1 • XXXI • 2020, p-ISSN 1024-0845, e-ISSN 2228-4893

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AGRAARTEADUS

JOURNAL OF AGRICULTURAL SCIENCE

Akadeemilise Põllumajanduse Seltsi väljaanne
Estonian Academic Agricultural Society publication
Tartu 2020

Agraarteadus
Journal of
Agricultural Science

Vol. **31** No. 1
June 2020

Abstracted / indexed: AGRICOLA, AGRIS, CABI, CABI Full Text, DOAJ, EBSCO, SCOPUS

p-ISSN: 1024-0845, **e-ISSN:** 2228-4893

Väljaandmist toetab Eesti Maaülikool / Supported by Estonian University of Life Sciences

Trükk / Print: Eesti Ülikoolide Kirjastus OÜ. Kaanepilt / Cover image by macrovector / Freepik

AGRAARTEADUS
JOURNAL OF AGRICULTURAL SCIENCE

1 ◆ XXXI ◆ 2020

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Agraarteaduses avaldatud teaduspublikatsioonid on retsenseeritud

SISUKORD

AGRAARTEADUS
JOURNAL OF AGRICULTURAL SCIENCE

1 ◆ XXXI ◆ 2020

Published by:	Estonian Academic Agricultural Society
Editor in Chief:	Alo Tänavots DSc (agriculture)
Technical Editor:	Irje Nutt MSc (animal science)
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Research articles published in Agraarteadus are peer-reviewed

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AGRAARTEADUS – 30

Seoses Akadeemilise Põllumajanduse Seltsi taastamisega 4. aprillil 1989. a tõstatus ka küsimus seltsi kirjastustegevusest. Juba seltsi volikogu esimesel koosolekul tõdeti oma akadeemilise põllumajandusalase ajakirja väljaandmise vajalikkust sarnaselt omaaegsele väljaandele "Agronoomia" (ilmus aastal 1921–1940). Eestseisuse koosolekul moodustatigi "Agraarteaduse" toimetuskolleegium ja peatoimetajaks määrati professor Ülo Oll. 19. veebruaril 1990 ilmunud avanumbri eessõnas kirjutab toonane seltsi president professor Olev Saveli, et väljaandest kujuneb sõltumatu ajakiri põllumajandusteadlastele, olles operatiivne info vahendaja teaduse ja praktika vahel.

Esialgu kujundasid "Agraarteaduse" näo seltsi liikmed, kuid raudse eesriide avanedes hakkasid teadlased suunama oma pilku piiri taha. Osaliselt sundis selleks ka riiklik teaduspoliitika. Seoses sellega on ajakiri läbi teinud mitmeid muudatusi, et suurendada oma usaldusväärsust ja tõsta nähtavust ka välismaal. Mitmel korral seati teaduspoliitika kujundajate poolt kahtluse alla ajakirja tõsiseltvõetavus. Viimane mobiliseeris nii ajakirja toimetust kui seltsi eestseisust. Suuremate muudatuste initsiaatoriks saab lugeda PhD Brian Lassenit (täna Kopenhaageni Ülikoolis), kes soovis ajakirja kujundada selliselt, et see vastaks COPEi (*Committee on Publication Ethics*) ja Elsivieri nõuetele. Selles tegevuses lõid innukalt kaasa hilisem seltsi president ja toonane toimetuse sekretär PhD Marko Kass, toimetuse liige PhD David Arney ning tolleaegne peatoimetaja pm-dr Maarika Alaru ja hilisem pm-dr Alo Tänavots. Ettevõetud jõupingutusi kroonis edu, kui pärast 1,5 aastast põhjalikku hindamist pidas 2018. aastal Elsivier B.V. "Agraarteaduse" taset nii kõrgeks, et indekseerida ajakirja artikleid oma andmebaasis SCOPUS.

Ehkki "Agraarteadus" oli algselt suunatud seltsi liikmetele, kes said oma teadustöö tulemusi ajakirjas avaldada, siis praeguseks laekub valdav osa käsikirjadest siiski välismaalt. Seoses sellega on tahaplaanile jäänud ka ajakirjale pandud teine ülesanne – emakeelse teaduskeele terminoloogia arendamine. Siinkohal sooviksingi kutsuda üles teadlasi kirjutama artikleid ka emakeeles, eriti teemadel, mil on suur kohalik tähtsus ja mis võiks äratada huvi ka kohalikes edumeelsetes põllumeestes.

"Agraarteaduse" peatoimetajateks on olnud lisaks professor Ü. Ollile olnud ka pm-dr Aleksander Lember (1997–2006) ja pm-dr Maarika Alaru (2007–2014). Alates 2015. a on teadusajakirja vastutusrikkas töö pm-dr Alo Tänavotsa õlgadel. Kokku on ajakirja 30-aastase ajaloo vältel ilmunud 95 numbrit, kus on artikleid ligi paarkümne riigi teadlaste sulest.

Õnnitlused kogu toimetusele ja suur tänu autoritele ning retsensentidele!

Pm-dr Alo Tänavots, peatoimetaja
PhD Marko Kass, APSi president

AGRAARTEADUS | JOURNAL OF AGRICULTURAL SCIENCES – 30

During the re-establishment meeting of the Estonian Academic Agricultural Society on April 4th, 1989, the issue of the publishing engagement of the society was raised. At the first meeting of the Council of the Society, the necessity of academic publishing duties was acknowledged, highlighting the publishing of the former journal of the society called "Agronoomia" (Estonian Journal of Agricultural Science, published from 1921–1940). Following the society's board meeting the editorial board of the journal was formed, and Professor Ülo Oll was appointed editor-in-chief. In the preface to the opening issue, on February 19th 1990, the president of the society, Professor Olev Saveli, declared that Agraarteadus would be an independent journal for researchers in agricultural disciplines, acting as a direct intermediate between science and practice.

Initially, the content of the Agraarteadus was provided by the members of the society. But as the Iron Curtain had fallen at the time, researchers began to look for publishing opportunities beyond the borders. This was partly forced by the policy of national research institutions. In this regard, the journal has made a number of improvements to increase its credibility and visibility, both here and abroad. The credibility of the journal was repeatedly questioned by research policy makers. The latter mobilized both the editorial board of the journal and the board of the society to further actions. One of the initiators of major changes was Brian Lassen, PhD (today at the University of Copenhagen), who called for actions to meet the requirements of COPE (Committee on Publication Ethics) and Elsevier. Editorial secretary Marko Kass, members of editorial board Professor David Arney and Maarika Alaru, PhD (editor-in-chief at the time), and later Alo Tänavots, PhD were enthusiastically engaged in order to bring the journal to the next level. The huge efforts made were crowned with success after one and half years of a tough evaluation process by Elsevier B.V. who confirmed in 2018 that "Agraarteadus" was accepted for inclusion in SCOPUS.

Although, the journal was originally aimed for the members of society to publish their research, today the majority of manuscripts submitted come from abroad. In connection with this, the second objective of the journal – the development of scientific terminology in Estonian – has been left aside. Therefore, we would like to call on researchers to submit papers in their mother tongue, especially on topics that are of great local importance and which could be of interest to local progressive farmers.

After Professor Ü. Oll, the editor-in-chief of the journal was Aleksander Lember, PhD from 1997–2006 and Maarika Alaru, PhD from 2007–2014. Since 2015, the governance of the journal's editorial board has been laid on the shoulders of Alo Tänavots, PhD. The journal has published 95 issues with numerous numbers of articles during its 30-year history, featuring papers by researchers from nearly twenty countries.

Congratulations to the editorial board and many thanks to the authors and reviewers!

Alo Tänavots, Editor-in-Chief
Marko Kass, President of Estonian Academic Agricultural Society

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A STUDY OF THE INTERACTION BETWEEN SOIL AND THE PNEUMATIC WHEELS OF AGRICULTURAL GANTRY SYSTEMS

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Saabunud: Received: 08.02.2020
Aktsepteeritud: Accepted: 05.03.2020

Avaldatud veebis: Published online: 07.03.2020

Vastutav autor: Corresponding author: Jüri Olt
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Keywords: efficiency factor, gantry machine, tyre width and diameter, wheeled agricultural system.

DOI: 10.15159/jas.20.03

ABSTRACT. At the stage at which agricultural gantry systems are being designed, developed, and studied, the question of a rational choice of tyres for such systems is relevant, as tyres are the most important part of an agricultural gantry system and have a significant effect on most of its operating properties. The methods that can be used for choosing tyres for traditional mobile-powered equipment are already well established by scientific experience, but the movement of agricultural gantry systems in permanent artificial tracks creates somewhat different conditions and demands for a pneumatic tyre when compared to a traditional tractor moving along agricultural soil. This is why the development of methods that will assist in finding rational parameters for the pneumatic tyres of agricultural gantry systems that are moving along compacted soil in permanent artificial tracks is an urgent and relevant task. The purpose of the study is to optimise the parameters for the tyres of agricultural gantry systems in terms of their being able to travel on compacted soil in permanent artificial tracks. Theoretical studies and the synthesis of the parameters for a pneumatic wheel to work with an agricultural gantry system took place by modelling on a PC the performance conditions of such a vehicle. The basis for the study methods was formed by the fundamentals of tractor theory and theoretical mechanics, using the software program Mathcad. The traction factor of an agricultural gantry system's pneumatic wheel was used as the performance criterion for the effectiveness of the work being done by the wheel. The physical object of study was an agricultural system that has been developed by us. As a result of the study, it was determined that the solving of the task that has been set out - using an analysis of partial derivates of the function of the efficiency of an agricultural gantry system's wheel – makes it possible to quickly and effectively determine the rational optimum points for its pneumatic tyre's parameters. It was determined that, for the agricultural gantry system at hand, and in view of the maximum efficiency of its pneumatic wheel, the wheel's tyre width[4] must be within the range of 0.20–0.30 m and its diameter must be within the range of 0.90–1.25 m. With those ranges, it is recommended that the tyre's inflation pressure be increased from 100 kPa to 160 kPa because the partial derivates of the function of the efficiency at those parameters would decrease to near zero. It has been proven that the choice of tyre type for agricultural gantry systems should be based first on the choice of its width and then its load-bearing capacity – its diameter. The proposed methods for finding rational parameters for pneumatic wheels make it possible to determine the tyre parameters for all kinds of agricultural gantry systems which will be required to travel on compacted soil in permanent artificial tracks. For the agricultural gantry system that has been developed by us, using tyres of the 9.5R32 type provides the highest levels of efficiency, *i.e.* at a factor of 0.86.

Introduction

The quick global development of wheeled agricultural systems (Blackwell *et al*., 2004; Gil-Sierra *et al*., 2007; Tullberg *et al*., 2007; Onal, 2012; Bindi *et al*., 2013; Chamen, 2015; Bulgakov *et al*., 2018a) clearly indicates a wide range of applications when it comes to using agricultural gantry systems (Webb *et al*., 2004; Pedersen, 2011; Bochtis *et al*., 2010; Pedersen *et al*., 2013, 2016; Bulgokov *et al*., 2017, 2019a) as a single powered module travelling along compacted trails that are formed by permanent artificial tracks. The latter's natural meaning is determined by the results shown in solving the fundamental contradiction in the system of "chassis-soil", *i.e*. that in order to achieve high traction performance the chassis has to be in contact with a dry, compacted soil surface but, in order to grow normally, crop plants need optimum moisture levels and uncompacted soil. In practice, these requirements can be met simultaneously only when setting clear borders between the travelling areas for powered equipment (the field's technological zone) and the growth areas for plants (the field's agricultural zone).

The movement of agricultural gantry systems along permanent artificial tracks creates somewhat different conditions and demands for a pneumatic tyre when compared to a traditional tractor that has agricultural soil beneath its wheels. This means that one of the requirements for the parameters of artificial tracks (Nadykto, Uleksin, 2008) is their sufficient compaction, ensuring the improvement of traction and operating performance for agricultural gantry systems that have to move along such tracks. As a result, any established normative limitations on the effect on the soil of chassis systems can be ignored with the area of artificial tracks. On the other hand, it has been established (Bulgakov *et al*., 2018b) that the wheel width of agricultural systems must be as small as possible. This reduces the amount of the field that is lost to the technological zone.

Tyres are the most important part of an agricultural gantry system. When interacting with the compacted ground surface of permanent artificial tracks, they have a significant effect on most of the agricultural gantry system's operating properties: its travel safety levels, traction and speed, travel performance over a rough surface, load-bearing capacity, stability, controllability, riding comfort, riding smoothness, and fuel economy levels (Bulgakov *et al*., 2019b). Therefore, at the design, development, and study stage for any agricultural gantry system, the question of a rational choice of tyres is relevant for such systems.

The methods used for choosing tyres for traditional powered mobile equipment have been well established through scientific experience (Guskov, 1996; Bulgakov *et al*., 2016). In light of being able to achieve the best levels of traction performance for powered equipment, the optimal tyre dimensions and tyre pressure must ensure the highest levels of performance by the pneumatic wheel at the specified load.

Those questions that relate to studying the traction properties of wheeled machinery are discussed in Panchenko, Kyurchev, 2008; Adamchuk *et al*., 2016, 2018). It must be noted that, for machinery as a whole, the established way of assessing traction properties and dynamic qualities is to use the efficiency factor and dynamic factor of the means of traction in question (Bulgakov *et al*., 2017). On the other hand, each wheel of an agricultural gantry system functions in individual conditions in terms of its vertical load, torque, and travelling conditions.

The traction properties of agricultural gantry systems depend upon a number of parameters. These include its structural parameters on the one hand and the physical and mechanical properties of the surface of any permanent artificial tracks on the other.

