutzwaldi 1, EE51014 Tartu, Estonia
[*]Correspondence: reijo.simson@etki.ee

Abstract. Field trials with two potato varieties were undertaken at the Estonian Research Institute of Agriculture in 2005 and 2006. Year 2005 was generally optimal for potato growth but year 2006 was dry and very warm, hence, it was adverse for growth. The effect of fertilizing on two main traits of potato, i. e. tuber dry matter (DM) and nitrate content was examined. Five rates of compound fertilizer were applied, $N_{50}P_{20}K_{85}$, $N_{70}P_{28}K_{119}$, $N_{90}P_{36}K_{153}$, $N_{110}P_{44}K_{187}$ and $N_{130}P_{52}K_{221}$. Results indicated that DM content was largely determined by variety but it also depended on fertilizer amounts and particular environmental conditions of a year. Nitrate content of tubers was quite clearly dependent upon variety, but growing season had significant effect on final nitrate content in tubers. Water stress during early and main bulking periods resulted in high tuber nitrate levels. In order to gain tuber yield fit for intended use, it is necessary to manage nutrient acquisition based on expected yield and nutrient supply from soils.

Key words: potato, fertilization, environmental conditions, dry matter content, nitrate content.

INTRODUCTION

Dry matter (DM) content is one of the most common indicators of tuber quality (Storey, 2007). Proper DM content ensures that a certain lot is fit for intended use, e. g. high percentage of solids is required in starch industry. In the literature, DM content, starch content, tuber solids content, and specific gravity are used interchangeably, although these represent the same variable (Stark & Love, 2003). Both direct and indirect determination methods can be used (Wilson & Lindsay, 1969).

Dry matter accumulates while tubers enlarge and mature (Leszczyński, 1989) as well as composition of DM alters during growth period, the proportion of starch increases and that of protein, sugar and minerals decreases (Snyder et al., 1977; Kolbe & Stephan-Beckmann, 1997). Early potato varieties have generally lower DM content than maincrop potatoes (Gray & Hughes, 1982). Studies undertaken in many countries and in different climates have referred to variety (genotype) being the key factor in determining DM content (Aamisepp, 1936; Stevenson et al., 1964; Hughes, 1974; Burton et al., 1992; Tsahkna, 1996; Putz, 1998). This genetic trait is modified by many other factors. Cultural practises, climate, and soil may largely affect final DM content (Storey & Davies, 1992). There are many comprehensive reviews showing vigorous effect of nitrogen (N) and potassium (K) (e.g. Laboski & Kelling, 2007). Nitrogen is often the limiting nutrient to achieve high tuber yields (Marshall, 2007) but excessive amounts of N may be deleterious to quality traits and pollute ground water due to leaching (Bucher & Kossmann, 2007).

Nitrogen is responsible for the extent of lateral branching of stems and size and life span of individual leaves whereby it affects canopy structure, size and longevity but it impacts neither canopy photosynthesis (Vos & Marshall, 1993; Hay & Porter, 2006) nor dry matter partitioning (Jenkins & Mahmood, 2003). The effect of N mainly results in delayed maturity, which is particularly obvious in the case a shorter growing period (Kunkel & Holstad, 1972; Gray & Hughes, 1982). It has been reported that the optimal rate of N is not detrimental to DM production and content (Stark & Love, 2003). Potassium ions are found in plant cell sap and condition osmotic pressure. Abundant K supply leads to decreasing DM content due to intensified water uptake, the latter is often enhanced with chloride (Marschner, 1995). On the other hand, K deficiency reduces partitioning of DM (Jenkins & Mahmood, 2003). Considering proper K rate, it is critical to be aware of soil potassium status. If the soil contains high concentration of potassium, then applying K fertilizer may reduce DM content but reverse may occur in soils low in K (Allison et al., 2001; Laboski & Kelling, 2007). Potassium also contributes to better uptake of N and N use efficiency (Gething, 1993). Phosphorus affects DM content to a lesser extent, though often positively, but this nutrient aids to alleviate adverse NK interaction in terms of DM content (Herlihy & Carroll, 1969). Regardless of specific interactions among ions, the effect of variety and location on tuber DM must be considered (Schippers et al. 1968). The effect of secondary nutrients and micronutrients on DM content is considered to be minor (Laboski & Kelling, 2007).

Nitrate content is not as crucial for tuber quality as dry matter content but it may impair food safety due to possible hazard to human health since nitrate ions can be converted into nitrite (Santamaria, 2006; Elias et al., 2011). Nitrate is a common ion in plant N metabolism as well as in the N cycle (Santamaria, 2006). Nitrate can normally comprise up to 1.0% of the total protein pool in potato tubers. In general, nitrate content of a crop is mainly controlled genetically (by variety) and modified by management practices (irrigation, fertilization, *etc.*), soil, and climate (Maynard & Barker, 1979; Blom-Zandstra, 1989; Lindhauer & Weber, 1993). Nitrogen fertilizer is an important source of plant-available N in the modern day crop production and it can also affect final nitrate content. Phosphorus chiefly reduces nitrate content through hastening plant senescence (Havlin et al. 2004). Potassium is responsible for activity of many enzymes among which is nitrate reductase (Marschner, 1995). However, the potato tuber is regarded as low-nitrate tissue (Serio et al., 2004) and nitrate content is reduced markedly by peeling and subsequent cooking (Bergthaller et al., 1986; Tartlan, 2005). At present, tuber nitrate content is not of particular concern in potato but it is still under investigation and regulated in some leafy vegetables (Santamaria, 2006; Järvan, 2009).

The objectives of the research were to examine the influence of different fertilizer rates on dry matter and nitrate content in commercially appreciated varieties, cv. 'Maret' in low-input farming and cv. 'Milva' in conventional potato production.

MATERIALS AND METHODS

Field trials were performed at the Estonian Research Institute of Agriculture at Saku in 2005 and 2006. Alsike clover (*Trifolium hybridum* L.) for seed was grown prior to potato experiments. Two potato varieties from different maturity groups, cvs. 'Maret' (middle early) and 'Milva' (maincrop), were examined. Five fertilizer treatments were applied: rates $N_{50}P_{20}K_{85}$, $N_{70}P_{28}K_{119}$, $N_{90}P_{36}K_{153}$, $N_{110}P_{44}K_{187}$ and $N_{130}P_{52}K_{221}$ added as compound fertilizer Kemira Cropcare 10-10-20 (10% N, 4% P and 17% K, Kemira Growhow Oy, Finland) into the hill before planting. Four replication, systematic block designe. Seed tubers of grade 35–55 mm were presprouted and planted by hand in 70-cm rows at 25-cm apart. Weed control performed by ridging and harrowing in 2005 and Titus+Sencor treatment supplemented cultural measures in 2006. Six sprays in 2005 and five sprays in 2006 were used to protect potato plants from foliar late blight including different fungicides such as Ridomil Gold, Acrobat Plus, Shirlan, and Ranman.

Endogleyic Cambisol (eutric) was the soil type in trial (Deckers et al., 2002) and the soil texture was a loamy sand. The soil contained 2.5–3.0% organic matter and available P 70 mg kg^{-1}, K 85 mg kg^{-1}, Ca 2,300 mg kg^{-1} and Mg 95 mg kg^{-1}. Soil pH_{KCl} was 5.5. Available nutrients were determined according to Mehlich 3 and pH by ISO 10390.

Experimental years differed in mean temperature and rainfall (Table 1). Year 2005 was warm and rainfall was sufficient for optimal growth, but 2006 was warm and dry which was unfavourable for potato.

Table 1. Meteorological data in the experimental years

Month	Temperatures, °C		Rainfall, mm	
	2005	2006	2005	2006
May	9.7	9.7	47	20
June	13.0	15.2	39	19
July	17.2	17.9	82	15
August	15.7	17.0	136	65
September	11.9	13.3	19	19

Year 2006 was adverse for potato development and assimilation because of severe water stress during early and main tuber bulking periods.

In order to determine DM content, tubers of size 35–55 mm were washed after digging up, surface moisture was then allowed to evaporate. Four samples per treatment were used, *i. e.* one sample was taken from a replicate. Each tuber sample of 500 g was cut into thin slices, laid onto paper trays, dried at 65 °C at first and then at 105 °C (24 + 2 h). The residue was weighed and dry matter content was calculated. Tuber nitrate content was determined according to EVS-EN 12014-7.