The classic theory regarding wheeled equipment states (Kutkov, 2014) that an increase in tyre size (the outer diameter and width) increases the powered equipment's traction properties upon an identical vertical load on the tyre. As the force countering the machine's rolling diminishes while the soil is in the process of being compacted as it is compressed by the moving equipment, the traction effect of power increases because the tyre's area that is in contact with the ground becomes greater. Moreover, its travel performance also improves (the chassis' specific pressure on the soil decreases and the ground clearance increases). Simultaneously, an increase of the tyre's dimensions (with the same vertical load upon it) leads to its higher levels of cost and the weight on the powered equipment. Rationally-chosen tyres, in terms of their diameter, width, and internal pressure, making it possible to achieve the highest levels of efficiency for the wheel in question.

The aim of this study was to optimise the parameters for the tyres on the chassis of an agricultural gantry system when travelling along the compacted ground surface of permanent artificial tracks.

Material and Methods

Theoretical studies regarding the pneumatic wheel of an agricultural gantry system, and the synthesis of the parameters involved, took place by modelling on a PC the conditions of its performance. The basis for the study methods were the fundamentals involved in tractor theory and theoretical mechanics (Popp, Schiehler, 2010; Rajamani, 2012), using the Mathcad software program.

The physical object of the study was an agricultural system that had been developed by us (Fig. 1). Its chassis consists of a frame to which wheels with pneumatic tyres of the 9.5R32 size are attached via four semi-axles.

The traction factor η_k of the agricultural gantry system's pneumatic wheel was used as the performance criterion for the effectiveness of the work being done by the wheel, being calculated from a known relation (Kutkov, 2014):

$$\eta_k = (1 - \delta) \cdot [1 - \frac{F_r}{F_k}], \qquad (1)$$

where:

δ – the spin factor of the wheels;

F_r – the rolling resistance of the pneumatic wheel;

F_k – the contact traction force created by the pneumatic wheel.

Figure 1. The agricultural gantry system used for experimental studies on the work of its pneumatic wheels.

According to the task that had been set out, *i.e.* to select the optimal parameters for pneumatic tyres on the wheels of agricultural gantry systems under conditions of a constant vertical load upon them (G_N = const), a compromise solution has to be found by solving the following equation:

$$\frac{\partial \eta_k}{\partial (D_0, b_0, p_w)} \to 0, \qquad (2)$$

where:

D_0 – static diameter of the tyre;
b_0 – width of the tyre;
p_w – internal pressure of the tyre.

Seeking an extreme of the tyre's parameters by way of solving the partial derivates Eq. 2 of its efficiency upon a constant load upon the tyre enables to determine the tyre's minimum width, b_0, its optimal diameter, D_0, and the internal pressure, p_w, upon which the value of η_k is the highest.

Results and Discussion

So that the theoretical studies could be carried out, the wheeled chassis of the agricultural gantry system is taken to be mobile along a horizontal, compacted, and deformable surface which is made up of permanent artificial tracks and is represented by an equivalent diagram indicating the forces affecting it (Fig. 2).

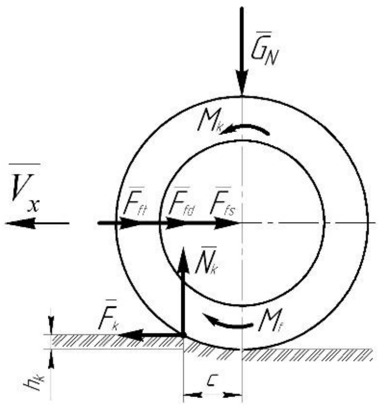

Figure 2. Equivalent diagram of the agricultural gantry system's pneumatic wheeled chassis

In a situation which involves uniform rolling of the agricultural gantry system's elastic tyre on a horizontal deformable surface and on permanent artificial tracks, the energy transferred to the wheel does three types of work that, all together, make up the total energy of rolling resistance on the wheel: further vertical compaction of the soil; elastic deformation of the soil causing internal friction in the tyre; friction of the tyre's tread against the ground's surface at the point of contact.

In that respect, the equation for the balance of the forces of the wheel's rolling resistance can be described as follows:

$$\mathrm{F_r} = F_{fs} + F_{fd} + F_{ft}, \qquad (3)$$

where:

F_{fs}, F_{fd}, F_{ft} – the forces of the wheel's rolling resistance, caused by the soil's vertical compaction, the tyre's internal friction, and the tyre tread's friction against the soil, respectively.

Viewing the indicated forces according to the methodology used (Guskov, 2007) makes it possible to determine the gross dependence Eq. 3 via parameters that define it as follows:

$$F_r = k_0 \cdot b_0 \cdot h_k^2 + k_r \cdot G_N \left(\frac{h_r}{D_0}\right)^{\frac{1}{3}} + \frac{2\mu_p \cdot G_N \cdot k_s \cdot h_r}{3D_0} \qquad (4)$$

where:

k_0 – the soil's compaction factor by volume, N·m$^{3-1}$;
h_k – the track's depth, m;
k_r – a dimensionless factor which is dependant upon the tyre's material, the structure of its body, and other circumstances;
h_r – the tyre's normal deformation (sag), m;
μ_p – the tyre tread's factor of friction against the ground's surface (soil);
k_s – the cinematic factor, taking into account the tyre's shape and the rotating plane's angle to the ground's surface (the soil);
G_N – load upon the tyre.

To be able to determine the value of h_r in terms of the tyre's normal deformation (sag), the following equation is used (Guskov, 1996):

$$h_r = \frac{G_N}{\pi \cdot p_w (D_0 \cdot b_0)^{\frac{1}{2}}}. \qquad (5)$$

To find the value of h_k *i.e.* the depth of the track formed by further deformation of the soil by the surface of the agricultural gantry system's wheel is determined from the following empirical equation (Nadykto, Uleksin, 2008):

$$h_k = \frac{0.01 \cdot p_w - 0.0002 \cdot H}{\rho \cdot g} + 4.655 \frac{G_N \cdot \rho \cdot g}{p_w^2}, \qquad (6)$$

where:

ρ – the soil's density, kg·m$^{3-1}$;
g – the gravitational acceleration, m·s$^{2-1}$;
H – the soil's harness, Pa.

The maximum contact traction force F_k that is generated by the agricultural gantry system's pneumatic wheel can be determined from the condition of its sufficient traction on the soil. Based on that condition, the contact traction force F_k depends upon the traction factor ψ and on the load G_N being applied to it (Kutkov, 2014):

$$F_k = \psi \cdot G_N, \qquad (7)$$

where:

ψ – the factor of traction for the pneumatic wheel on the ground's surface where permanent artificial tracks are being used.

After substituting Eqs. 4–7 into Eq. 1 and carrying out a number of mathematical transformations, we achieve an equation that relates to the pneumatic wheel's efficiency η_k to its parameters and the soil's properties:

$$\eta_k = (1-\delta)\cdot\left[1 - k_0\cdot b_0\left(\frac{0.01\cdot p_w - 0.0002\cdot H}{\rho\cdot g} + 4.655\,\frac{G_N\cdot\rho\cdot g}{p_w^2}\right)^2\cdot(\psi\cdot G_N)^{-1} - \frac{k_r\cdot G_N^{\frac{1}{3}}}{\psi(\pi\cdot p_w)^{\frac{1}{3}}\cdot D_0^{\frac{1}{2}}\cdot b_0^{\frac{1}{6}}} - \right.$$
$$\left. - \frac{\mu_p\cdot k_s\cdot G_N}{3\psi\cdot\pi\cdot p_w\cdot b_0^{\frac{1}{2}}\cdot D_0^{\frac{3}{2}}}\right]. \qquad (8)$$

Partial derivative equations (8) for all three of the tyre parameters being studied upon a constant load are as follows:

$$\frac{\partial\eta_k}{\partial D_0} = \frac{(1-\delta)}{2}\cdot\left(\frac{A'_5}{p_w^{\frac{1}{3}}\cdot D_0^{\frac{3}{2}}\cdot b_0^{\frac{1}{6}}} + \frac{3A'_6}{p_w\cdot D_0^{\frac{5}{2}}\cdot b_0^{\frac{1}{2}}}\right), \qquad (9)$$

$$\frac{\partial\eta_k}{\partial b_0} = (1-\delta)\cdot\left[-A'_1\left(A'_2\cdot p_w - A'_3 + \frac{A'_4}{p_w^2}\right)^2 + \frac{A'_5}{3p_w^{\frac{1}{3}}\cdot D_0^{\frac{1}{2}}\cdot b_0^{\frac{7}{3}}} + \frac{A'_6}{p_w\cdot D_0^{\frac{3}{2}}\cdot b_0^{\frac{3}{2}}}\right], \qquad (10)$$

$$\frac{\partial\eta_k}{\partial p_w} = (1-\delta)\cdot\left(-2A'_1\cdot A'^2_2\cdot p_w + \frac{2A'_1\cdot A'_2\cdot A'_4 + A'_1\cdot A'^2_4}{p_w^2} + \frac{A'_5}{3D_0^{\frac{1}{2}}\cdot b_0^{\frac{1}{3}}\cdot p_w^{\frac{4}{3}}} + \frac{A'_6}{D_0^{\frac{3}{2}}\cdot b_0^{\frac{1}{2}}\cdot p_w^2}\right), \qquad (11)$$

where

$$A'_1 = \frac{k_0}{\psi\cdot G_N};\ A'_2 = \frac{0.01}{\rho\cdot g};\ A'_3 = \frac{0.0002H}{\rho\cdot g};\ A'_4 = 4.655\cdot G_N\cdot\rho\cdot g;\ A'_5 = \frac{k_r\cdot G_N^{\frac{1}{3}}}{\psi(\pi)^{\frac{1}{3}}};\ A'_6 = \frac{\mu_p\cdot k_s\cdot G_N}{3\cdot\psi\cdot\pi}.$$

A further solution for the compromise task Eq. 2 for this agricultural gantry system indicated that, in searching for the extremes of the first area of equations Eqs. 9–11 for the parameters D_0, b_0 and p_w, the latter will reach towards infinity (Fig. 3).

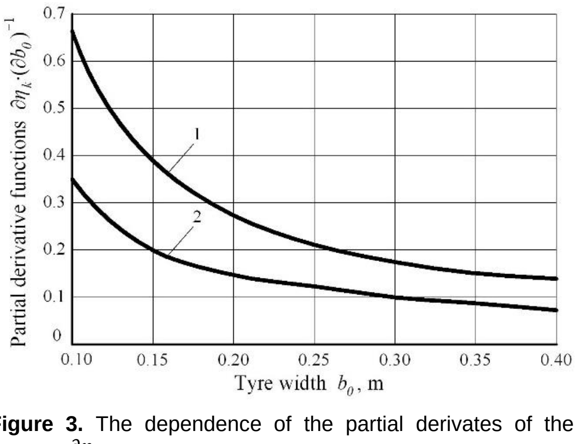

Figure 3. The dependence of the partial derivates of the function $\frac{\partial\eta_k}{\partial b_0}$ in terms of the efficiency of the agricultural gantry system's wheel on its width b_0 while G_N = const: 1) D_0 = 0.6 m, p_w = 100 kPa; 2) D_0 = 1.2 m, p_w = 160 kPa

The nature of the function of the created dependency (see Fig. 3) provides for two characteristic zones of intensive dynamics from its argument. As a rule, such graphs have points of rational optimum. By using the methodology (Nadykto, Velichko, 2014) of searching for the optimum of this type graph, it was determined that the zone of the tyre's rational width b_0 is in the range of 0.20–0.30 m. With that result having been determined, it is recommended that the tyre's internal pressure p_w be increased from 100 kPa to 160 kPa because the partial derivate of the function $\frac{\partial\eta_k}{\partial b_0}$ would then decrease to near zero. On the basis of this analysis, it can be concluded that when the stated conditions of use can be met for the agricultural gantry system, the width of its tyres must be at least 0.20 m to maximise the highest possible levels of efficiency for the tyres.

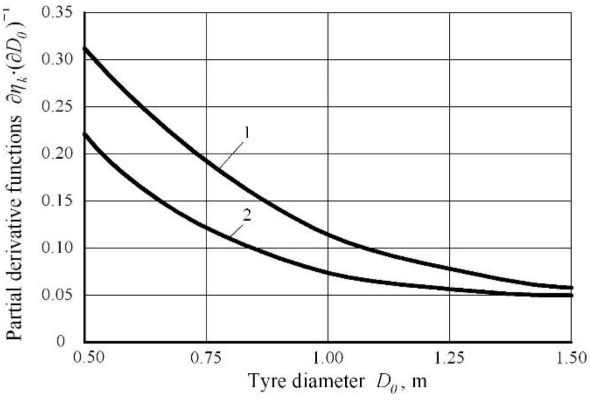

Figure 4. The dependence of the partial derivates of the function $\frac{\partial\eta_k}{\partial D_0}$ of the efficiency of the agricultural gantry system's wheels on its tyre diameter D_0 at G_N = const: 1) b_0 = 0.20 m, p_w = 100 kPa; 2) b_0 = 0.30 m, p_w = 160 kPa.

For the indicated values of the zones of rational optimum for the parameter b_0, a graphical dependency of the partial derivative of $\frac{\partial \eta_k}{\partial D_0}$ on D_0 was plotted (see Fig. 4). The nature of that dependency is similar to that for Fig. 3. Its analysis indicated that the zone of rational optimum for D_0 falls within the range of 0.90–1.25 m. With this as with the previous area, it is also recommended that the tyre's internal pressure p_w be increased from 100 kPa to 160 kPa because of the partial derivates of the function $\frac{\partial \eta_k}{\partial D_0}$ would then decrease to near zero. Therefore, under the stated conditions of use for the agricultural gantry system, the diameter of its tyres must be at least 1.20 m, which will maximise the levels of efficiency of the tyres.

The results yielded when searching for rational parameters for the wheel tyres of an agricultural gantry system have been confirmed by the results shown in plotting the dependencies of the efficiency of its wheels (Fig. 5).