The results were analyzed with Statistica 11, using ANOVA and Fisher LSD test. Statistically significant differences ($p < 0.05$) between treatments are denoted with letters.

RESULTS AND DISCUSSION

A steady decrease in dry matter content was observed in cv. 'Maret' in 2005 (Fig. 1). The treatment without any additional fertilizer ($N_0P_0K_0$) resulted in the highest DM percentage (25.6%). In most treatments supplied with higher amounts of nutrients, DM content decreased significantly ($p < 0.05$) (minimum value reached 21.7% in $N_{130}P_{52}K_{221}$, i.e. 15% lower than in $N_0P_0K_0$).

Cv. 'Milva' had lower DM value (19.9%) in the treatment without fertilizer than cv. 'Maret', but the effect of increasing fertilizer amounts was less pronounced (Fig. 1). Values obtained with applying fertilizer were significantly lower ($p < 0.05$) than those in $N_0P_0K_0$ treatment. Four treatments led to a decrease in DM content by 0.9–1.4%. The highest rate ($N_{130}P_{52}K_{221}$) had lower DM content (17.7%) compared with $N_0P_0K_0$.

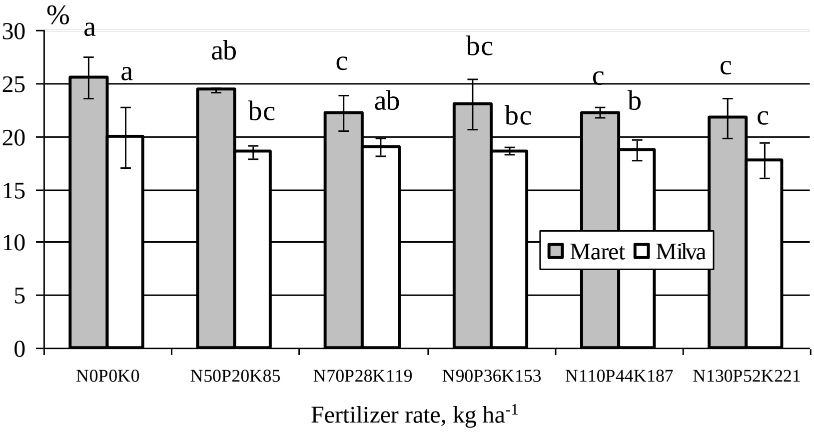


Figure 1. The effect of fertilizer rates on dry matter content, % on cvs. 'Maret' and 'Milva' in 2005. Different lower case letters indicate significant differences ($p < 0.05$) in columns (ANOVA, Fisher LSD test).

In 2006, there was also a definite decrease of DM percentage in fertilizer treatments on cv 'Maret'. Rates $N_{50}P_{20}K_{85}$ and $N_{70}P_{28}K_{119}$ reduced DM levels by 0.9 and 1.3%, respectively, compared with $N_0P_0K_0$ and those differed significantly ($p < 0.05$) from $N_0P_0K_0$. The following treatments ($N_{90}P_{36}K_{153}$, $N_{110}P_{44}K_{187}$ and $N_{130}P_{52}K_{221}$) reduced DM content by 1.7%, on an average (Fig. 2). In cv. 'Milva' in 2006, irregular fluctuations were noticed, regardless of fertilizer amounts, hence, no treatment differed significantly from $N_0P_0K_0$ (17.9%) (Fig. 2).

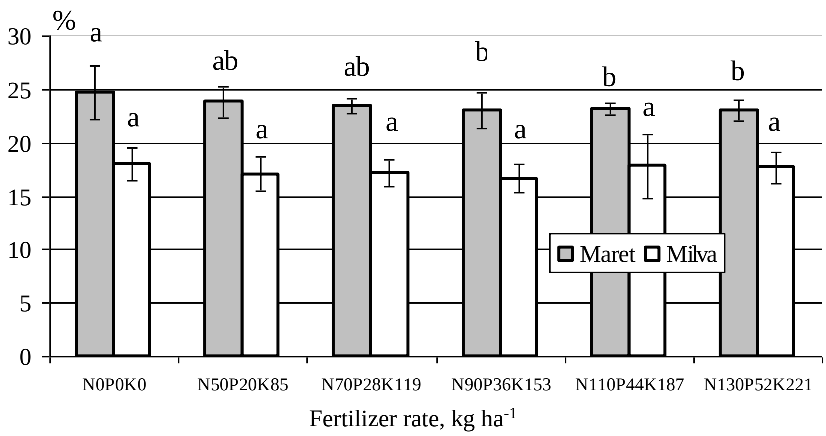


Figure 2. The effect of fertilizer rate on dry matter content on cvs. 'Maret' and 'Milva' in 2006. Different lower case letters indicate significant differences ($p < 0.05$) in columns (ANOVA, Fisher LSD test).

Likewise, the apparent effect of fertilizing on tuber nitrate content was noted in cv. ‘Maret’ in 2005. Lower values were found in those treatments provided with less nutrients (Table 2). Applying $N_{50}P_{20}K_{85}$, $N_{70}P_{28}K_{119}$, $N_{90}P_{36}K_{153}$ resulted in nitrate levels below 50 mg kg^{-1} fresh weight (FW), while highest contents were found with $N_{110}P_{44}K_{187}$ and $N_{130}P_{52}K_{221}$ (111 and 126 mg kg^{-1}, respectively). Cv. ‘Milva’ tubers had nitrate below 100 mg kg^{-1} in $N_0P_0K_0$, $N_{50}P_{20}K_{85}$, $N_{70}P_{28}K_{119}$ (81, 95 and 99 mg kg^{-1}, respectively). The highest content (244 mg kg^{-1} $N0_3$-N) was recorded in the highest fertilizer treatment. The effect of fertilizing was also found in cv. ‘Maret’ in 2006. The initial value (in $N_0P_0K_0$) was relatively high (133 mg kg^{-1} FW) and increased with increasing nutrient level (Table 2). At the maximum fertilizer rate, nitrate increased to 256 mg kg^{-1} FW . In cv. ‘Milva’, the effect of increasing fertilizer rate was not significant (Table 2) and initial level (in $N_0P_0K_0$) was exceptionally high (254 mg kg^{-1} FW). Differences between two varieties as well as growing seasons were significant ($P < 0.05$).

Table 2. The effect of fertilizer rates on nitrate content of tubers (mg kg^{-1} FW)

Fertilizer rate,	‘Maret’		‘Milva’	
kg ha^{-1}	2005	2006	2005	2006
$N_0P_0K_0$	31	133	81	254
$N_{50}P_{20}K_{85}$	35	167	95	374
$N_{70}P_{28}K_{119}$	42	180	99	297
$N_{90}P_{36}K_{153}$	45	161	105	443
$N_{110}P_{44}K_{187}$	111	202	191	460
$N_{130}P_{52}K_{221}$	126	256	244	293

Results obtained in the study are consistent with earlier reports (Kunkel & Holstad, 1972; Gray & Hughes, 1982; Tartlan, 2005; Laboski & Kelling, 2007). DM percentage was inherent to a particular variety, i.e. cv. ‘Maret’ contained more DM than cv ‘Milva’. In terms of DM, cv. ‘Maret’ responded more clearly to increasing fertilizer rates in 2005 (Fig. 1). In 2006, differences were not so evident due to adverse environmental conditions. Final DM content is regarded as an outcome of interactions of genotype (variety) and environment (Howard, 1974; Hughes, 1974). Environment is complex and interactions are diverse at particular sites and in different years. Consequently, a certain variety performs differently in different years. Another aspect is crop maturity. DM content attains a maximum value shortly before tuber yield is maximized and tubers with the highest DM content are obtained from plants senesced naturally (Maag, 1993; Ierna, 2010). Cv. ‘Maret’ reached maturity in 2005 but cv. ‘Milva’ did not in 2005. In 2006, it was impossible to score maturity in either case due to premature death as a result of water stress. Hence, tubers lifted were immature and did not contain maximum levels of DM, although solar radiation and temperatures were adequate for DM assimilation during the bulking period (Kooman et al., 1996). In addition, the effect of main nutrients separately (N, P and K) has been extensively investigated but interactions among them on potato are less understood (Jenkins & Mahmood, 2003).

Nitrate levels appeared to be related to a particular variety, fertilizer rate, maturity and particularly, to water availability. On an average, cv. ‘Maret’ contained less nitrate in fresh tubers than cv. ‘Milva’. In general, nitrate content of tubers has been confirmed to be within the range 10–500 mg kg^{-1} FW (Spaar et al., 1999), but most frequently, values are between 40–250 mg kg^{-1} FW (Leszczyński, 1989). Fertilizer rates clearly affected nitrate levels under adequate water supply but the effect of fertilizer was less definite under stress conditions in 2006. Inadequate water availability led to high nitrate levels. As confirmed by McDole & McMaster (1978) and Spaar et al. (1999), insufficient water supply is the key factor leading to undesired nitrate levels in potato tubers. In the case of water stress, activity of nitrate reductase is supressed more than nitrate uptake (Schuddeboom, 1993) which gives rise to nitrate accumulation. Regardless of N fertilizer rates, tubers from plants affected by moisture stress contained nitrate twice as high as tubers from optimum or excessive irrigation treatments (McDole & McMaster, 1978). Furthermore, one should take into account that potato was preceded by alsike clover which is capabale of N fixation 100–200 kg ha^{-1}. This in turn could have contributed to increased nitrate content in the potato tubers (Kõrgas, 1969).

CONCLUSION

This research demonstrated that increasing fertilizer rates clearly reduced tuber dry matter content in both varieties, but the effect was more pronounced under favourable environmental contitions in 2005 than under water stress in 2006. On the other hand, increasing fertilizer increased nitrate levels in tubers in both years, but the effect of year, particularly due to water stress during the bulking period, promoted higher nitrate levels. Consequently, most traits of potato are determined both by genotype and environment. The latter is very complicated to manage in order to achieve tubers suitable for intended use. As a result, tuber quality is primarily controlled by planting appropriate varieties and implementing proper cultural practises. Above all, installation of irrigation systems is advisable in order to maintain optimal soil moisture level during the growing season and to achieve expected tuber quality in years with inadequate rainfall.

ACKNOWLEDGEMENTS. I would like to thank Mrs. E. Rumberg for excellent assistance in field trials and Mrs. L. Kurimu for kind advice and guidance in laboratory work. My special thanks go to Mrs. A. Ivanova for valuable discussion at the final stage. This research was funded by Ministry of Agriculture of Estonia.

REFERENCES

Aamisepp, J. 1936. Our potato from view point of starch and spirit industries. *Agronomy* **4**, 157–169 (in Estonian).

Allison, M.F., Fowler, J.H. & Allen, E.J. 2001. Responses of potato (*Solanum tuberosum*) to potassium fertilizers. J. Agric. Sci. **136**(04), 407–426.

Bergthaller, W., Putz, B. & Ocker, H.D. 1986. Der Einfluss der Verarbeitung auf die Nitratkonzentration in Produkten der Kartoffelverarbeitung. *Kartoffelbau* **37**, 337–341 (in German).

Blom-Zandstra, M. 1989. Nitrate accumulation in vegetable and its relationship to quality. *Ann. Appl. Biol.* **115**(3), 553–561.

Bucher, M. & Kossmann, J. 2007. Molecular physiology of the mineral nutrition of the potato. In Vreugdenhil, D. (ed.): *Potato Biology and Biotechnology. Advances and Perspectives*. Elsevier, Oxford, pp. 311–329.

Burton, W.G., Es, A. & van Hartmans, K.J. 1992. The physics and physiology of storage. In Harris, P. M (ed.): *The Potato Crop. The scientific basis for improvement*. Second edition. Chapman & Hall, London, pp. 608–727.

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 & L. Montanarella), *European Soil Bureau Research Report No. 7*, EUR 20398 EN, pp. 173–181.
Elias, T., Elias, A., Kiis, A., Reinik, M., Püssa, T., Meremäe, K. & Roasto, M. 2011. Nitrate and nitrite contents in vegetables and vegetable-based raw juices and dietary intake. *Journal of Agricultural Science* **XXII**(1), 10–17 (in Estonian).
Gething, P.A. 1993. The Potassium– Nitrogen Partnership. Improving Returns from Nitrogen Fertilizer. IPI Research Topics No. 13. 2nd Revised Edition. International Potash Institute, Basel, 51 pp.
Gray, D. & Hughes, J.C. 1982. Tuber quality. In Harris, P. M (ed): *The Potato Crop*. *The scientific basis for improvement*. Chapman & Hall, London, pp. 504–544.
Havlin, J.L., Beaton, J.D. Tisdale & Nelson, W.L. 2004. *Soil Fertility and Fertilizers. An Introduction to Nutrient Management.* 7th edition. Prentice Hall.
Hay, R.K.M. & Porter, J.R. 2006. *The Physiology of Crop Yield*. Second edition. Blackwell Publishing, Oxford, 314 pp.
Herlihy, M. & Carroll, P.J. 1969. Effects of N, P and K and their interactions on yield, tuber blight and quality of potatoes. *J. Sci.Food Agr.* **20**(9), 513–517.
Howard, H.V. 1974. Factors influencing the quality of ware potatoes 1. The genotype. *Potato Res*. **17**, 490–511.
Hughes, J.C. 1974. Factors influencing the quality of ware potatoes 2. Environmental factors. *Potato Res.* **17**, 512–547.
Ierna, A. 2010. Tuber yield and quality characteristics of potatoes for off-season crops in a Mediterranean environment. *J.Sci.Food Agr.* **90**(1), 85–90.
Jenkins, P.D. & Mahmood, S. 2003. Dry matter production and partitioning in potato plants subjected to combined deficiencies of nitrogen, phosphorus and potassium. *Ann. Appl. Biol.* **143**(2), 215–229.
Järvan, M. 2009. *The Nitrates in Plant Production.* Estonian Research Institute of Agriculture, Saku, 116 pp (in Estonian).
Kolbe, H. & Stephan-Beckmann, S. 1997. Development, growth and chemical composition of the potato crop (*Solanum tuberosum* L.). II. Tuber and whole plant. *Potato Res.* **40**(2), 135–153.
Kooman, P.L., Fahem, M., Tegera, P. & Haverkort, A.J. 1996. Effects of climate on different potato genotypes 2. Dry matter allocation and duration of a growth cycle. *Eur. J. Agron.* **5**(3–4), 207–217.
Kunkel, R. & Holstad, N. 1972. Potato chip color, specific gravity and fertilization with N-P-K. Am. Potato J. **49**(2), 43–62.
Kõrgas, L. 1969. About value of legumes as preceding crops. *Transactions of Estonian Research Institute of Agriculture* **15**, 89–98 (in Estonian).
Laboski, C.A.M. & Kelling, K.A. 2007. Influence of fertilizer management and soil fertility on tuber specific gravity: a review. *Am. J. of Potato Res*. **84**, 283–290.
Leszczyński, W. 1989. Potato tubers as a raw material for processing and nutrition. In Lisińska, G. & Lesczczyński, W. (eds.): *Potato Science and Technology*. Elsevier Applied Science, Barking, pp. 11–128.
Lindhauer, M. & Weber, L. 1993. Critical comments on nitrate in potatoes. Abstracts of 12th Triennial Conference of the European Association for Potato Research. Paris, pp 363–364.
Maag, M. 1993. Effect of maturity and haulm killing on tuber yield, starch content and crisps. Abstracts of 12th Triennial Conference of the European Association for Potato Research. Paris, pp 34–35.
Marschner, H. 1995. Mineral Nutrition of Higher Plants. 2nd revised edition. Academic Press, London, 889 pp.