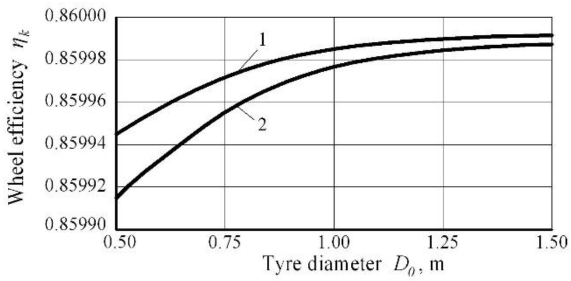

Figure 5. The dependence of the efficiency η_k of the agricultural gantry system's wheel on its diameter D_0: 1) b_0 = 0.30 m; 2) b_0 = 0.20 m

The analysis of the dependence graph in Fig. 5 supplies the conclusion that, under the conditions of there being an identical load G_N = const on the agricultural gantry system's wheel, its efficiency η_k increases with an increase in the wheel's diameter D_0 and width b_0. The nature of such a dependency provides from its argument two characteristic zones of intensive dynamics. The search for the rational optimum of D_0 indicated that the outer diameter of the agricultural gantry system's tyre must be 1.245 m. The value yielded is taken as a base value for further calculations.

Pursuant to the requirements of the agricultural track system and for the task that has been set out for the study, it is recommended that the pneumatic tyre b_0 be as narrow as possible. In order to be able to satisfy that requirement, the following dependency shall be analysed where it relates to the efficiency η_k of the agricultural gantry system's wheel in relation to its width b_0 (Fig. 6).

The nature of the dependency shown in Fig. 6 also provides for two zones in which the graph has a point of rational optimum. The search for that point indicated that it is located where the tyre width b_0 equals 0.250 m.

Based on the values yielded in terms of rational parameters for tyres for the agricultural gantry system's wheels, tyres of a size of 9.5R32 were selected, with D_0 = 1.245 m and b_0 = 0.241 m because, amongst the possible tyre alternatives with parameters that come close to those values, the tyre selected had the smallest profile width while simultaneously also having the highest wheel efficiency η_k.

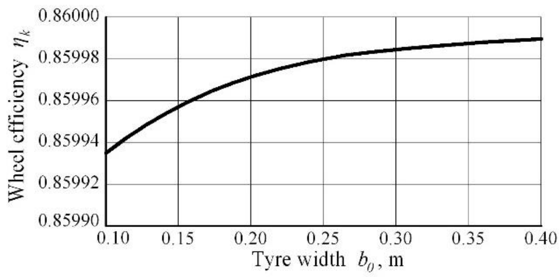

Figure 6. The dependency of the efficiency η_k of the agricultural gantry system's wheel on its tyre width b_0 at D_0 = 1.245 m.

The proposed methods for finding rational parameters for pneumatic wheels make it possible to determine the tyre parameters for all kinds of agricultural gantry systems when they are required to travel on compacted soil in permanent artificial tracks.

Conclusions

1. When adapting the parameters for the tyres of agricultural gantry system wheels which are required to travel on compacted soil in permanent artificial tracks, a compromise solution has to be found where, on the one hand, the profile width of the tyres of an agricultural gantry system must be as small as possible but, on the other hand, the wheel must still operate at its maximum levels of efficiency. In solving the task that has been set out, the use of the analysis of partial derivates of the function of the efficiency of an agricultural gantry system's wheel makes it possible, quickly and effectively, to determine the points of rational optimums for its pneumatic tyre's parameters.
2. The search for rational parameters in relation to the pneumatic wheels of the agricultural gantry system that has been developed by us indicated that the range of rational optimum tyre widths is between 0.20–0.30 m, and the range of optimum tyre diameters is between 0.90–1.25 m. With that in mind, it is recommended that the inflation pressure of the tyres be increased from 100 kPa to 160 kPa because the partial derivates of the function of the efficiency at those parameters would decrease to near zero.
3. The studies that have been conducted indicate that, under the conditions of there being an identical load on the agricultural gantry system's tyre, the efficiency of its wheels increases with an increase of the tyre's diameter and width. From their argument, the nature of these dependencies provides for two characteristic zones of intensive dynamics. The search for the rational optimums of the indicated parameters showed that the outer diameter of the agricultural gantry system's tyre must be 1.245 m and its width must be 0.250 m. It has been proven that the choice of tyre

type for agricultural gantry systems should be first based on the choice of width and then on load-bearing capacity – its diameter.

4. The fact has already been identified that there are tyre parameters for every agricultural gantry system. With that in mind, the operating weight of such a system imposes a certain load on its wheels, which enables its pneumatic wheels to work at their maximum levels of efficiency. For an agricultural gantry system with the described structure, and based on the yielded values for rational tyre parameters, tyres that are of the 9.5R32 size were chosen where they also had the highest efficiency levels, *i.e*. 0.86.

5. The proposed methods of choosing tyre types for pneumatic wheels make it possible to determine the tyre parameters for all kinds of agricultural gantry systems for travelling on compacted soil in permanent artificial tracks.

Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Author contributions

VB – study conception and design, critical revision and approval of the final manuscript;
JO – drafting of the manuscript, critical revision and approval of the final manuscript;
VK – analysis and interpretation of data;
MC, MS, SK – acquisition of data.

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1 • XXXI • 2020 10–16

Journal of Agricultural Science
1 • XXXI • 2020 10–16

A THEORETICAL AND EXPERIMENTAL STUDY OF THE TRACTION PROPERTIES OF AGRICULTURAL GANTRY SYSTEMS

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Saabunud: Received: 12.04.2020
Aktsepteeritud: Accepted: 18.05.2020

Avaldatud veebis: Published online: 18.05.2020

Vastutav autor: Corresponding author: Jüri Olt
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Keywords: agricultural gantry system, drawbar pull, rolling resistance, tractive force, slip coefficient.

DOI: 10.15159/jas.20.08

ABSTRACT. The movement conditions experienced by an agricultural gantry system along the solid and level ground surface of permanent artificial tracks must make it possible to generate most of its maximum tractive force. Concurrently, the adhesive ability of the agricultural gantry system on the ground surface of such permanent artificial tracks must be sufficient to generate nominal drawbar pull when working at a certain level of slip. This means that there exists the need to seek out the following compromise: the maximum slippage experienced by the wheeled chassis of an agricultural gantry system must be such that, in a situation in which the level of adhesion with the surface of permanent artificial tracks is suitable, it will be able to generate the maximum possible tractive force. The effect of the parameters that involve an agricultural gantry system's wheels – and the physical and mechanical properties of the ground surface along which they move – on potential slippage has not yet been sufficiently studied. This effect cannot be taken into consideration without taking into account the dynamics of any rolling resistance being offered by the agricultural gantry system's chassis. The purpose of this particular study is to research the traction properties of an agricultural gantry system's wheeled chassis in terms of its movement along compacted and level ground upon which have been mounted permanent artificial tracks. The research determines that the wheels of such an agricultural gantry system that are rolling along permanent artificial tracks suffer less slippage and therefore generate a higher level of tractive force. As a result, the agricultural gantry system loses less of its speed of movement and, therefore, uses less energy in that movement. When an agricultural gantry system moves across an agricultural field that has been prepared for sowing, the research also determines the maximum tractive force that its wheels can develop when the adhesion coefficient is set at a figure that is between 0.22–0.24. Once such movement begins along permanent artificial tracks, this coefficient decreases to between 0.15–0.17. An agricultural gantry system's wheels are able to generate a higher level of tractive force when moving along on permanent artificial tracks. This figure is at least 30% higher when its movement has to be considered across an agricultural field that has been prepared for sowing.

Introduction

The modern agricultural production industry is being characterised by a qualitatively new stage of technological rearming. International scientific publications are providing more and more information about the outlook regarding, and the effectiveness of using, gantry tractors (or agricultural gantry systems) (Webb *et al.*, 2004; Önal, 2012; Pedersen *et al.*, 2013; Antille *et al.*, 2015; Chamen, 2015; Bulgakov *et al.*, 2017; Bulgakov *et al.*, 2018).

The nominal drawbar pull that is generated by a gantry tractor in a situation in which its chassis has sufficient adhesion with a ground surface that is formed by permanent artificial tracks must naturally be higher than that of a traditional tractor even with equal technical parameters being available. In that context, the adhesion ability of the chassis of a gantry tractor to the surface of permanent artificial tracks must be sufficient to generate nominal drawbar pull when working at a certain level of slippage. At the same time, it is already known that a smaller slip coefficient correlates with a lower value for the tractive force that is generated by a tractor.

The conditions under which a gantry tractor that is moving on a compacted level ground surface as formed by permanent artificial tracks must provide for a higher value of maximum tractive force, while for a traditional tractor the maximum tractive force goes into slippage, which significantly increases the level at which it is possible to cause unacceptable damage to the soil environment (Grosch, 1996; Nadykto *et al.*, 2015; Battiato, Diserens, 2017; Czarnecki *et al.*, 2019). This leads to a need to seek out the following compromise: the maximum permitted slippage values for the wheeled chassis of a gantry tractor must be such that it will generate the maximum levels of tractive force under conditions of sufficient adhesive ability with a ground surface that is formed by permanent artificial tracks (Gil-Sierra *et al.*, 2007).

The relevance of the study at hand stems also from the fact that the tractor theory includes no separate discussion of the effect of the wheel's parameters and the ground surface's physical and mechanical properties on any slippage. This effect cannot be considered without accounting for changes in the rolling resistance of the chassis. Such rolling resistance naturally has to be smaller for a gantry tractor that moves along on permanent artificial tracks than it would be for a moving tractor on the soil of an area that has been set aside for crops.

When discussing problems that are related to the development of a scientific basis for using gantry tractors, some researchers have reached the conclusion (Chen *et al.*, 2010; Bulgakov *et al.*, 2019a) that their theory and the relevant technological properties require further development.

The well-known theory regarding the traditional wheeled tractor states that its traction properties largely depend upon the adhesion properties of its driven wheels (Lebedev, 2012; Nadykto, Velychko, 2015; Battiato, Diserens, 2017). The adhesive ability of driven wheels in regards to soil is considered to be the result of two forces: the friction forces between the tyre's support surface and the ground surface (as a rule, this means soil), and the adhesive forces of the tyre's tread lugs (its ‘ground-hooking' elements) in the soil (Zoz, Grisso, 2003; Bulgakov *et al.*, 2020). On tracks which have a solid surface, the friction forces have a more prominent role. On soft ground (typical for tractor work), the adhesive forces are more significant. On ground under the wheels which is of intermediate density, the forces of friction and adhesion have nearly equal significance (Bulgakov *et al.*, 2019b).

Multi-year studies (Lebedev, 2012; Nadykto, Velychko, 2014; Nadykto *et al.*, 2015; Adamchuk *et al.*, 2016; Bulgakov *et al.*, 2019b) have shown that, in terms of tractor work on soft ground of the type that is characteristic of almost all agricultural operations, the tread lugs on the wheels tend to penetrate deeply into the soil layer. While they are dug into the soil the tread lugs compress that soil horizontally, in a direction that is opposite to that of the tractor's direction of movement. As a result, the tractor's speed of movement decreases. The relative loss of speed for the tractor is estimated as the slip coefficient (Zoz, Grisso, 2003; Ekinci *et al.*, 2015; Nadykto *et al.*, 2015). The aforementioned horizontal deformation of the soil depends upon the individual pressure that is applied to the soil's elements by the tread lugs of the tyres and on the soil's ability to resist deformation, the latter being closely estimated as the individual deformation coefficient (Guskov, 1996). The value of the individual horizontal pressure is determined by the value and the nature of any change in the tractive force (Wulfsohn, Way, 2009).

In that direction, scientists have not yet carried out sufficient levels of research that could be applied to the conditions under which gantry tractors move on permanent artificial tracks.

The purpose of this research is to study the traction properties of the wheeled chassis of an agricultural gantry system when it moves along on the levelled and compacted ground surface of permanent artificial tracks.

Material and Methods

The theoretical research methods that were used were a determination of the tractive force in various positions. On the one hand, the maximum tractive force P_{kmax} which the wheel of an agricultural gantry system generates is determined by the conditions of its sufficient adhesive ability on a ground surface that is formed by permanent artificial tracks:

$$P_{kmax} = f(\varphi), \quad (1)$$

where φ is the adhesive coefficient, realised by the agricultural gantry system's chassis under the conditions of it interacting with the ground surface.

According to condition Eq. 1, a wheel's adhesive ability must be sufficient for the agricultural gantry system to generate a nominal drawbar pull when working on crop soil with a determined slippage coefficient.

On the other hand, the value of the tractive force P_{kmax}, which is what a wheel of the agricultural gantry system generates, depends upon the normal load being applied to it, as well as on the parameters of the wheel itself, the physical and mechanical properties of the ground surface where that is formed by permanent artificial tracks, and the mode of its movement (the slippage coefficient):

$$P_{kmax} = f(\delta_{max}, f_k, N_{ek}, k_0, r_0, b_0, \ldots), \quad (2)$$

where δ_{max} is the slip coefficient (that maximum) of the agricultural gantry system's chassis; f_k is the rolling resistance coefficient of the agricultural gantry system's wheel; k_0 is the coefficient of the physical and mechanical properties of the ground surface as formed by permanent artificial tracks; N_{ek} is the vertical operational load applied to the agricultural gantry system's wheel; r_0, b_0 are the static diameter and the static width of the agricultural gantry system's wheel.

Figure 1. An agricultural gantry system with a design that had been developed by us, during the experimental studying of its traction properties

In the course of the experimental studies, the tractive force P_k which was generated by a wheel of the agricultural gantry system (Fig. 1) was assessed as a sum of its two constituent forces – the drawbar pull and the rolling resistance (Macmillan, 2002):

$$P_k = P_h + P_f, \quad (3)$$

where P_h is the drawbar pull force that is generated by a wheel of the agricultural gantry system; and P_f is the rolling resistance that the wheel of the agricultural gantry system must overcome.