Marshall, B. 2007. Decision support systems in potato production. In Vreugdenhil, D. (ed.): *Potato Biology and Biotechnology. Advances and Perspectives*. Elsevier, Oxford, pp. 777–800.
Maynard, D.N. & Barker, A.V. 1979. Regulation of nitrate accumulation in vegetables. *Acta Hort.* **93**, 153–162.
McDole, R.E. & McMaster, G.M. 1978. Effects of moisture stress and nitrogen fertilization on tuber nitrate-nitrogen content. *Am. J. of Potato Res.* **55**(11), 611–619.
Putz, B. 1998. *Kartoffeln: Züchtung. Anbau. Verwertung.* Behr's Verlag, Hamburg, 263 pp. (in German).
Santamaria, P. 2006. Nitrate in vegetables: toxicity, content, intake and EC regulation. *J. Sci.Food Agr.* **86**, *10–17.*
Schippers, P.A. 1968. The influence of rates of nitrogen and potassium application on the yield and specific gravity of four potato varieties. *Eur. Pot. J.* **11**(1), 23–33.
Schuddeboom, L.J. 1993. *Nitrates and nitrits in foodstuffs*. Council of Europe Press, 124 pp.
Serio, F., Elia, A., Signore, A. & Santamaria, P. 2004. Influence of nitrogen form on yield and nitrate content of subirrigated early potato. *J. Sci.Food Agr.* **84**(11), 1428–1432.
Snyder, J. Desborough, S. & Holm, D. 1977. Accumulation of protein, non-protein and starch during tuber growth of three potato cultivars. *Amer. J. of Potato Res*. **54** (11), 545–555.
Spaar, D., Dreger, D., Ivanyuk, V., Kürzinger, W., Postnikov, A., Schumann, P., Cherbakov, V. & Yaster, K. 1999. Kartofelj. Minsk, FUAinform, 272 pp (in Russian).
Stark, J.C. & Love, S.L. 2003. Tuber quality. In Stark, J. C & Love, S. L. (eds): *Potato Production Systems*. Univ of Idaho Extension, Moscow, pp. 329–343.
Stevenson, F.J., Akeley, R.V. & Cunningham, C.E. 1964. The potato– its genetic and environmental variability. *Am. Potato. J.* **41**(2), 46–53.
Storey, R.M.J., Davies, H.V. 1992. Tuber quality. In Harris, P.M (ed): *The Potato Crop*. *The scientific basis for improvement.* Second edition. Chapman & Hall, London, pp. 507–569.
Storey, M. 2007. The harvested crop. In Vreugdenhil, D. (ed): *Potato Biology and Biotechnology. Advances and Perspectives.* Elsevier, Oxford, pp. 441–470.
Tartlan, L. 2005. *Potato quality and factors affecting it*. Estonian Research Institute of Agriculture, 68 pp. (in Estonian).
Tsahkna, A. 1996. Dry matter and reducing sugars as the main determiners of quality of chips and French fries. *Transactions of the Estonian Academic Agricultural Society* **1**, 26–29 (in Estonian).
Wilson, J.H. & Lindsay, H.M. 1969. The relation between specific gravity and dry matter content of potato tubers. *Am. Potato. J.* **46**(9), 323–328.
Vos, J. & Marshall, B. 1993. Nitrogen and potato production: strategies to reduce nitrate leaching. Abstacts of 12th Triennial Conference of the European Association for Potato Research. Paris, pp. 305–306.

Agronomy Research **14**(4), 1494–1504, 2016

Effects of nutrient supply and planting material quality on yield and survival rate of a short rotation coppice culture in Hungary

O. Szabó*, G. Kovács and B. Heil

Institute of Environmental and Earth Science, Faculty of Forestry, University of West–Hungary, Bajcsy–Zs. street 4, HU–9400 Sopron, Hungary
*Correspondence: szabo.orsolya@emk.nyme.hu, orsoy@freemail.hu

Abstract. In May 2011, a short rotation woody energy plantation (SRC) was established near Dejtár village in Northern–Hungary. The goal of the experiment was comparative analyses of different fertilization treatments on three clones of Populus (AF2, Monviso, Pannonia) and one Salix cultivar ('Dékány'). We used three fertilization treatments: (1) 5 t ha^{-1} of wood ash, (2) 40 t ha^{-1} of farmyard manure and (3) both 5 t ha^{-1} of wood ash and 40 t ha^{-1} of farmyard manure. The Monviso clone had the highest survival rate (92%), followed by Pannonia (80%) and AF2 (78%). Initially, the white willow 'Dékány' cultivar was also included in the experiment, but due to differing site preferences of this cultivar, it was not viable in the area. Based on the data of the first three growing seasons, it was demonstrated that the important nutrients had already been present in optimal amounts from the start of the experiment, and their contents were increased due to the treatments. At the end of the first growing season, the effect of the fertilization treatment could not be detected, but by the third year the results showed a significant positive effect. Already in the second, but mostly at the end of the third growing season, the wood ash + manure fertilizer treated plots showed significant increases in height growth and biomass yield.

Key words: *Populus* Spp; Farmyard manure; Wood ash; Biomass production.

INTRODUCTION

The growing energy demands of modern societies depend mostly on fossil fuels. Growing political and social tensions threaten the continuous supply. Political decision makers in the European Union (EU) have set joint strategies to ensure energy supply including the generation of energy from renewable sources, mainly biomass (European Commission, 1996). The EU goal is to get 20% of its energy from renewable energy sources by the year 2020, including renewable sources such as solar, hydro–electric, wind, geothermal energy, and biomass.

Hungary's Renewable Energy Plan has set the target of a 14.65% minimum share of renewable energy in gross final energy consumption by 2020, with more than 60% originating from biomass (Vágvölgyi et al., 2014a). Besides decreasing external energy dependence, further potential benefits of the generation of energy from biomass as a renewable source are widely published in scientific literature (Ericcson & Nilsson, 2006; Blaschke et al., 2013).

The two main tree species for biomass energy generation in Europe are willow and poplar. Willow is more useful in the Northern countries, while the growth region of poplar is more widely extended in Central, Southern and Eastern Europe. Among tree species used in plantations in Hungary, poplar has been shown to have the greatest yield potential (Kovács et al., 2011). Substantial areas of poplar had already been established in the 1960's and 70's, revealing that Hungary has a long tradition of poplar cultivation, as from 1,939 thousand hectares of forested area 6.2% are planted with Euramerican poplar cultivars, and further 4,4% with domestic indigenous poplars. In a European comparison of poplar SRC plantations we are second after Italy (Weitz et al., 2013). Farmers here are attracted to woody energy plantations, with a continuously increasing interest in the management of short rotation coppices.

As high biomass production in short time is the goal of SRCs, high nutrient losses of the soil can be estimated in each case (Paris et al., 2015). Literature sources show the possibility of treatments with wood ash as well as wood ash combined with manure for nutrient addition in plantations (Holzner et al., 2011; Holzner, 2014).

The general aim of this study was to provide scientific data for the use of different tree species and their clones in short rotation coppices in Hungary to obtain best quality and yield in biomass production. Results are reported in terms of species/clone survival rate, stand growth, effects of different fertilization methods, and soil investigation data.

MATERIALS AND METHODS

Experimental set–up and plant material

In May 2011, a 5 ha short rotation coppice (SRC) plantation was established in a nursery of Ipoly Forest cPlc., Dejtár, Hungary (48°02'01.8"N, 19°12'12.6"E). The nursery was established in a former forest compartment in the 1960's, and is still surrounded by forests. The topography of the area is flat with sandy soils. Mottling of oximorphic colors appeared from 80 cm depth, and gleyic color pattern from 100–120 cm, indicating a high groundwater level. The soil type is Eutric Cambisol (IUSS, 2014), which poor in colloids, but this is partly equilibrated by the humus content. The soil contains humus to a depth of 80 cm, but only in low concentrations (1.1–0.2%). The nutrient supply depends mostly on this humus, reaching a medium rate (Járó, 1963). The soil pH (H_2O) is slightly acidic to neutral (pH 5.4–6.5 in 0–25 cm depth).

The plant available P content of the soil is 12.5–17.2 mg 100 g^{-1} through the whole soil profile, implying a weak to medium phosphorus supply. The available K content is 4.2–6.9 mg 100 g^{-1} soil, implying low potassium content.

The altitude above sea level is 150 m, the annual mean temperature is 10.0 °C, the annual precipitation is 650 mm, and the long term groundwater level average is 150–220 cm below soil surface in April.

We used three poplar clones and one willow cultivar, representing the most frequently used trees in Hungary (Vágvölgyi et al., 2014b) – Pannónia poplar (*Populus x euramericana cv. Pannonia*, female) (PAN), Italian AF2 (*Populus x canadensis,* male, 1994, Alasia New Clones) (AF2), Italian Monviso clones (*Populus x generosa X Populus nigra*, female, 1991, Alasia New Clones) (MON) and *Salix alba* ''Dékány'' bred in Hungary.

Literature suggests 5,000–20,000 ha^{-1} planting density (Dickmann, 2006), therefore the planting was made with the usual 25–30 cm cuttings in 3 x 0.5 m initial space (6,660 pcs ha^{-1}). In some plots, we planted approx. 3 m long unrooted pole cuttings in 3 x 1 m space (3,330 pcs ha^{-1}). We configured 60 experimental plots with 4 types of treatments. Each treatment – as in other experiments (Fortier et al., 2010) – has Latin square design with three replicates for each (Fig. 1).

WA+OF AF2 1.	WA+OF MON 2.	WA+OF AF2 PC 3.	WA+OF PAN 4.	WA+OF SAL 5.	OF AF2 6.	OF MON 7.	OF AF2 PC 8.	OF PAN 9.	OF SAL 10.
WA+OF AF2 PC 20.	WA+OF PAN 19.	WA+OF SAL 18.	WA+OF AF2 17.	WA+OF MON 16.	OF AF2 PC 15.	OF PAN 14.	OF SAL 13.	OF AF2 12.	OF MON 11.
WA+OF SAL 21.	WA+OF AF2 22.	WA+OF MON 23.	WA+OF AF2 PC 24.	WA+OF PAN 25.	OF SAL 26.	OF AF2 27.	OF MON 28.	OF AF2 PC 29.	OF PAN 30.
WA AF2 40.	WA MON 39.	WA AF2 PC 38.	WA PAN 37.	WA SAL 36.	C AF2 35.	C MON 34.	C AF2 PC 33.	C PAN 32.	C SAL 31.
WA AF2 PC 41.	WA PAN 42.	WA SAL 43.	WA AF2 44.	WA MON 45.	C AF2 PC 46.	C PAN 47.	C SAL 48.	C AF2 49.	C MON 50.
WA SAL 60.	WA AF2 59.	WA MON 58.	WA AF2 PC 57.	WA PAN 56.	C SAL 55.	C AF2 54.	C MON 53.	C AF2 PC 52.	C PAN 51.

Legend: C: control, WA: wood ash, OF: manure as organic fertilizer, PC: pole cutting, SAL: *Salix alba*, MON: Monviso, PAN: Pannonia

Figure 1. Layout of the experimental design.

The nutrient supply was 5 t ha^{-1} wood ash and 40 t ha^{-1} organic fertilizer which means manure, separately and combined. The application was made by disking, before tree planting.

Measurements and sampling

Survival analyses

After the planting (5–6 May 2011) we conducted the first survival examination on 25–26 May 2011. We sampled 2 lines each per plot, the 4th line from the left or right hand side each.

Soil and plant nutrient analyses

In April 2011, before the establishment of the plantation, a site survey was done. We analyzed the soil by opening 2 soil pits to a depth of 2.2 m, and disturbed soil samples were taken from the profile from each horizon, for a general description of soil types of the research site. We assessed soil nutrient status with disturbed soil samples taken from the upper 30 cm from each plot of all treatments, before planting and treatments were applied. A second soil sampling in the same depth of 0–30 cm for each plot was done one year after the fertilization.

The soil pH was measured potentiometrically in a 1:2.5 mass proportion soil:water suspension. Determination of soil organic matter content was done using the wet combustion method described in FAO (1990) and humus was calculated with a multiplication of organic carbon content by 1.72. Nitrogen contents were determined by Büchi B–426 and B–323 apparatus with titration after sulfuric acid digestion (Bellér, 1997). Determination of ammonium lactate/acetic acid extractable phosphorus (plant available P) is done colorimetrically (Bellér, 1997). Determination of K used the same soil extract as obtained for available phosphorus measurement, and ammonium lactate/acetic acid extractable (plant available) potassium determination was done by flame photometry (Bellér, 1997). For the determination of plant nutrient concentrations from each plot of all treatments, a mixed sample per plot was made from leaves of 3 trees in August 2011. Plant leaf C– and N–contents were measured again in 2013. Plant total nutrient–amount (Ca, Mn, Zn, Cu) analyses from leaves were done after a H_2O_2–HNO_3 total digestion with ICP–measurement (Buzás, 1983).

Altimetry and circumference measurement

The height of trees was measured annually from the first year of the plantation. In the case of the plots planted with short cuttings, height was measured only in the first two growing seasons. In the case of plots with pole cuttings, measurements went on each following year. In addition, in March 2013 (before beginning of third growing season) we measured the height and circumference at the base of each tree which was originally planted as 3 m long unrooted pole. The heights were measured with 5 cm accuracy with a telescopic height gauge.

The circumference measurement was realized in mm precision with a millimeter level accuracy tape measure. Diameter was calculated from the circumference. Measurement was taken each September beginning from the first year of the plantation. In the case of the plots planted with short cuttings, circumference was measured only in the first two growing seasons. In the case of plots with pole cuttings, measurements went on each following year. From 2012, parallel to height measurements, we measured the circumference at the base of all trees planted as pole cuttings.

Dendromass measurement

We used a 25 kg strength, 0.01 kg accurate fish scale for dendromass measurement. For the plots planted with short cuttings, dendromass was measured only in the first two growing seasons. For plots with pole cuttings, measurements went on each following year.

All shoots from the same stump were measured together. In coppice systems, the total mass estimation relies on an estimation function, including stock number and tree parameters. Nine specimens were cut out and measured from each plot originating from short cuttings, and then their average was calculated.

We considered that at the normal planting the initial spacing was 3 x 0.5 m and the number of plants was 6,660 per hectare. From the weight of the nine samples, we calculated the average weight of the plots, and then converted to dry weight assuming 55% moisture content (determined with weight measurements). We report the biomass results in dry (atro–) tons per hectare (t ha^{-1}). In the case of the pole cuttings, beginning from the second vegetation period we measured the weight of poles by thinning 1 3^{-1} of the plots; i.e. thinning of 4 rows each year, beginning from the eastern side of the plot, removing each second tree.

Statistical analyses of the results

Data from the first three vegetation periods were analyzed. The statistical evaluation was performed with Microsoft Excel and STATISTICA 11 software. The goal of the analyses was to make general descriptive statistics and to determine whether there are significant differences between different treatments and between tree varieties. In the analyses, the general descriptive statistics (*t–test*, *F–test*) and one–way analyses of variance (*one–way ANOVA*) were used, specified with the *Duncan's test*. These tests helped to look for significant differences of plant growth due to treatment, tree species and/or planting material.

RESULTS

Soil and plant nutrient analyses

One year after treatment, the average of %N was 0.07. Significant differences were not found between the different treatments (Table 1).

Table 1. Results of soil nutrient analyses, one year after treatment (Mean ± S.E.)

Treatment	N (%)	H (%)	K (mg kg^{-1})	P (mg kg^{-1})
Control	0.07 ± 0.01	1.10 ± 0.08	62.5 ± 4.87	102.7 ± 13.19
WA+OF	0.07 ± 0.01	1.02 ± 0.08	54.1 ± 4.87	163.0* ± 13.19
OF	0.09 ± 0.01	1.14 ± 0.08	56.4 ± 4.87	181.6* ± 13.19
WA	0.07 ± 0.01	1.17 ± 0.08	60.3 ± 4.87	94.0 ± 13.19

Legend: WA: wood ash, OF: manure as organic fertilizer, *: significance at 5% (%N: p = 0.23964, %H: p = 0.59000, K: p = 0.62413, P: p = 0.00001).

In case of the plant available P, the control (9.4) and wood ash (10.2) plots lag behind the fertilized (18.2) and combined (16.3) treatment (Table 2).

Table 2. Plant leaf total–nutrient contents depending on nutrient supply treatment (Mean ± S.E.)

Treatment	N (%) 2011	N (%) 2013	C (%) 2011	C (%) 2013	P (mg kg^{-1}) 2011
Control	2.41 ± 0.18	2.24 ± 0.07	45.17 ± 3.69	42.71 ± 0.20	7,204.97* ± 1,233.27
WA+OF	2.67 ± 0.18	2.23 ± 0.07	44.92 ± 3.69	41.99* ± 0.20	1,3853.44 ± 1,233.27
OF	2.62 ± 0.19	2.06* ± 0.07	44.92 ± 3.41	42.11 ± 0.20	1,6441.16 ± 1,233.27
WA	2.58 ± 0.18	2.28 ± 0.07	39.18 ± 3.69	42.88 ± 0.20	1,1099.55 ± 1,233.27

Treatment	Ca (mg kg^{-1}) 2011	Mn (mg kg^{-1}) 2011	Zn (mg kg^{-1}) 2011	Cu (mg kg^{-1}) 2011
Control	7,897.38 ± 619.15	750,98* ± 107.94	51.36 ± 12.33	5.03 ± 0.41
WA+OF	7,895.30 ± 619.15	705,00* ± 107.94	117.08* ± 12.33	6.19 ± 0.41
OF	8,641.96 ± 619.15	388,38 ± 107.94	96.00 ± 12.33	5.12 ± 0.41
WA	6,589.34* ± 619.15	336,31 ± 107.94	57.87 ± 12.33	6.45* ± 0.41

Legend: WA: wood ash, OF: manure as organic fertilizer, *: significance at 5% (%N 2011: p = 0.76533, %N 2013: p = 0.14907, %C 2011: p = 0.56194, %C 2013: p = 0.00337, P: p = 0.00026, Ca: p = 0.16210, Mn: p = 0.02423, Zn: p = 0.00312, Cu: p = 0.05146).