The slip coefficient δ of the agricultural gantry system's chassis was determined experimentally from the following expression:

$$\delta = 1 - \frac{n_{k0}}{n_{km}} \cdot \frac{V_m}{V_0}, \quad (4)$$

where n_{k0} and n_{km} are the number of revolutions of the agricultural gantry system's wheel over one and the same track distance whilst proceeding without a load and then whilst in work mode, respectively; V_0 and V_m are the movement speeds for the agricultural gantry system when travelling without a load and when in work mode, respectively.

The research programme proposed a study of the dependence of the traction properties of an agricultural gantry system in regard to the normal load applied to its wheel, and on the wheel's parameters, on the physical and mechanical properties of the ground surface that is formed by the permanent artificial tracks, and on the agricultural gantry system's movement mode (the slip coefficient).

The accuracy of the research results was assessed on the basis of experimental results which were drawn from testing the agricultural gantry system.

Results and Discussion

For the purpose of theoretical studies we shall present as an equivalent diagram the agricultural gantry system as it moves along on the ground surface that is formed by permanent artificial tracks (Fig. 2), showing the forces that are generated by its chassis.

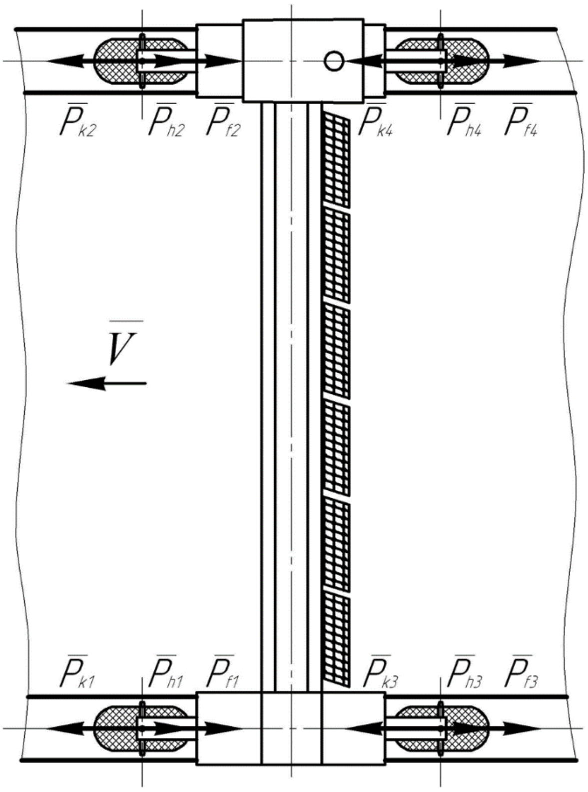

Figure 2. The equivalent diagram showing the agricultural gantry system, moving on permanent artificial tracks

The maximum tractive force that is generated by the gantry tractor's wheel in condition Eq. 2 is expressed as follows:

$$P_{kmax} = \delta_{max} \cdot S_k \cdot k_0 \cdot L, \quad (5)$$

where S_k is the sum of vertical projections of the tread lug surfaces on the agricultural gantry system's wheel that have been plunged into the ground, in m^2; k_o is the coefficient of volume compression of the ground surface (on permanent artificial tracks) (Guskov, 2007), in $N \cdot m^{-3}$; L is the length of the ground surface adhesive arch for the tread lugs on the agricultural gantry system's wheel (on permanent artificial tracks), in metres.

The expression for determining the dimension L is as follows:

$$L = r_k \left(arctan \frac{f_k \cdot (1 - f_k^2)^{\frac{1}{2}}}{0.5 - f_k^2} + 2 \cdot f_k^2 \right), \quad (6)$$

where r_k is the wheel's rolling radius, in metres.

The wheel's rolling radius r_k can be expressed through its static radius r_0 and its tyre's normal sag h_z:

$$r_k = r_0 + h_z \quad (7)$$

The tyre's normal sag is determined from the following expression:

$$h_z = \frac{N_{ek}}{\pi \cdot \rho_w \cdot \sqrt{2 r_0 \cdot b_0}}, \quad (8)$$

where ρ_w is the air pressure inside the tyre, in Pa.

The sum S_k of vertical projections of the tread lug surfaces plunged into the ground on the agricultural gantry system's wheel is determined from the following equation (Guskov, 1996):

$$S_k = \pi \cdot h_z \cdot [(2r_0 - h_z) \cdot (b_0 - h_z)]^{\frac{1}{2}} \quad (9)$$

At the same time, the agricultural gantry system's realisation of the tractive power is determined by its adhesive properties. From this it follows that the adhesive ability must be sufficient for the agricultural gantry system's wheel in condition Eq. 1 to generate the maximum tractive force (Guskov, 1996):

$$P_{kmax} = \varphi \cdot N_{ek} \quad (10)$$

Putting the values of S_k, L, r_k from expressions Eqs. 6–9 into expression Eq. 5 and equalising Eqs. 5 and 10, we get:

$$\delta_{max} \cdot \pi \cdot h_z \cdot [(2r_0 - h_z) \cdot (b_0 - h_z)]^{\frac{1}{2}} \cdot k_0 \cdot (r_0 + h_z) \times \left(arctan \frac{f_k \cdot (1 - f_k^2)^{\frac{1}{2}}}{0.5 - f_k^2} + 2 \cdot f_k^2 \right) = \varphi \cdot N_{ek} \quad (11)$$

An analysis of the resulting Eq. 11 indicates that, with an increase of the tractive coefficient φ which is generated by the agricultural gantry system's chassis in its interaction with the ground surface as formed by permanent artificial tracks, the maximum slip coefficient δ_{max} will also increase. With an increase of the wheel's radius r_0, tyre width b_0, and internal air pressure ρ_w, as well as the vertical load N_{ek} applied to it, the tractive coefficient φ of the agricultural gantry system's wheel on the ground surface as formed by permanent artificial tracks will also increase. This leads to the conclusion that the higher the adhesive ability of an agricultural gantry system's wheel on the ground surface as formed by permanent artificial tracks, the higher the levels of slippage that can be achieved in that situation. The nature of that interaction is determined by the agricultural gantry system's parameters, its movement mode, and the properties of the ground surface as formed by permanent artificial tracks.

The resulting mathematical model 11 makes it possible for us to study the dependence of the driving and adhesive properties of an agricultural gantry system on the vertical load that is applied to its wheel, and on the wheel's parameters, and also on the physical and mechanical properties of the ground surface that is formed by permanent artificial tracks, and even on the agricultural gantry system's mode of movement (its slippage coefficient). For this end, we will present the Eq. 11 that resulted from our studies as the dependence of the maximum slip coefficient δ_{max} of the agricultural gantry system's wheel on the indicated parameters:

$$\delta_{max} = \frac{\varphi \cdot N_{ek}}{\pi \cdot h_z \cdot [(2r_0 - h_z) \cdot (b_0 - h_z)]^{\frac{1}{2}} \cdot k_0 \cdot (r_0 + h_z) \times \left(arctan \frac{f_k \cdot (1 - f_k^2)^{\frac{1}{2}}}{0.5 - f_k^2} + 2 \cdot f_k^2 \right)} \quad (12)$$

We will now study the character of the dependence of the slip coefficient δ_{max} of the wheel of an agricultural gantry system, with the design having been developed by u, based upon the value of its tractive coefficient φ when moving on two variants of the ground's surface. According to the first variant, the agricultural gantry system moves on crop soil that corresponds in terms of its condition to those of soil that has been prepared for sowing. In that context, the crop soil's coefficient of resistance to the rolling of the agricultural gantry system is $f_k = 0.15$. According to the second variant, the agricultural gantry system moves on levelled, compacted ground that is formed by permanent artificial tracks. The coefficient of resistance to the rolling of the agricultural gantry system on its permanent artificial tracks is $f_k = 0.05$. The results of the study are presented in Fig. 3.

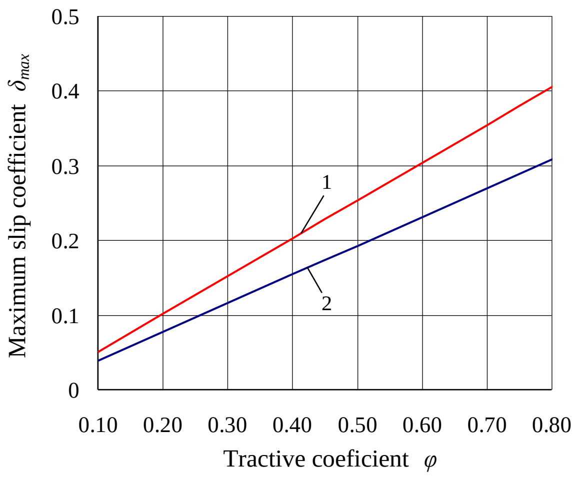

Figure 3. The dependence of the maximum slip coefficient δ_{max} for an agricultural gantry system's wheel on its tractive coefficient φ on the ground's surface: 1) soil that has been prepared for sowing of crop ($f_k = 0.15$); 2) permanent artificial tracks ($f_k = 0.05$)

The analysis of the diagrams shown in Fig. 3 indicates that a decrease of the coefficient f_k of resistance to the rolling of the agricultural gantry system makes it possible to increase the maximum slip coefficient δ_{max} of its wheels. An increase of the latter means a higher maximum tractive force being generated by the gantry tractor under conditions in which sufficient adhesive ability can be applied to the ground's surface, as would result from dependency Eq. 12. For example, with the slip coefficient of an agricultural gantry system's chassis being the same, ie. δ_{max} = 0.22, at which level it applies the maximum tractive force to the crop soil, its tractive coefficient is φ = 0.43. On permanent artificial tracks this coefficient increases to φ = 0.55. This means that the movement of an agricultural gantry system on permanent artificial tracks is characterised by better traction properties when compared with its movement on crop soil that has been prepared for sowing.

This result can be explained by the following: the traction properties of an agricultural gantry system when working on porous soil are determined mainly by the soil's ability to resist the horizontal deformation (shift) that is caused by the wheel's tread lugs. Therefore the slippage coefficient of its wheels is determined on the basis of the horizontal deformation (shift) of the soil as caused by the tread lugs. This horizontal deformation of the soil depends upon the individual pressure being applied to the soil's elements by the tread lugs of the tyres and on the soil's ability to resist the resultant deformation, the latter being estimated as the individual deformation coefficient. The phenomenon of slippage itself appears as a result of the tread lugs shifting the soil until contact forces of sufficient strength appear in the soil to resist it. The higher the strength of the soil's ground surface on which the agricultural gantry system's wheel is running, the lower the effect that the slippage has on the connections between the soil's particles. As a result, the depth at which the wheels sink into the ground decreases, correspondingly reducing the energy spent on forming the tracks.

The experimentally-derived dependence of the tractive force on the rolling mode of the agricultural gantry system's wheel provided a rather complex result (Fig. 4).

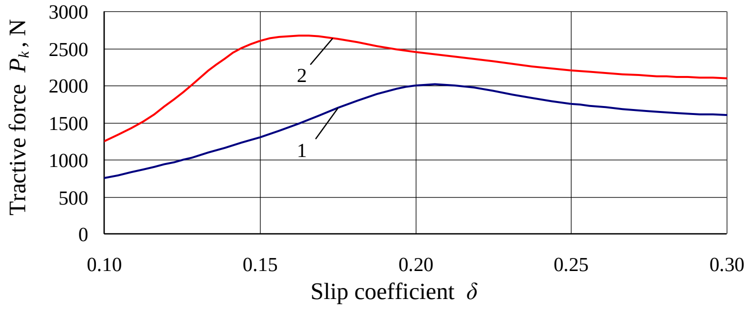

Figure 4. The dependence of the tractive force P_k of an agricultural gantry system's wheel on the slippage coefficient $\boldsymbol{\delta}_{max}$ when moving over soil that has been prepared for sowing of crop (1) and on permanent artificial tracks (2)

The graphs in Fig. 4 indicate that, in both variants, the driving force increases until the slippage coefficient reaches a certain value. Thereafter it starts decreasing. The decrease of the driving force upon high slippage values is explained by the process of soil chunks being cut loose, thrust between the tread lugs, and rotating as part of the wheel. As the values for the soil's resistance forces at the time of shifting are less than those for the maximum force when it is at rest, the wheel's driving force is also lower.

The slip coefficient δ_{max} at which a wheel on an agricultural gantry system that has been designed and developed by us applies the maximum tractive force to soil that has been prepared for sowing of crop falls within the range of between 0.22–0.24. Within that context, the value for this force for the agricultural gantry system at hand is 2 kN. When moving along on permanent artificial tracks, the value for the maximum slip coefficient δ_{max} decreases to between 0.15–0.17, while the maximum driving force being generated by the wheel increases to 2.65 kN, i.e. more than 30%.

Conclusions

1. The theoretical and experimental studies that have been carried out indicate that the rolling of the agricultural gantry system's wheel on permanent artificial tracks is accompanied by a lower slippage value, while at the same time the wheel generates a higher tractive force. As a result, the agricultural gantry system loses less of its intended movement speed and uses less energy to reach that speed. It has been determined that, when the agricultural gantry system moves on soil that has been prepared for sowing of crop, the maximum tractive force is generated at the slip coefficient of between 0.22–0.24. When moving on permanent artificial tracks, this value decreases to between 0.15–0.17.
2. The studies that have been carried out indicate that the maximum tractive force being generated by the wheel of an agricultural gantry system is higher when that system is moving on permanent artificial tracks. When compared to moving on soil that has been prepared for sowing of crop, this value is at least 30% higher.

Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Author contributions

VB – study conception and design;
JO – drafting of the manuscript, critical revision and approval of the final manuscript;
VK – analysis and interpretation of data;
SS – acquisition of data.

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Agraarteadus
1 • XXXI • 2020 17–21

Journal of Agricultural Science
1 • XXXI • 2020 17–21

THE AROMATIC PLANT *MELISSA OFFICINALIS* AND EFFECTS OF ITS AQUEOUS EXTRACTS ON SUMMER ANNUAL AND INVASIVE WEED SPECIES

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Saabunud: Received: 14.05.2020
Aktsepteeritud: Accepted: 25.05.2020

Avaldatud veebis: Published online: 25.05.2020

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Keywords: *Melissa officinalis*, allelopathy, weeds, invasive species.

DOI: 10.15159/jas.20.09

ABSTRACT. The effects of aqueous extracts of the aromatic plant *Melissa officinalis* were studied on the seed germination and early seedlings growth of ten summer annual species in Petri dish bioassays and pot experiments. The *in vitro* experiments on the aqueous extracts from *M. officinalis* on seed germination shows that the extracts of 5 and 10% were the most active inhibitors for all the studied weed species. Seed germination reduction by the aqueous extracts was up to 54% of the untreated seed lot for each species. On the contrary, the concentration of 1% resulted in germination reduction ranging from 1 to 11%, while in some of the weed species (*P. minor*, *S. nigrum*, *P. angulata* and *C. albida*) the effect was rather stimulatory. This finding is in full agreement with “novel weapons hypothesis” and supports that native plants compared with invasive (like *C. albida* and *P. angulata*) are affected more due to the absence of tolerance or resistance to the allelochemicals. The allelopathy RI of aqueous extracts of lemon balm was negative in most cases, while in the case of 10% concentration, emergence was reduced by 58, 54, 48, 46 and 43% for *X. strumarium*, *C. album*, *S. faberi*, *C. canadensis* and *C. bonariensis*, respectively. The allelopathic activity of *M. officinalis* could be exploited in future studies, to identify and isolate the allelochemicals, as models for future herbicides for integrated weed management.

Introduction

Weeds are considered to be among the most important constraints for crop production, with average yield crop reduction being higher than 30% (Oerke, 2006; Travlos, 2012). Chemical weed control remains one of the most widely used, effective and cheap methods of weed management. Unfortunately, this overreliance on herbicides has led to serious problems, such as herbicide resistance development and environmental issues, with negative impacts and side effects (Jabran *et al.*, 2015). Consequently, ecologically-based strategies for weed management are necessary.

Allelopathy is the phenomenon of interaction between plant species, with many of them possessing inhibitory or stimulatory effects on the growth of neighbouring or successional plants by releasing chemicals and several secondary metabolites into the soil (Rice, 1984; Seigler, 1996). The potential use of allelochemicals or even allelopathic crops for weed management is not something new (Putnam, Duke, 1978); however, lately, the interest is rapidly increasing (Foy, 2001; Travlos, Paspatis, 2008; Mirmostafaee *et al.*, 2020). Many allelochemicals from various plant species have been identified, including phenolics, terpenes, benzoxazinoids, sorogoleones, glucosinolates and others (Niinemets *et al.*, 2014; Jabran, 2017). They can be found in different plant tissues and are biodegradable (Bhowmik, Inderjit, 2003; Rasulov *et al.*, 2019). Besides, they can be selective and also be the basis for a new mode of actions (Macias *et al.*, 2007; Dayan *et al.*, 2012).

Several aromatic and medicinal plants have been evaluated in terms of their allelopathic potential due to the volatile compounds which are important secondary metabolites. For instance, many *Origanum* species can be used as biopesticides due to their strong allelopathic effects (Azirak, Karaman, 2008; Economou *et al.*, 2011). Lemon balm (*Melissa officinalis* L.) is a perennial aromatic plant and its essential oil contains polyphenols, tannins, flavonoids and other substances (Scholey *et al.*, 2014). To date, there is some information regarding the potential allelopathic effects of *M. officinalis* on weeds and other plants; however, very few data are available on the comparative study of the same extracts on a wide range of weeds (Kato-Noguchi, 2001; Geimadil *et al.*, 2015)

For this reason, this research aimed to study the allelopathic potential of *M. officinalis* on seed germination and plant emergence of ten common summer annual weeds, with two of them considered as invasive for Mediterranean regions.

Material and Methods

Fresh material was sampled from an *M. officinalis* crop at flower stage (2018), from a field located in western Greece (20º 53′54″ E, 38º 53′38″ N). 1 kg of leaves was washed and ground. Afterwards, an equal quantity was mixed with 1 l of distilled water as proposed by Norsworthy (2003). Next day the mixture was filtered through filter paper to minimize the solid fraction. From this solution and after dilution with distilled water, four different concentrations (1, 2, 5 and 10%) of aqueous extracts were obtained. The prepared aqueous extracts were stored in a refrigerator (4 °C) for further use.

There were used five replicates (glass Petri dishes) for each aqueous extract (treatment), while untreated weed seeds were used as a control for each experiment (only diluted water was added). Twenty seeds of ten different weed species (Table 1) were placed between two Whatman No. 1 paper filter disks and 5 ml of distilled water was added. Seeds were considered germinated at the emergence of the radicle (Bewley, Black, 1994) at 7 days after placement. It has to be noted that mature seeds of the tested weed species have been collected during previous summer (2017) from fields of several annual and perennial crops in the area of western Greece. After their collection, seeds were cleaned, stored in paper bags, selected to have similar size and colour and put in a refrigerator at 5 °C until germination and emergence studies.

Allelopathic response index (RI) was also calculated as proposed by Williamson and Richardson (1988):

$$RI = 1 - \left(\frac{C}{T}\right)\ (when\ T > C) \qquad (1)$$

and

$$RI = \left(\frac{C}{T}\right) - 1\ (when\ T < C) \qquad (2)$$

where T and C represent seed germination (%) for the treated plants and the untreated control, respectively.

Besides, the emergence of the weed seedlings was also recorded in two pot experiments in a glasshouse. Minimum/maximum air temperature and relative humidity were: 25/40 °C and 30/60%, respectively and the plants were subjected to a natural day length ranging between 12–14 h during the experiments. Ten pregerminated seeds of each treatment having a radicle of 1–2 cm length were sown at 1–2 cm depth in five plastic pots filled with 2 l of a sandy clay loam (SCL) soil (pH = 7.1) and the several aqueous extracts were added. The only exceptions to that were the *Conyza* species, the seeds of which were placed on soil surface due to their small size.

Analysis of variance was performed for all data and differences were tested at the 5% level of significance using the Fisher's Protected LSD test. Statsoft software package (Statsoft, Inc. 2300 East 14th Street, Tulsa, OK 74104, USA) was used.

Table 1. Weeds species included in the present study

Common name	Scientific name	Family	Biological cycle
Small canarygrass	*Phalaris minor*	Poaceae	Summer annual
Giant foxtail	*Setaria faberi*		
Cutleaf groundcherry*	*Physalis angulata*	Solanaceae	
Black nightshade	*Solanum nigrum*		
Lambsquarters	*Chenopodium album*	Amaranthaceae	
Prostrate pigweed	*Amaranthus blitoides*		
Common cocklebur	*Xanthium strumarium*	Asteraceae	
Tall fleabane*	*Conyza albida*		
Flaxleaf fleabane	*Conyza bonariensis*		
Horseweed	*Conyza canadensis*		

* considered as invasive for Mediterranean regions

Results

The *in vitro* experiments on the aqueous extracts from *M. officinalis* on seed germination shows that the extracts of 5 and 10% were the most active inhibitors for all the studied weed species. In particular, seed germination reduction by the aqueous extracts of 10% was ranged between 21 and 54% of the untreated seed lot for each species (Table 2). On the contrary, the concentration of 1% resulted in germination reduction ranging from 1 to 11%, while in some of the weed species (*P. minor*, *S. nigrum*, *P. angulata* and *C. albida*) the effect was rather stimulatory (Table 2).

Table 2. Effects of aqueous extracts of *M. officinalis* on seed germination (%) of the tested species.

Weed species	Untreated	1%	2%	5%	10%
Phalaris minor	84^{a}	85^{a}	82^{a}	72^{b}	64^{b}
Solanum nigrum	38^{a}	40^{a}	37^{a}	29^{ab}	23^{b}
Chenopodium album	62^{a}	55^{a}	52^{ab}	46^{bc}	38^{c}
Setaria faberi	75^{a}	72^{a}	62^{b}	64^{ab}	48^{c}
Physalis angulata	94^{a}	95^{a}	88^{ab}	81^{b}	74^{c}
Amaranthus blitoides	92^{a}	91^{a}	85^{ab}	79^{b}	63^{c}
Xanthium strumarium	56^{a}	52^{a}	47^{a}	38^{b}	26^{c}
Conyza albida	96^{a}	97^{a}	89^{a}	76^{b}	62^{c}
Conyza bonariensis	100^{a}	95^{a}	88^{ab}	76^{c}	59^{d}
Conyza canadensis	100^{a}	96^{a}	85^{b}	72^{c}	57^{d}

Means followed by the same superscript letter within a row are not significantly different at 5 % Fisher's least significant difference test.

Table 3. Effects of aqueous extracts of *M. officinalis* on the allelopathic response index (RI) of the tested species

Weed species	Untreated	1%	2%	5%	10%
Phalaris minor	–	0.012[a]	-0.024[a]	-0.143[b]	-0.238[b]
Solanum nigrum	–	0.050[a]	–0.026[b]	–0.237[c]	–0.395[d]
Chenopodium album	–	–0.113[a]	–0.161[a]	–0.258[b]	–0.387[c]
Setaria faberi	–	–0.040[a]	–0.173[b]	–0.147[b]	–0.360[c]
Physalis angulata	–	0.011[a]	–0.064[a]	–0.138[b]	–0.213[c]
Amaranthus blitoides	–	–0.011[a]	–0.076[ab]	–0.141[b]	–0.315[c]
Xanthium strumarium	–	–0.071[a]	–0.161[b]	–0.321[c]	–0.536[d]
Conyza albida	–	0.010[a]	–0.073[a]	–0.208[b]	–0.354[c]
Conyza bonariensis	–	–0.050[a]	–0.120[a]	–0.240[b]	–0.410[c]
Conyza canadensis	–	–0.040[a]	–0.150[a]	–0.280[b]	–0.430[c]

Means followed by the same superscript letter within a row are not significantly different at 5% Fisher's least significant difference test.

The allelopathy RI of aqueous extracts of lemon balm was negative in all weed species except *P. minor*, *S. nigrum*, *P. angulata* and *C. albida* in the concentration of 1% (Table 3). The major negative effects were observed in the higher concentration (10%) for *X. strumarium*, *C. bonariensis* and *C. canadensis*.

Seedling emergence of the several weeds was significantly and negatively affected by the addition of *M. officinalis* extracts in concentrations higher than 1% (Table 4). In the case of aqueous extracts of 1%, seedling emergence of *S. nigrum*, *C. album*, *P. angulata*, *A. blitoides* and *C. albida* was slightly increased but without any significant changes. On the other hand, in the case of 10% concentration, emergence was reduced by 58, 54, 48, 46 and 43% for *X. strumarium*, *C. album*, *S. faberi*, *C. canadensis* and *C. bonariensis*, respectively.

Table 4. Effects of aqueous extracts of *M. officinalis* on seedling emergence of the tested species

Weed species	Untreated	1%	2%	5%	10%
Phalaris minor	74[a]	72[a]	63[b]	61[b]	51[c]
Solanum nigrum	26[ab]	28[a]	32[a]	21[b]	18[b]
Chenopodium album	41[a]	43[a]	32[b]	28[b]	19[c]
Setaria faberi	67[a]	66[a]	53[b]	48[b]	35[c]
Physalis angulata	86[a]	87[a]	78[a]	68[b]	65[b]
Amaranthus blitoides	85[a]	88[a]	74[b]	68[b]	57[c]
Xanthium strumarium	52[a]	49[a]	44[a]	34[b]	22[c]
Conyza albida	92[a]	93[a]	86[a]	74[b]	58[c]
Conyza bonariensis	96[a]	95[a]	85[b]	72[c]	55[d]
Conyza canadensis	100[a]	95[a]	82[b]	68[c]	54[d]

Means followed by the same superscript letter within a row are not significantly different at 5% Fisher's least significant difference test.

Discussion

Allelopathy is one of the main forces in the development of plant communities and spatial patterns (Rice, 1984). The effects of several aromatic plants on weed species' germination and growth have been extensively studied (Economou *et al.*, 2011; Kashkooli, Saharkhiz, 2014). To date, the effects of lemon balm on weeds have been evaluated in a few studies. For instance, Geimadil *et al.* (2015) found an inhibitory effect of aqueous extracts of *M. officinalis* on seed germination of *Sinapis arvensis*. Moreover and Kato-Noguchi (2001) showed that water-soluble fractions obtained from aqueous acetone extracts of lemon balm inhibited the seed germination and plant growth of weeds like *Digitaria sanguinalis* and *Lolium multiflorum*.

Another interesting finding is related to the different germinability of the untreated seeds for the several weeds and it could be attributed to the potential dormancy for some of them and the enormous variability and plasticity of the weeds. Furthermore, stimulation of seed germination at low rates of aqueous extracts is in agreement with previous studies on several aromatic plants and weeds (Travlos, Paspatis, 2008; Economou *et al.*, 2011). According to Ambika (2013), a compound may cause inhibition at high concentration, stimulation at low concentration, or no significant effect in intermediate rates.

Regarding RI, the observed variability among weeds has been previously reported by Scavo *et al.* (2018) and can be partially attributed to the different combination and concentration of allelochemicals' profile in each aqueous extract.