Plant analyses of total phosphorus showed that the control plots lagged far behind the treated plots; all treated areas showed significantly higher results (Table 2). The amount of total calcium was the smallest in the case of wood ash–treated plots; the highest value was measured in the manure treated block. In the case of the wood ash treatment the total manganese content was more than double of those of that of control. The zinc concentration greatly increased due to the manure treatment, and the highest amount was found in the combined treatment.

In case of plant–%C and –%N, there was no significant difference between treatments in the 2011 measurements, but in 2013, there were considerable differences. In the block fertilized with manure, the %N was markedly lower after two years compared to wood ash plots. Changes of %C after two years were small and not significant.

Survival analyses

In the case of the examination of survival in the first growing season, we evaluated the different clones and the two different varieties of cutting type as well (Table 3).

Table 3. Survival rate of different species (Mean ± S.E.)

	AF2	Monviso	Pannonia	Salix 'Dékány'	AF2 (pole)
Survival (%)	77.65 ± 2.65	92.03 ± 2.65	80.3 ± 2.65	61.76* ± 2.65	96.82 ± 2.65

*: significance at 5%, ($F(4, 55)$=26,681, p = 0.00000).

At the end of the second week the short cutting survival was significantly lower than that of 3 m long AF2 poles. During the first growing season, *Salix alba* 'Dékány' had 100% mortality, due to a longer drought period during summer.

Yield analyses

The results of the pole cuttings were considerably different from the normal cuttings (Szabó, 2016). Height and biomass of AF2 pole cuttings was significantly higher in the combined treatment plots compared to all other plots (Table 4). The diameter of all treated plots was notably higher than that of the control.

Table 4. Yield analyses due to different fertilization treatments of pole cutting plots (Mean ± S.E.)

	Pole cuttings					
Treatment	H 2012 (cm)	d 2012 (cm)	Mass 2012 (dry t ha^{-1})	H 2013 (cm)	d 2013 (cm)	Mass 2013 (dry t ha^{-1})
Control	465.61 ± 13.47	6.91* ± 0.07	5.97* ± 0.16	689.87 ± 10.39	9.73 ± 0.09	13.74 ± 0.39
WA+OF	519.32* ± 12.16	7.26 ± 0.09	9.98* ± 0.25	759.15* ± 12.72	10.34* ± 0.14	16.30* ± 0.59
OF	470.19 ± 13.26	7.29 ± 0.09	7.65 ± 0.21	696.07 ± 10.95	9.61 ± 0.12	14.37 ± 0.51
WA	475.01 ± 7.46	7.24 ± 0.07	7.84 ± 0.17	685.67 ± 13.41	9.82 ± 0.10	13.13 ± 0.41

Legend: H: height, d: diameter, WA: wood ash, OF: manure as organic fertilizer, *: significance at 5% (H 2012: p = 0.00677, d 2012: p = 0.00324, Mass 2012: p = 0.0000, H 2013: p = 0.00013, d 2013: p = 0.00047, Mass 2013: p = 0.00015).

In 2013, i.e. after the third growing season of the plantation, base diameter of combined treated plots was significantly higher compared to all other treatments. At the height measurement, the highest and most significant values came also from the combined treatment.

DISCUSSION

Soil and plant nutrient analyses

Soil pH was mildly acidic before treatment. This made the wood ash additions reasonable due to its well–known alkalizing effect.

A year after the fertilization, measurements showed no significant changes in the soil organic carbon content of the 0–30 cm layer, however values were higher in the manure and in the the combination–treated area compared to the control. Humus contents are altogether low compared with other Hungarian forest soils (Stefanovits et al., 1996). In the case of %N, the nutrient supplied plots showed the highest values. So it can be concluded that due to the manure mineralization, the nutrient concentrations in the soil were raised. The average N value of the soil measured in our experiment is considered as low in comparison with Hungarian forest soils. Taking into account the sandy texture, the amount of AL–K in the soil (5.83) was very low (Bellér, 1997). For AL–P it was clearly shown that after one year, the amount of phosphorus from the manure was not taken up by the plants, possibly it was not mobilized or leached out (Heckrath et al., 1995). The AL–P contents of the wood ash treated and control plots were low (6–10), the fertilized areas were in the good to medium (17–25) category (Buzás, 1983).

Plant leaf analyses strongly showed the fertilization effect in the case of total phosphorus (Table 2). The phosphorus in the topsoil gets rapidly immobilized after the microbial digestion, making it available for the plants. The average nutrient supply of poplars is between 0.18 and 0.30% (Lyr et al., 1992). Based on this, the amount of phosphorus in the plants was sufficient in the control area, and continued to grow with the treatments, reaching the highest rate in the manure treatment block. Lowest amount of total calcium was found in the wood ash treated plots which was still within the optimum range (3,000–15,000 mg kg^{-1}) for plant growth (Lyr et al., 1992). Plants optimal manganese content is 35–150 mg kg^{-1} (Lyr et al., 1992), in our case double the optimum amount was already present prior to treatment, and was further increased with the wood ash treatment. The optimal quantity of copper in the plants is 6–12 mg kg^{-1} (Lyr et al., 1992). This amount was not available in the untreated area, but the wood ash application increased copper contents significantly to the optimal zone. For zinc, the optimal quantity for plants is 15–50 mg kg^{-1} (Lyr et al., 1992). In our case, this amount has already been exceeded prior to treatment but increased values were even significantly higher in the manure and combined treatments. Zinc is normally bound with organic compounds, explaining why the quantity was higher in treated blocks.

According to the literature, the optimum N supply of poplar is between 1.8–2.5% (Lyr et al., 1992). Table 2 shows that total N supply of the plants in the research area is adequate for good growth of the trees. As the amount of N was significantly reduced during the period of 2011–2013, it is expected that additional N fertilization is required to achieve good yield in future. Comparing the treatments, in the beginning the organic fertilized plots utilized N in the most effective way; therefore, the strongest attenuation was detected in that treatment after 2 years.

Survival analyses

During the experiment plots planted with the pole cuttings showed the highest survival rate (Table 3). Treatments didn’t have a significant effect on survival rates of the first year, probably due to the more important role of planting material, as well as a later utilization of added nutrients only. This is probably due to the planting method: approximately 3 m long poles were set to a depth of 100–120 cm and possibly could reach the deeper to the wet soil layers. Another important factor for survival after planting is the high quality of planting material. The planting was preceded by a wet year (918 mm year^{-1}), the soil moisture conditions were favorable, with groundwater partly appearing in the planting holes. High survival rates of pole cuttings show also the good quality of the planting material. Cuttings were soaked in water before planting to store as much water as possible for the period until rooting. As the willow 'Dékány' has a high demand for water, it was not able to cope with the drought and low water holding capacity of the sandy soil. It had a low survival rate, and after the first growing season it disappeared from the area. From the meteorological data it appears that in 2011 the average minimum temperature was slightly lower than usual (4.5 °C), but this didn't effect higher survival rates of the clones AF2 and Monviso, which were selected originally for Italy, where average temperatures are higher than in Hungary. The literature data and nursery descriptions showed that even in extra favorable conditions these varieties are able to produce a 95–100% survival rate (Paris et al., 2011).

There was no significant difference between the different fertilizer treatments in terms of survival rate. In the case of the varieties, the low result of the 'Dékány' willow and the outstanding survival of the Monviso significantly differed from the other varieties.

The treatments were applied a few weeks before planting. The experimental data clearly showed that its effect has not influenced plant growth in the first few weeks. Therefore the extra nutrient amount of the wood ash and manure fertilization was not utilized in a rate which could cause detectable differences in the initial survival of the cuttings. This is consistent with past experience; when cuttings are taking root, the stored nutrients are utilized first, and initially the water supply has the greatest impact on survival.