Concerning the different responses observed between the weed species, this is also something common in previous studies. For instance, Azizi and Fuji (2006) have found that the extracts of *Hypericum perforatum* and *Salvia officinalis* had a significant inhibitory effect on seed germination for *A. retroflexus*, but not for *P. oleracea*. Another interesting finding is related to the response of two invasive plants on aqueous extracts of low concentrations. In particular, aqueous extracts of 1% have not affected or slightly stimulated seed germination and seedling emergence of *the species P. angulata* and *C. albida*. These two species are considered as invasive for the Meditteranean and other regions (Travlos, 2012). Therefore, our results suggest that agro-ecologically speaking, their observed 'resistance' to allelopathy may correlate with their invasiveness and dispersal dynamics or with an allelopathic potential of the particular species as previously indicated (Economou *et al.*, 2002). Indeed, allelopathy is a possible explanation for the mechanism of success of many invasive plants (Hierro, Callaway, 2003), while the "novel weapons hypothesis" supports that native plants are affected due to the absence of tolerance or resistance to the chemicals (Callaway, Ridenour, 2004).

In agronomy and weed science, herbicides are the focus of many studies (Foy, 2001). However, further research is necessary to identify novel ecologically-based methods of weed management. Finding new effective allelopathic species and evaluating them against a wide range of agronomically important weed species can be crucial in this regard. Consequently, results on the potential effect of aromatic plants on seedling emergence could be of great value. For the case of *M. officinalis* it could be said that the findings on the reduction of seedling emergence up to 58% for several weeds could be a clear indication and a basis for the further exploitation under field conditions.

Conclusions

The allelopathic effects of aqueous extracts of *M. officinalis* on ten common summer annual weeds in Greece were evaluated in the present study. Concentration was partially responsible for the observed differences, even if different response was recorded among the studied weed species. Seed germination reduction by the aqueous extracts was up to 54% of the untreated seed lot for each species. Seed germination and seedling emergence reduction by the aqueous extracts were up to 54 and 58% of the untreated seed lot for each species. Moreover, aqueous extracts of 1% have not affected or slightly stimulated seed germination and seedling emergence of the invasive species *P. angulata* and *C. albida*, indicating the potential role of allelopathy on plant invasion process. These results are very promising to further exploit aromatic plants in terms of their allelopathy and their potential role in ecologically based weed management.

Acknowledgements
We are grateful to the editors and peer reviewers that gave of their time to ensure that the manuscript was strengthened via their insights.

Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Author contributions

PK contributed to the design and implementation of the research, to the analysis of the results and to the writing of the manuscript.

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Agraarteadus
1 • XXXI • 2020 22–27

Journal of Agricultural Science
1 • XXXI • 2020 22–27

MINI-REVIEW: THE ROLE OF CROP ROTATION, INTERCROPPING, SOWING DATES AND INCREASED CROP DENSITY TOWARDS A SUSTAINABLE CROP AND WEED MANAGEMENT IN ARABLE CROPS

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Saabunud: Received: 17.05.2020
Aktsepteeritud: Accepted: 29.05.2020
Avaldatud veebis: Published online: 30.05.2020

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Keywords: sustainability, crop rotation, intercropping, weed management.

DOI: 10.15159/jas.20.11

ABSTRACT. The extended and in many cases unjustified use of herbicides has resulted in herbicide resistance development and serious environmental concerns. Therefore, the need for implementation and wider adoption of several agronomic and cultural practices is imperative. Ecologically-based crop management practices like crop rotation, intercropping, delay of sowing date and increased crop density can be also the basis for effective and sustainable weed management. In the present review, several cases are presented and the key points of each method are discussed. Special attention is given to the fact that the efficacy of each practice is depended on the specific soil and climatic conditions along with the field history of each site and crop. Alternative methods of weed management should be further studied and optimized to include them in both organic and conventional production systems and ensure the sustainability of agroecosystems.

Introduction

Among the different biotic factors negatively affecting crop yield in field crops, weeds are considered to be the most important ones (Oerke, 2006; Kanatas *et al.*, 2020[a]). Chemical control remains the "king" of weed management, however, the various negative effects make necessary the need for the development of alternative methods and strategies (Jabran *et al.*, 2017). Consequently, ecologically-based strategies for weed management are necessary.

During the next years, not many new modes of actions for chemical weed control are expected. Therefore, research focuses on the improvement and potential exploitation of several agronomic and cultural practices like crop rotation, intercropping, increased crop density, delayed sowing, mulching, green manure *etc*. towards a sustainable crop and weed management (Travlos *et al.*, 2014; Weerarathne *et al.*, 2017; Weisberger *et al.*, 2019; Kanatas *et al.*, 2020[a]). Decision support systems are expected to give significant help to the farmers of the near future with the precondition not only to optimize herbicides use but also to enhance weed management tactics less reliant on herbicides (Kanatas *et al.*, 2020[b]). Moreover, weed pressure associated with climate change is a major challenge for arable crops and therefore the implementation of several sustainable methods and practices could have positive crosscutting environmental benefits and be more climate-resilient (Ramesh *et al.*, 2017).

The objective of the present review was to highlight some examples on different ecologically based weed management methods such as crop rotation, intercropping and modified sowing date and crop density in arable crops.

Crop rotation

Monoculture or even simplified crop-rotations increase weeds' repeated exposure to the same set of ecological and agronomic conditions (Weisberger *et al.*, 2019) and therefore weed management cannot be achieved in the mid- and long-term. In general, crop rotations are considered to be the basis of sustainable agriculture since they allow the field to rest, they reduce the weed and pest pressure and they enhance the soil balance and water economy. Moreover, they usually implement changes in the tillage practices and therefore several weed species are suppressed. Weed management is feasible since the growth habits and life cycles of specific weeds are disrupted by employing different planting and harvest dates (Liebman, Staver, 2001). Employing diverse crop rotations can also provide higher flexibility in choosing herbicides with different modes of action and thus reduce the risk of selecting for herbicide-resistant weed biotypes. Research conducted in western Canada indicated that, in the absence of herbicides, cutting barley for silage was very effective for reducing wild oat populations, especially when the crop was cut at an early growth stage (Harker *et al.*, 2003). Each crop rotation may have a different influence on weed flora (Simic *et al.*, 2016). In a 3-yr study conducted in Serbia, maize-soybean-wheat rotation reduced biomass of perennial and annual weeds and significantly increased maize yield in comparison to maize monoculture or other crop rotation regimes (Simic *et al.*, 2016).

Rotations in organic production systems often include winter annual crops such as rye, hairy vetch, whose maximum growth occurs before the period of low Canada thistle (*Cirsium arvense*) carbohydrates reserves (HDRA, 2006). Combining cowpea (*Vigna unguiculata*) with sudangrass (*Sorgum sudanense*) produces a large amount of diverse residue which suppresses weeds (Creamer, Baldwin, 2000; Bicksler, Masiunas, 2009).

In a 2-yr experiment conducted by Fisk *et al.* (2001), the influence of several annual cover crops on weed populations in a winter wheat-corn rotation system was studied. The density of winter annual weeds was between 41 and 78% lower following most cover crops when compared with the absence of cover crops, while dry weight was between 26 and 80% lower in all sites. There are several mechanisms responsible for the effect of cover crops on weeds.

In all cases, well-structured crop rotations can give the time and the flexibility to the growers to effectively control the important weeds (both annual and perennial) preferably using ecologically-based methods and with a certainly lower reliance on herbicide inputs. Long and justified crop rotations are very important in sustainable and ecologically based crop production systems. For instance, Anderson (2015) has found that some no-till, complex crop rotations improve nutrient cycling and soil porosity but also they can reduce or delay weed emergence, avoid yield losses and reduce invasion.

In a meta-analysis of 54 studies conducted by Weisberger *et al.* (2019), it was found that diversification of crop rotations using the addition of more crops can significantly reduce weed density (49%) and keep its high efficacy under varied environmental conditions and different crop production systems.

Intercropping

Intercropping is a system with two (or rarely more than two) crop species growing in the same field during the same cultivation period (Ofori, Stern, 1987). Intercropping can stabilize grain yield and reduce pest problems (Anil *et al.*, 1998) and globally, many organic and conventional farmers are already familiar with this practice (Entz *et al.*, 2001). Bulson *et al.* (1997) revealed that the 25% reduction of the recommended crop density for wheat and bean intercropping was more efficient than the monoculture of each crop. Another form of intercropping except a cereal together with a legume involves cover crops and promotes weed suppression (Liebman, 1986) and N supply to following crops (Thiessen Martens *et al.*, 2005).

Because the quality of cereal forage is usually lower than legumes, cereal forages (barley and oat) are often mixed with field pea and other legumes in many countries to increase protein content with no negative effect on total yield (Anil *et al.*, 1998; Chapko *et al.*, 1991; Hall, Kephart, 1991). Other benefits of these mixtures include greater use of light, higher absorption of water and nutrients and improved weed suppression (Anil *et al.*, 1998).

Additionally, using a winter cereal grain as a companion crop during legume establishment can provide a cash grain and straw (Exner, Cruse, 2001) and reduce soil erosion (Kaspar *et al.*, 2001), nitrate losses (Strock *et al.*, 2004), and weed competition (Hesterman *et al.*, 1992; Singer, Cox, 1998). Red clover is one of the best choices for winter cereal grain intercrops because it tolerates shading (Blaser *et al.*, 2006) and has similar feed value to alfalfa (Broderick *et al.*, 2001). Moreover, some potential benefits to the farming system of intercropping a legume in sunflower are nitrogen fixation, soil erosion control, and improvement of the soil structure and organic matter content (Biederbeck, Bouman, 1994). Intercropping may also improve snow trapping and green manure production during the year after the legume establishment (Lilleboe, 1991).

Furthermore, cover crops have long been used to reduce soil erosion and water runoff, reduce herbicide inputs and improve water infiltration, soil moisture retention, organic carbon and nitrogen (Teasdale, 1996; Yenish *et al.* 1996). Among the commonly used and studied cover crops there are many annual legumes such as crimson clover, hairy vetch and subterranean clover (Teasdale, Daughtry, 1993; Yenish *et al.* 1996).

According to Dhima *et al.* (2007), common vetch intercropped with cereals resulted in higher yields and profitability. Moreover, intercropping hairy vetch (*Vicia villosa*) at a specific growth stage (V4) of sunflower appears superior because it did not reduce sunflower yield, provided soil cover adding between 540 and 2400 kg ha^{-1} above-ground dry matter to the system, and increased NO^{-}_{3}–N levels at the beginning of the subsequent wheat season in several environments (Kandel *et al.*, 2000). Intercropping berseem clover (*Trifolium alexandrinum*) with cereals has increased the yield and quality of cereal forage crops in India (Singh *et al.*, 1989), increased total biomass production without reducing cereal grain yields in Mexico

(Reynolds *et al.*, 1994) and USA (Ghaffarzadeh, 1997; Holland, Brummer, 1999), and improved forage quality, reduced fertilizer needs, and increased subsequent crop yields in British Columbia (Stout *et al.*, 1997) and Iowa (Ghaffarzadeh, 1997). It has to be noted that in many cases intercropping may reduce crop yields compared to monoculture; however, land area is used more efficiently (Anil *et al.*, 1998; Pridham, Entz, 2008). This was also the case described by Szumigalski and Van Acker (2005), in which total yield of wheat and pea intercropping was similar (or lower) than the individual crops under monoculture. Legumes are also beneficial for intercropping, especially under low fertility conditions (Lunnan, 1989). Carr *et al.* (2004) revealed a significantly higher production for barley-pea intercrops in low N soils; while, the inclusion of pea had not any significant effect in rich soils. In many intercrops, modifications in canopy architecture are proposed for adequate weed management and reduction of their competitiveness (Weerarathne *et al.*, 2017).

However, it has to be noted that the potential effects of intercropping on weed control can vary according to the specific soil and climatic conditions and followed crop management practices. For instance, in an intercrop of sunflower/soybean in Argentina, it was found that richness and abundance of total, annual and perennial weeds were similar with sole crops (de la Fuente *et al.*, 2014). Therefore, the suggestion of Weerarathne *et al.* (2017) for further research on intercropping before endorsing it as an adequate alternative to herbicides seems rational. It has to be noted that such extensive research revealed that *e.g.* a higher planting density of maize in a cassava/maize intercrop can significantly reduce weed density (Muoneke, Mbah, 2007).

Sowing date, crop density and other agronomic practices

Varying seeding times can also be disadvantageous to weeds that tend to germinate at specific periods during the growing season. For example, late seeding of the crop may be an effective option with relatively early-germinating weeds such as wild oat. In the UK, a review of weed management options for organic cropping systems suggests waiting until various flushes of weeds emerge and then depleting the soil seed bank through tillage or other non- chemical methods (Bond, Grundy, 2001). A stale seedbed approach would be difficult to implement in conventional cropping systems in western Canada mainly due to the short growing season. In one study, delayed seeding resulted in a consistently high degree of control of wild oat, but also caused major losses in grain yield and quality (Hunter, 1983). In Greece, this delayed crop sowing was the basis of false and stale seedbed in barley and soybean and resulted in the satisfactory control of several kinds of grass and broadleaf weed species (Kanatas *et al.*, 2020[a,c]; Travlos *et al.*, 2020).

In a study conducted in the USA, seeding barley at relatively high rates enhanced the effects of reduced rates of tralkoxydim on wild oat control (O'Donovan *et al.*, 2001[b]). For example, there was little difference in the seed bank regardless the application of tralkoxydim at 50% or 100% of the recommended rate, with the only condition of barley sown at a rate of 175 kg ha^{-1}. However, when barley was seeded at a lower rate, much larger amounts of wild oat seed were present when the herbicide rate was reduced to 25% or 50% of the recommended rate. Other studies also indicate that herbicide activity can be improved considerably if the competitiveness of the crop is enhanced through planting competitive varieties and/or increasing the crop seeding rate. These results are in general agreement with similar studies conducted in the US (Wille *et al.*, 1998) and Europe (Christensen, 1994; Salonen, 1992).