Compared with other experiments, the survival results (about 85%) give cause for satisfaction (Dillen et al., 2013) and show that it is not uncommon that a variety fails to survive for some reason (Al Afas et al., 2008). According to Kaczmarek et al. (2013), the ability of root initiation may be one of the main factors in survival. In addition, the quality of the propagation material and size can greatly affect the survival and growth.

Yield Tests

Yield data were obtained in the first and second growing season from all plots, in the third growing season only in the pole cutting plots, due to work capacity reasons.

First we analyzed data of all plots (independently from planting material type) together. At the end of the first growing season, the highest values for height and diameter were found in the control plots, so the effects of the fertilization has not yet been reflected in these parameters of the trees. The fertilization had also no significant effect on the biomass production during first year, but the results were still satisfactory, as the literature results were similar (Al Afas et al., 2008). During second growing season, the base diameters showed significantly different (p value) results due to the application of organic manure. In case of plant height, the manure and manure–wood ash treated plots showed the maximum values (Szabó, 2016), the positive impact of organic fertilizer has already been shown, but the wood ash effect is less noticeable. We think that in the nutrient–poor sandy soil, nutrient ratios have also played an important role; probably the low nitrogen accessibility could not be compensated by the addition of wood ash compared to organic fertilizers, so that in this case nitrogen could have been a factor limiting the uptake of other nutrients (Goodmann & Perkins, 1968).

The organic fertilized block showed the highest level of dendromass, followed by the mixture–treated block, control, and the wood ash treatments in the second growing season (Table 4.). This might be due to the positive effects of manure application. The measurement data slightly lagged behind those from the literature (10–14 odt ha^{-1}) (odt=oven dry ton measured after drying by 105 °C till constant weight reached) (Al Afas et al., 2008). From the data we can conclude that the height and the base diameter positively correlated with each other (Vágvölgyi et al., 2014a).

In the case of height for pole cutting plots, the effect of the combined treatment stood out again. The areas treated only with organic or wood ash had nearly equal results to each other, and much lower results were obtained in the control plots. The combined treatment produced significant difference as well. The yield in two years achieved the expected results. The combined treatment was substantially higher than the single treatments and the control area, with the lowest weight results given by the control area. Under these circumstances we conclude that the different methods of fertilization have already shown significant effects in the end of the second growing season. These effects are manifested also in the organic and inorganic treated blocks, only their quantity was lower than by the combined application.

At the end of the third growing period, results obtained in the pole cutting plots reflected the same tendencies as at the end of the second year. In the case of the base diameter, the values of combined fertilization plots had significantly different results compared to all other treatments. The wood ash or manure–fertilized plots didn't show significant differences from each other and from the control. In the case of height, the combined treatment showed a significantly high value again. However, the lowest value was not in the control, but in the wood ash treatment. Similar results were obtained in the analyses of yield after three years. The highest yield was showed by the combined treatment, the lowest was by the wood ash. This can be again a result of the limiting effect of nitrogen due to the low organic content of the soil. We can conclude that for optimal biomass production on poor sandy soils, nutrient addition is crucial, with great emphasis on proper nutrient proportions.

The average annual yield of the plantation was 5 odt ha^{-1} $year^{-1}$. Compared to some experiments, our yield results were slightly lower (Berthelot et al., 2000; Al Afas et al., 2008), conversely to other sources, which presented similar yields (Johansson & Karačić, 2011), or sometimes even lower ones (Laureysens et al., 2004; Walle et al., 2007).

CONCLUSIONS

In our small–scale comparative experiment in Hungary, based on examination of SRC plots established with short cuttings and pole cuttings, Alasia New Clones® Monviso poplar clone showed the best survival rate, while AF2 clone had the highest growth rate, and both performed better AF2 and Monviso poplar clones showed the best survival rate and the highest growth rate, as against the lower yield producing Hungarian Pannonia species or the *Salix alba* 'Dékány' willow clone, which became extinct after the first growing season due to drought occurring in 2011. This is probably related to the different site requirements of the compared clones: the Southern–born poplar clones have a higher temperature demand and better drought tolerance than the willow clone; the latter requires water surplus for the more intense evaporation needed for growth (Guidi et al., 2005). In drought periods, the survival of 2.5–3 m long pole cuttings set down to a depth of ca. 1.2–1.3 meters was more favored than that of short cuttings, which could extend their roots only in the fast drying sandy topsoil that was heated up much more due to sun exposure.

Our fertilization experiment showed that although important nutrients had already been present in optimal amounts from the start of the investigations, their contents were increased due to all treatments. At the end of the second growing season, in the case of pole cuttings the manure + wood ash combined treatment, and in the case of short cuttings the manure treatment resulted in the highest significant biomass yield. Pole cuttings yield tests carried out in the third vegetation period also showed a continuation of this trend. However, plant (leaf) nutrient analyses carried out in the fourth growing season no longer showed a significant effect of the one–off application of fertilizers.

ACKNOWLEDGEMENTS. This study has been supported by the Ipoly Forestry cPlc, Hungary.

REFERENCES

Al Afas, N., Marron, N., Van Dongen, S., Laureysens, I. & Ceulemans, R. 2008. Dynamics of biomass production in a poplar coppice culture over three rotations (11 years). *For. Ecol. Manage* **255**, 1883–1981.

Bellér, P. 1997. *Soil Testing Methods*. University of West–Hungary, Faculty of Foresty, 52–95 pp. (in Hungarian).

Berthelot, A., Ranger, J. & Gelhaye, D. 2000. Nutrient uptake and immobilization in a short-rotation coppice stand of a hybrid poplar in north–west France. *For. Ecol. Manage* **128**, 167–179.

Blaschke, T., Biberacher, M., Gadocha, S. & Schardinger, I. 2013. 'Energy landscapes': Meeting energy demands and human aspirations. *Biomass Bioenergy* **55**, 3–16.

Buzás, I. 1983. *The Handbook of Plant Nutrition.* Mezőgazdasági Kiadó, Budapest, 45–67 pp. (in Hungarian).

Dickmann, D.I. 2006. Silviculture and biology of short–rotation woody crops in temperate regions: Then and now. *Biomass Bioenergy* **30**, 696–705.

Dillen, S.Y., Djomo, S.N., Al Afas, N., Vanbeveren, S. & Ceulemans, R. 2013. Biomass yield and energy balance of a short-rotation prplar coppice with multiple clones on degraded land during 16 years. *Biomass Bioenergy* **56**, 157–165.

Ericcson, K. & Nilsson, L.J. 2006. Assessment of the potential biomass supply in Europe using a resource–focused approach. *Biomass Bioenergy* **30**, 1–15.

European Commission 1996. *Energy for the future: Renewable sources of energy*. COM (96) 576 final (20/11/96).

FAO 1990. *Guidelines for Soil Profile Description*. Third edition (revised). Soil Resources, Management and Conservation Service, Land and Water Development Division. Rome.

Fortier, J., Gagnon, D., Truax, B. & Lambert, F. 2010. Biomass and volume yield after 6 years in multiclonal hybrid poplar riparian buffer strips. *Biomass Bioenergy* **34**, 1028–1040.

Goodman, G. & Perkins, D. 1968. The Role of Mineral Nutrients in Eriophorum Communities: IV. Potassium Supply as a Limiting Factor in an E. Vaginatum Community. *J. Ecol.* **56**(3), 685–696.

Guidi, W., Bonari, E. & Bertolacci, M. 2005. *Water consumption of poplar and willow short rotation forestry used as vegetation filter: Preliminary results*. Integrated Land and Water Resources Management: Towards Sustainable Rural Development, 15–19.

Heckrath, G., Brooks, P.C., Poulton, P.R. & Goulding, K.W.T. 1995. Phosphorous leaching from soils containing different P concentrations in the Broadbalk experiment. *J. Environ. Qual.* **24**, 904–910.

Holzner, H., Obernberger, I., Berger, T., Danzer, M., Humer, J., Jurik, P., et al. 2011. Richtlinie für den sachgerechten Einsatz von Pflanzenaschen zur Verwertung auf land- und forstwirtschaftlich genutzen Flächen. 66. Wien, Österreich: Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft.

Holzner, H. 2014. *Nährstoffrücklieferung aus Holzasche zu Energieweiden und -pappeln im Kurzumtrieb. Central European Biomass Conference*, Graz, Austria, 65 pp.

IUSS Working Group WRB 2014. *World Reference Base for Soil Resources 2014. International soil classification system for naming soils and creating legends for soil maps.* World Soil Resources Report No. 106. FAO. Rome.