Recommended crop seeding rates in western Canada have traditionally been based on the results of experiments conducted under relatively weed-free conditions. Several studies have shown that seeding crops at higher than recommended rates can improve competitiveness with weeds in barley (O'Donovan *et al.*, 1999). The importance of crop plant density as an IWM strategy was also evident from a study conducted in farmers' fields in Alberta (O'Donovan *et al.*, 2001[a]). Costs of barley and wheat seed tend to be low compared to the benefits associated with increasing the seeding rates (O'Donovan *et al.* 2001[b]) and that's why farmers often increase seed quantity at sowing. On the contrary, the high seed cost of herbicide-tolerant canola varieties, especially hybrids, maybe a major economic constraint to using increased canola seeding rate as an IWM strategy (O'Donovan *et al.*, 2004). It should also be taken into account that understanding the interactions between weeds, crops, crop and weed management methods and climate change is very important to avoid the expected ecological, environmental, and economic costs (Ziska, McConnell, 2016).

Conclusions

In the present study, agronomic practices like crop rotation, intercropping, delayed sowing and increased crop density were discussed and factors determining their efficacy against weeds were presented. Such practices ought to be the basis of integrated weed management systems and further studied and exploited in both organic and conventional production systems. Climate change is also something that should be taken into account and properly quantified to highlight the potential interactions between crops, weeds and management practices and ensure the overall sustainability. The frequent shift of strategy, the flexibility and the adaptation to the specific conditions of each farm and agroecosystem are crucial for the overall success and the satisfactory long-term crop and weed management in arable crops.

Acknowledgements
We are grateful to the editors and peer reviewers that gave of their time to ensure that the manuscript was strengthened via their insights.

Conflict of interest
The authors declare that there is no conflict of interest regarding the publication of this paper.

Author contributions
PK contributed to the design and implementation of the research, to the analysis of the results and the writing of the manuscript.

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Agraarteadus
1 • XXXI • 2020 28–40

Journal of Agricultural Science
1 • XXXI • 2020 28–40

EESTI EROSIOONIST HÄIRITUD MULDKATTED: MULDADE NOMENKLATUUR JA UURIMISE AJALUGU

EROSION-AFFECTED SOILS IN ESTONIAN SOIL COVER: NOMENCLATURE OF SOILS AND THEIR RESEARCH HISTORY

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Saabunud: Received: 26.04.2020
Aktsepteeritud: Accepted: 11.06.2020

Avaldatud veebis: Published online: 30.06.2020

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Keywords: erosion-affected soils, eluvial and deluvial soil, year soil, Estonian soil classification, water and wind erosion, research history.

DOI: 10.15159/jas.20.12

ABSTRACT. The work, dedicated to the eroded soil *i.e*. the year 2020 soil of Estonia, consists of two-part. In Part I the general overview (a) the regularities of erosion processes and their forming conditions in the soil cover, and (b) the agro-ecological properties and nomenclature of formed erosion-affected soils (EAS), are treated. Totally in the Estonian soil classification (ESC) 11 eroded and 3 deluvial (colluvial) soil species have been determined. For the main criteria of eroded soils' determination is (a) the intensity or stage of erosion, and (b) the calcareousness of soil cover, but deluvial soils (a) the soils' water regime and (b) the thickness of formed deluvial humus horizon. In this part also the determination criteria of erosion-prone soils and the agronomic quality of EAS are analysed. In Part II the historic overview about scientific researches dedicated to the study of influenced by erosion soils during the last century in Estonia. In this overview, the main thematic issue and the role of leading scientists on researches of most actual problems are presented. The most important themes during this period were: (a) the elaboration suitable for local conditions EAS classification and methods for their field researches; (b) the distribution of EAS in Estonia; (c) the studies upon forming, composition and status of EAS-s; (d) forming databases on essential properties of EAS-s and derived from this the rules of their ecologically sustainable use, and finally (e) the international aspects of Estonian EAS presentation and local researches.

I Ülevaade erosioonist mõjutatud muldade nomenklatuurist ja nende kujunemisest

Erosiooniprotsessid ja nende toimumise eeldused

Erosioonist häiritud (mõjutatud, rikutud, degradeeritud) mullad on oma olemuselt anormaalsed mullad. Nende anormaalsus seisneb selles, et loomulik bioloogilise olemusega mullatekkeprotsess on neil olnud häiritud erosioonist kui geoloogilisest protsessist. Antud töös on nende koondnimetuseks ***erosioonist häiritud mullad*** ja koodiks ***EHM***. EHM hulka kuuluvad ühelt poolt ***erodeeritud (E)*** ehk ära uhutud mullad ja teiselt poolt ***deluviaal- (D)*** ehk peale uhutud mullad (joonis 1; tabel 1).

Sademete- ja lumesulamise vete mõjul erodeeritud mullad esinevad praegustel või endistel üle 3° kallakuga haritavatel maadel. Künklikel põllumajandusmaastikel on tavaliselt erosioonist mõjutatud (rikutud) kühmude, künniste, kuplite ja seljakute laed ning nende nõlvade ülemised kumerad osad (Maa-uuringud, 2009). Tugevasti liigestatud tasandike puhul esinevad vee-erosioonist mõjutatud mullad orulaadsete pinnavormide nõlvade ülemistel servadel. Taolise põllumaadel esineva pinnapealse kiirendatud (võrreldes looduslike aladega) erosiooni kõrval esineb sageli ka muldkatet väga tugevasti degradeerivaid uhtevagusid ja -kraave (joonis 2).

Tuuleerosioon, mis on üpris harva esinev nähtus Eesti oludes, võib selleks sobivatel eeldustel (taimkatteta ala, tugev tuul, rohke mulla struktuuriagregaatideks sidumata tolmu ja peenliiva sisaldus, peenestunud humifitseerumata vare esinemine mulla pinnal ja kuiv maapind) tekitada siiski märgatavat kahju (Ratas, Int, 1978). Kuna tuuleerosioon (mullaosakeste ära- ja pealekanne) on Eesti põllumajandusmaastikke vähe mõjutav nähtus ja oleneb vaid maakasutuse tehnoloogiast, ei ole neid muldasid mullaliikide nimekirjas (Astover, 2012). Küll on aga mullastiku uurimisel välja selgitatud tuuleerosiooniohtlikud alad.

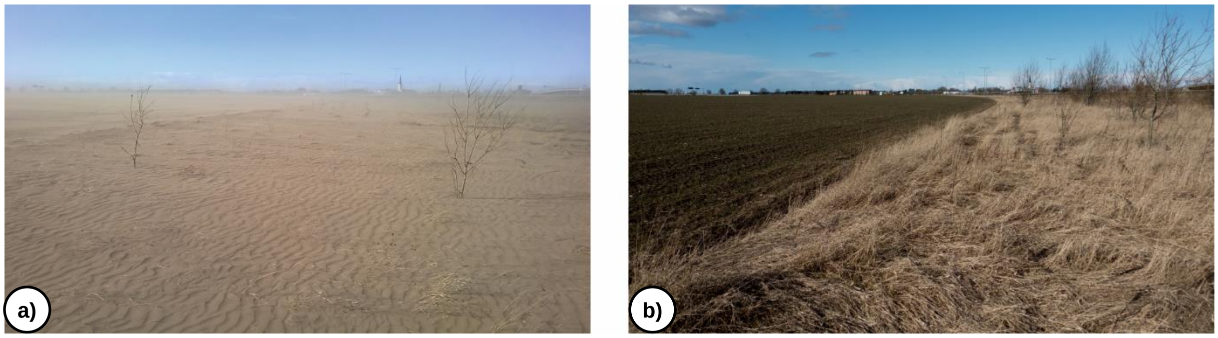
Joonis 1. Erosioonist häiritud muldade (EHM) profiilid: a) Erodeeritud mullad (E) ja b) Deluviaalmullad (D). Allikas: EMÜ mullamuuseum
Figure 1. *Profiles of erosion-affected soils (EAS): a) Eroded soils (E) and b) Deluvial soils (D). Source: Soil museum of EULS*

D mullad, mis kaasnevad E muldadega, esinevad eelpoolmainitud maastike positiivsete pinnavormide alumistel nõgusatel nõlvaosadel, nende jalamitel või E muldadega vahetult (mõnekümne meetri laiuselt) piirnevatel madalamatel (seega ka osaliselt niiskematel) tasandikel või lohkudes. Tunduvalt selgemini on võimalik eristada, võrreldes tuule ärakandest mõjutatud aladega, neid alasid, kuhu on toimunud tuulega ära kantud setete akumuleerumine (joonis 3).

Teatavasti on E mullad, kui olulisim osa EHM-st, valitud ka Eesti 2020. aasta mullaks (Leedu, Astover, 2019). Seega väärivad nad käesoleval ajal teistest suuremat tähelepanu ja esiletõstmist Eesti loodust käsitlevates publikatsioonides. On selge, et aastamulla 2020 iseloomustamisel ei saa piirduda ainult ühe erodeeritud mullaliigiga, sest et Eesti pedo-ökoloogilistes tingimustes on osutunud otstarbekaks eristada kokku 11 erodeeritud mulla liiki. E mullad ei erine üksteisest mitte ainult erosiooni astme poolest vaid ka mullaprofiili karbonaatsuse, huumusseisundi ja viljakuse poolest.

Vee- ja tuuleerosiooni kõrval esineb põllumajandusmaastike muldkattes ka tehnogeenset erosiooni, mis kaasneb kallakuliste alade harimisele (Kask, Heinsalu, 1991). Haritava mullakihi nihutamine esmase paiknemise kohast madalamale võib toimuda nii künni kui kultiveerimise käigus. Olulisemaks tehnoloogilise erosiooni toimumise näitajaks põldudel on huumushorisondi tüsenemine maastike madalametel osadel ning ka selle ebaühtlaseks muutumine.

Joonis 2. Vee-erosioonist mõjutatud põllumajandusmaastike muldkate: a) vee-erosioon värskelt haritud põllul ja b) uhtekraavide ja -vagudega rikutud teraviljapõld. Foto: I. Lemetti
Figure 2. *Soil cover of affected by water erosion agricultural landscape: a) sheet water erosion on freshly tilled field, and b) spoilt with gully erosion channels and furrows field of cereals. Photo: I. Lemetti*



Joonis 3. a) Tuuleerosioonil tekkinud tuulevired kahkjal saviliiv-mullal 2015. aasta aprillis ja b) sama ala ilme 2020. aasta aprillis. Asukoht: Haljala lõunapoolne (vt kiriku torn ja viadukt) ala, mille täiendavaks orientiiriks on fotol 3a nähtav kõlvikute piir. Foto: T. Kõlli
Figure 3. *a) Formed by wind-erosion gusts on Pseudopodzolic loamy sands in April of 2015, and b) the appearance of same area in April of 2020. Location: Southern area of the village Haljala, whereas for the landmarks the church steeple, road viaduct and headland between fields may be taken Photo: T. Kõlli*

Erosioonist häiritud muldade nomenklatuur

Eesti muldade klassifikatsioonis (EMK) ja muldade suuremõõtkavalise (1:10000) uurimise kaardistamisühikute nimekirjas (tabel 1) on eristatud 11 erodeeritud ja 3 deluviaalse mulla liiki (EPP, 1982; Astover, 2013). Seega on EMK-s kokku 14 EHM liiki, mis moodustavad *ca* 14% EMK mullaliikide koguarvust. EHM suur mitmekesisus ja mullakaartide suur kirjusus EHM leviku aladel selgub kasvõi juba sellest, et Eesti muldkatte kogupinnast moodustavad EHM vaid *ca* 1,2%.

EHM liikide paljusus on tingitud soovist võtta võimalikult täpselt arvele kõik nende erinevad variandid ja kajastada need mullastiku kaardil. Samas on oluline teada, et EHM maastikul või muldkattes on selgemini kui teiste muldade korral tajutav muldade kontiinuumi taolise leviku (pidevalt ühest mullast teiseks muutumise) printsiip. See omakorda tingib selle, et eri muldade kontuuride eraldamisega on keeruline anda head ülevaadet ühe või teise EHM liigi levikust. EHM-di ja nende esinemise iseloomu saab hoopiski adekvaatsemalt uurida-kirjeldada kasutades maastikule rajatud transektide meetodit (Kokk, Rooma, 1971; Heinsalu, 1982; Kõlli, 1993). Ülevaade Eestis tehtud kateenade s.o mullastikulis-geomorfoloogiliste pikiprofiilide uurimistest antakse töö II osas.

EHM põhinimestikku (Tabel 1) detailiseeritakse koodide ja indeksitega. (1) Koodid: DG1 on turvastunud deluviaalmuld, ning Lke koondab kõik nõrgalt erodeeritud erineva leetumisastmega (st nõrgalt, keskmiselt ja tugevasti leetunud) mullad, milliste täpsustatud koodid on vastavalt LkIe, LkIIe ja LkIIIe; (2) Koodidele lisatud indeksite tähendused on: a – nõrk alluviaalsus, al – allikaline veerežiim, (g) – nõrk liigniiskus; d –nõrk pealeuhe (deluviaalsus); e – nõrgalt erodeeritud, ning (3) EHM nimetusi üldistatakse järgmiselt: E – erodeeritud ja D – deluviaalmullad, ning E1 – võtab kokku kõik nõrgalt erodeeritud mullad, sealhulgas Ke → E1k, Koe&KIe → E1o ja LPe&Lke → E1l.