Járó, Z. 1963. *Soil Types.* Országos Erdészeti Főigazgatóság, Budapest, 36–38 pp. (in Hungarian).

Johansson, T. & Karačić, A. 2011. Increment and biomass in hybrid poplar and some practical implications. *Biomass Bioenergy* **35**, 1925–1934.

Kaczmarek, D.J., Coyle, D.R. & Coleman, M.D. 2013. Survival and growth of a range of Populus clones in central South Carolina USA through age ten: Do early assessments reflect longer-term survival and growth trends? *Biomass Bioenergy* **49**, 260–272.

Kovács, G., Magyari, Cs., Heil, B. & Győri, T. 2011. *Standortverhältnisse und Wuchsleistungen von Energieholzplantagen in Ungarn. Central European Biomass Conference*, Graz, Austria, 123 pp.

Laureysens, I., Bogaert, J., Blust, R. & Ceulemans, R. 2004. Biomass production of 17 poplar clones in a short–rotation coppice culture on a waste disposal site and its relation to soil charasteristics. *For. Ecol. Manage* **187**, 295–309.

Lyr, H., Fiedler, H.J. & Tranquillini, W., 1992. *Physiologie und Ökologie der Gehölze*. Gustav Fischer Verlag, Jena, Stuttgart.

Paris, P., Mareschi, L., Sabatti, M., Pisanelli, A., Ecosse, A., Nardin, F. & Scarascia-Mugnozza, G. 2011. Comparing hybrid Populus clones for SRF across northern Italy after two biennial rotations: Survival, growth and yield. *Biomass Bioenergy* **35**, 1524–1532.

Paris, P., Mareschi, L., Sabatti, M., Tosi, L. & Scarascia–Mugnozza, G. 2015. Nitrogen removal and its determinants in hybrid Populus clones for bioenergy plantations after two biennial rotations in two temperate sites in northern Italy. *iForest* **8**, 668–676.

Szabó, O. 2016. *Nutrient supply with natural materials in short rotation coppice.* Doctoral thesis, University of West–Hungary, Hungary (in Hungarian).

Stefanovits, P., Filep, Gy. & Füleky, Gy. 1996. *Soil Science*. Mezőgazda Kiadó, Budapest, Hungary, 169–187 pp. (in Hungarian).

Vágvölgyi, A., Heil, B. & Kovács, G. 2014a. *Development trends of woody energy plantations in Hungary. Central European Biomass Conference*, Graz, Austria, 149 pp.

Vágvölgyi, A. 2014b. *Woody energy crops development tendencies in Hungary.* Doctoral thesis, University of West–Hungary, Hungary (in Hungarian).

Walle, I.V., Van Camp, N., Van de Casteele, L., Verheyen, K. & Lemeur, R. 2007. Short–rotation forestry of birch, maple, poplar and willow in Flanders (Belgium) I – Biomass production after 4 years of tree growth. *Biomass Bioenergy* **31**, 267–275.

Weitz, M., Klippel, C. & Peschel, T. 2013. Energieholzplantagen. (Germany), Lignovis GmbH, 22–23.

INSTRUCTIONS TO AUTHORS

Papers must be in English (British spelling). English will be revised by a proofreader, but authors are strongly urged to have their manuscripts reviewed linguistically prior to submission. Contributions should be sent electronically. Papers are considered by referees before acceptance. The manuscript should follow the instructions below.

Structure: Title, Authors (initials & surname; an asterisk indicates the corresponding author), Authors' affiliation with postal address (each on a separate line) and e-mail of the corresponding author, Abstract (up to 250 words), Key words (not repeating words in the title), Introduction, Materials and methods, Results and discussion, Conclusions, Acknowledgements (optional), References.

Layout, page size and font

- Use preferably the latest version of **Microsoft Word**, doc., docx. format.
- Set page size to **B5 Envelope or ISO B5 (17.6 x 25 cm)**, all margins at 2 cm.
- Use single line spacing and justify the text. Do not use page numbering. Use indent 0.8 cm (do not use tab or spaces instead).
- Use font Times New Roman, point size for the title of article **14 (Bold)**, author's names 12, core text 11; Abstract, Key words, Acknowledgements, References, tables and figure captions 10.
- Use *italics* for Latin biological names, mathematical variables and statistical terms.
- Use single ('…') instead of double quotation marks ("…").

Tables

- All tables must be referred to in the text (Table 1; Tables 1, 3; Tables 2–3).
- Use font Times New Roman, regular, 10 pt. Insert tables by Word's 'Insert' menu.
- Do not use vertical lines as dividers; only horizontal lines (1/2 pt) are allowed. Primary column and row headings should start with an initial capital.

Figures

- All figures must be referred to in the text (Fig. 1; Fig. 1 A; Figs 1, 3; Figs 1–3). Use only black and white or greyscale for figures. Avoid 3D charts, background shading, gridlines and excessive symbols. Use font **Arial** within the figures. Make sure that thickness of the lines is greater than 0.3 pt.
- Do not put caption in the frame of the figure.
- The preferred graphic format is EPS; for half-tones please use TIFF. MS Office files are also acceptable. Please include these files in your submission.
- Check and double-check spelling in figures and graphs. Proof-readers may not be able to change mistakes in a different program.

References

- **Within the text**

In case of two authors, use '&', if more than two authors, provide first author 'et al.':

Smith & Jones (1996); (Smith & Jones, 1996);
Brown et al. (1997); (Brown et al., 1997)

When referring to more than one publication, arrange them by following keys: 1. year of publication (ascending), 2. alphabetical order for the same year of publication:

(Smith & Jones, 1996; Brown et al., 1997; Adams, 1998; Smith, 1998)

- **For whole books**

Name(s) and initials of the author(s). Year of publication. *Title of the book* (*in italics*). Publisher, place of publication, number of pages.

Shiyatov, S.G. 1986. *Dendrochronology of the upper timberline in the Urals*. Nauka, Moscow, 350 pp. (in Russian).

- **For articles in a journal**

Name(s) and initials of the author(s). Year of publication. Title of the article. *Abbreviated journal title* (*in italic*) volume (in bold), page numbers.

Titles of papers published in languages other than English, German, French, Italian, Spanish, and Portuguese should be replaced by an English translation, with an explanatory note at the end, e.g., (in Russian, English abstr.).

Karube, I. & Tamiyra, M.Y. 1987. Biosensors for environmental control. *Pure Appl. Chem.* **59**, 545–554.

Frey, R. 1958. Zur Kenntnis der Diptera brachycera p.p. der Kapverdischen Inseln. *Commentat.Biol.* **18**(4), 1–61.

Danielyan, S.G. & Nabaldiyan, K.M. 1971. The causal agents of meloids in bees. *Veterinariya* **8**, 64–65 (in Russian).

- **For articles in collections:**

Name(s) and initials of the author(s). Year of publication. Title of the article. Name(s) and initials of the editor(s) (preceded by In:) *Title of the collection (in italics)*, publisher, place of publication, page numbers.

Yurtsev, B.A., Tolmachev, A.I. & Rebristaya, O.V. 1978. The floristic delimitation and subdivisions of the Arctic. In: Yurtsev, B. A. (ed.) *The Arctic Floristic Region*. Nauka, Leningrad, pp. 9–104 (in Russian).

- **For conference proceedings:**

Name(s) and initials of the author(s). Year of publication. Name(s) and initials of the editor(s) (preceded by In:) *Proceedings name (in italics)*, publisher, place of publishing, page numbers.

Ritchie, M.E. & Olff, H. 1999. Herbivore diversity and plant dynamics: compensatory and additive effects. In: Olff, H., Brown, V.K. & Drent R.H. (eds) *Herbivores between plants and predators. Proc. Int. Conf. The 38th Symposium of the British Ecological Society*, Blackwell Science, Oxford, UK, pp. 175–204.

....………

Please note

- Use '.' (not ',') for decimal point: 0.6 ± 0.2; Use ',' for thousands – 1,230.4;
- Use '–' (not '-') and without space: pp. 27–36, 1998–2000, 4–6 min, 3–5 kg
- With spaces: 5 h, 5 kg, 5 m, 5°C, C : D = 0.6 ± 0.2; p < 0.001
- Without space: 55°, 5% (not 55 °, 5 %)
- Use 'kg ha^{-1}' (not 'kg/ha');
- Use degree sign ' ° ' : 5 °C (not 5 ^{O} C).