Tabel 1. Eesti muldade klassifikatsioonis (EMK) ja muldade kaardistamisühikute nimekirjas eristatud erosioonist häiritud muldade (EHM) liiginimetused ja koodid
Table 1. *Erosion-affected soil species' names and codes of Estonian soil classification and of soil mapping units list*

Kood *Code*	Mullaliigi nimetus / *Name of soil species*
	Erodeeritud mullad (E) / *Eroded soils (E)*
Ke	Nõrgalt erodeeritud karbonaatne muld *Slightly eroded calcareous soil*
Koe	Nõrgalt erodeeritud leostunud muld *Slightly eroded leached soil*
KIe	Nõrgalt erodeeritud leetjas muld *Slightly eroded eluvial soil*
LPe	Nõrgalt erodeeritud kahkjas muld *Slightly eroded pseudopodzolic soil*
Lke	Nõrgalt erodeeritud leetunud muld *Slightly eroded sod-podzolic soil*
E2k	Keskmiselt erodeeritud rähkmuld *Moderately eroded calcareous soil*
E2o	Keskmiselt erodeeritud leostunud muld *Moderately eroded leached soil*
E2I	Keskmiselt erodeeritud leetunud muld *Moderately eroded eluvial soil*
E3k	Tugevasti erodeeritud rähkmuld *Severely eroded calcareous soil*
E3o	Tugevasti erodeeritud leostunud muld *Severely eroded leached soil*
E3I	Tugevasti erodeeritud leetunud muld *Severely eroded eluvial soil*
	Deluviaalmullad (D) / Deluvial soils (D)
Dam[1)]	Automorfne deluviaalmuld / *Automorphic deluvial soil*
Dg	Gleistunud deluviaalmuld / *Gleyed deluvial soil*
DG	Deluviaal-gleimuld / *Deluvial gley-soil*

[1)] Mullastiku kaartidel kasutatakse selle mullaliigi nimetusena koodi D
[1)] Code D is used as the name of this soil type on soil maps

Erosioonist häiritud muldade jaotamise kriteeriumid

EHM hulka kuuluvad automorfsed (põuakartlikud ja parasniisked) E mullad jaotatakse ühelt poolt **erosiooniastme alusel**:

- nõrgalt erodeeritud (paiknevad kallakutel <5°) mullad (E1, E[1], e): Ke, Koe, KIe, LPe, Lke;
- keskmiselt erodeeritud (kallakutel 5–10°) mullad (E2, E[2]): Ek2, Eo2 ja EI2 (NB! sõltuvalt kontekstist on aktsepteeritav ka E2k, E2o ja E2l);
- tugevasti erodeeritud (kallakutel 10–20°) mullad (E3, E[3]): Ek3, Eo3, EI3);
- väga tugevasti erodeeritud (kallakus >20°) mullad (tähistatakse mullakaardil tingmärgiga) kuna nad on oma olemuselt muldkatteta rikutud pinnased.

Koos E muldadega esinevad maastiku kõrgematel tasandikel vee-erosioonist puutumata mullad, millisteks võivad olla rähksed (K), leostunud (Ko), leetjad (KI), kahkjad (LP) või leetunud (Lk) mullad, mis moodustavad erineva mullaliikide koosseisuga mullakooslusi.

Teiselt poolt jaotatakse E mullad **profiili karbonaatsuse** või mulla kihisemise sügavuse järgi kolmeks:

- karbonaatsed E mullad (kihisemine kuni 30 cm sügavusel): Ke, Ek2, Ek3;
- leostunud E mullad (kihisemine sügavusel 30–60 cm): Koe, KIe, Eo2, Eo3 ja
- leetunud E mullad (kihisemine profiilis puudub või on sügavamal kui 60 cm): Lke (või LkIe kuni LkIIIe), LPe, EI2, EI3.

EHM hulka kuuluvad D mullad jaotatakse, esiteks **veerežiimi** järgi, eristades:

- automorfsed (parasniisked) D mullad – Dam;
- gleistunud ehk niisked D mullad -– Dg;
- deluviaalsed-gleimullad – DG ja
- turvastunud D mullad – DG1.

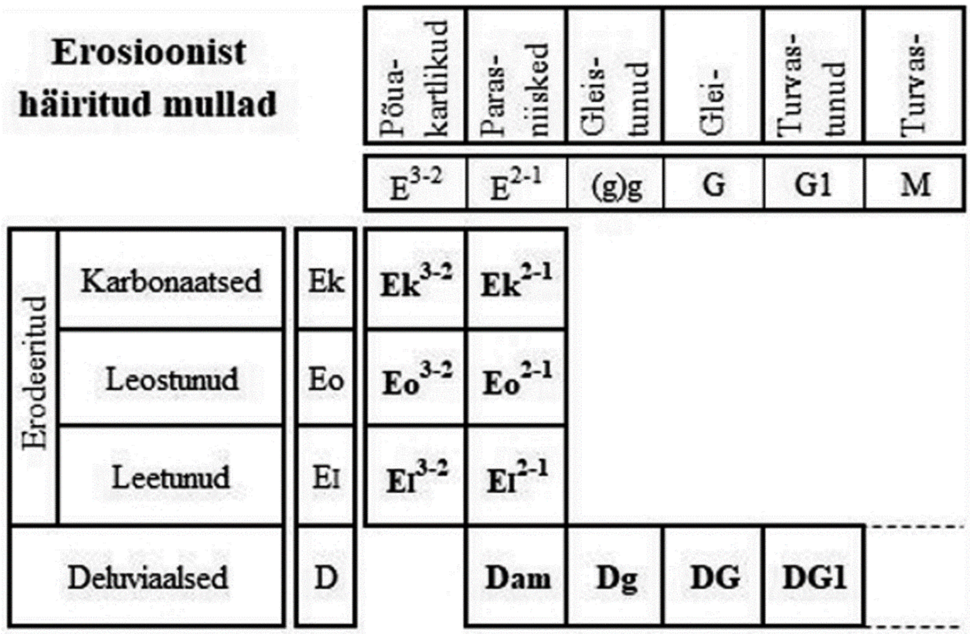
Teiselt poolt jaotatakse D mullad **pealeuhutud mullakihi tüseduse** järgi:

- nõrgalt pealeuhutud (Ad horisondi tüsedus on <30 cm) – D';
- keskmiselt pealeuhutud (Ad 30–60 cm – D'' ja
- tugevasti pealeuhutud (Ad tüsedus >60 cm) – D'''.

EHM mullaliikide omavaheline seos on kujutatud anormaalsete muldade maatriksil (joonis 4). See maatriks näitab EHM-de kui anormaalsete muldade seost vastavate normaalsete muldadega. Vertikaalse skalaari esimesel real paiknevad erodeeritud karbonaatsed (Ek) mullad on tekkinud rähk-(K)muldadest; Eo mullad – leostunud (Ko) ja leetjatest (KI) muldadest ning EI mullad kahkjatest (LP) ja leetunud (Lk) muldadest. Automorfsed deluviaalmullad (Dam) on omadustelt lähedased KI-LP-Lk muldadele.

Horisontaalse (mulla vee-olude) skalaari 0 positsioonil ehk esimeses tulbas on põuakartlikud mullad, millisteks on kõik E3 mullad (Ek3, Eo3 ja EI3) ning kerge lõimisega E2 mullad. Teises tulbas on parasniisked mullad, millisteks on kõik nõrgalt erodeeritud (E1, e) mullad (Ke, Koe, KIe, LPe ja Lke) ning keskmise ja raske lõimisega keskmiselt erodeeritud (E2) mullad. Deluviaalmuldade (maatriksi 4. rida) näitab, et lisaks joonisel toodud mullaliikidele võivad looduses esineda veel ka deluviaalsete setetega kaetud madalsoomullad (M).

Peale EHM kompleksi on Eesti muldkatte suuremõõtkavalisel uurimisel eristatud kallakulistel aladel esinevad erosiooniohtlikud mullad (EOM). Erosiooniohtlikeks peetakse muldasid, millistel võib nende üles-harimisel vallanduda mulda degradeeriv vee- või tuule erosioon. EOM jaotamise aluseks on mulla liik, selle lõimis ja kallakuse aste, millistest mõlemad on fikseeritud ka 1:10000 mullastiku kaartidel (Maa-uuringud, 2009). EOM nomenklatuur ja määramise alused on kättesaadavad suuremõõtkavaliste mullastiku kaartide seletuskirjadest ja välitööde juhenditest (Astover, 2012, 2013). Väliuurimistel on erosiooniohtlikkuse määramise aluseks mõõdetav suurus – ala kallakus kraadides (3–5° nõrgalt, 5–10° keskmiselt, 10–20° tugevasti ja >20° väga tugevasti erosiooniohtlikud), mis on märgitud kaardile astmete numbritega mullakoodi järgi sulgudes (vastavalt (1), (2), (3) ja (4)). Samas tuleb arvestada, et väiksemal hulgal juhtudel võib tegelik erodeeritus olla ohtlikkuse astmest nii suurem kui väiksem.



Joonis 4. Erosioonist häiritud muldade maatriks. Muldade nimetused leiab koodide järgi tabelist 1
Figure 4. *Matrix of erosion-affected soils. Vertical scalar: Eroded calcareous soils, Eroded leached soils, Eroded eluvial soils and Deluvial soils; Horizontal scalar: Drought timid soils, Normal moisture soils, Gleyed soils, Gley-soils, Peaty soils and Peat soils. For soil names after their codes see Table 1*

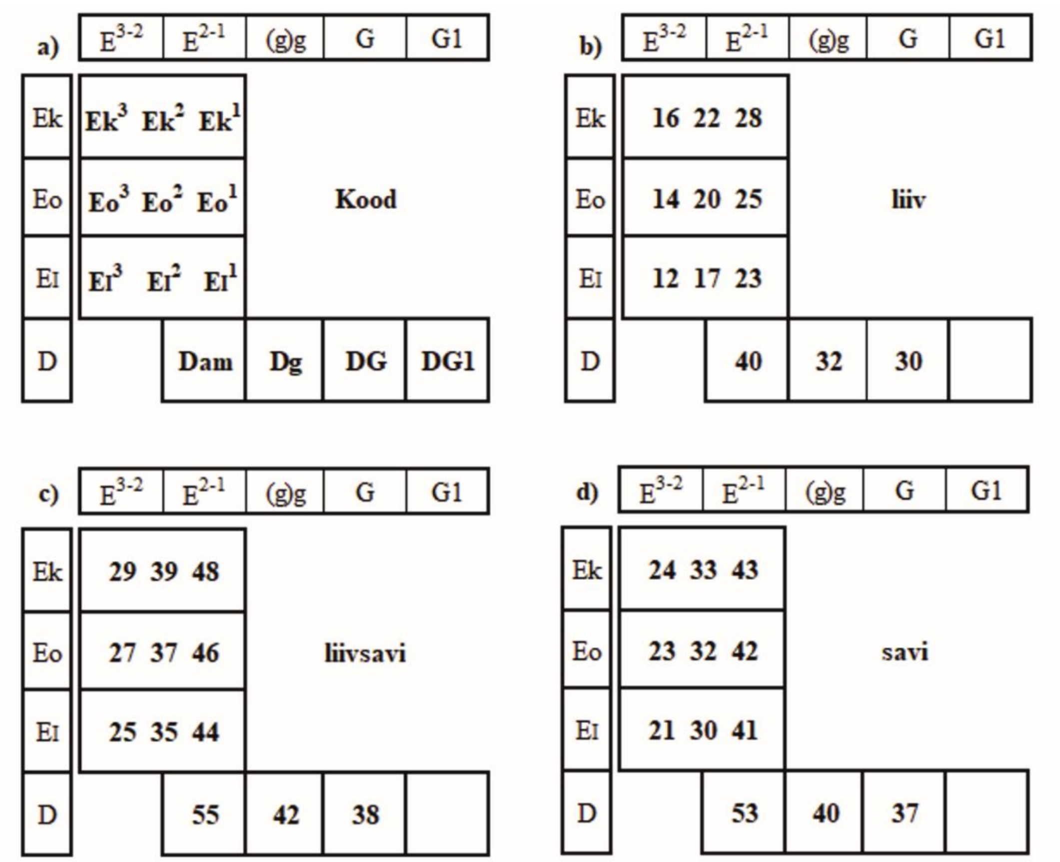
EHM ülesehitusest, omadustest, leviku seaduspärasustest ja produktiivsusest

EHM nomenklatuur määrab paljuski ära ka E ja D muldade huumusseisundi (Ae ja Ad tüsedus, huumuse sisaldus ja varu ning aastakäibe iseloom) ning viljakuse või produktiivsuse (boniteet, hindepunktid). Mistahes mullaliigi (või -erimi) huumusseisundi all mõistetakse selle mulla orgaanilise aine majandamise iseloomu ehk orgaanilise aine voogu läbi muldkatte: sisend mulda → seisund või olek ja muundumine → väljund. Muldade huumusseisundit saab peale huumuse (ehk orgaanilise aine) kaudu tehtava iseloomustuse teha ka mullas oleva orgaanilise süsiniku (C_{org}) või huumuses sisalduva energia alusel. EHM puhul on mulla orgaanilise aine käibes tegemist valdavalt hästi humifitseerunud orgaanilise aine ehk huumusega. Vaid liigniisketes deluviaalmuldade huumusprofiili alumises osas või maetud mulla profiilis võib esineda toorhuumust (pooleldi humifitseerunud orgaaniline aine) või turvast (väga vähesel määral humifitseerunud).

Käesolevaks ajaks on EMK-is välja kujunenud E muldade erosiooniastme järgi jaotamine üldistatud skeem kogu mullamassi (või ka selle koostis oleva huumuse või C_{org}) ärakantud ja paigale jäänud koguste järgi, kus E1 puhul on <1/4 ära kantud ja >3/4 paigale jäänud; E2 puhul on need arvud vastavalt 1/4−1/2 ja 1/2−3/4; E3 puhul 1/2−3/4 ja 1/4−1/2 ning E4 puhul >3/4 ja <1/4. Kuna maapinna kulumist ehk erosiooni ei ole võimalik määrata ärakantud mullakihi paksuse kaudu, tehakse erosiooni aste kindlaks kohale jäänud (olemasoleva) huumusevaru pindtiheduse (Mg ehk tonni hektari kohta või kg $m^{2\,-1}$) alusel.

Erosioonist mõjutatud huumushorisondi (Ae) tüsedus ei sobi hästi erosiooniastme määramiseks, sest muld võib olla küntud sügavamalt kui seda on põhjustanud erosioon. Ei sobi ka huumuse (*pro* C_{org}) sisaldus (kontsentratsiooni mõttes), sest see võib olla lahjendatud liialt sügava künni tõttu. Küll aga on heaks näitajaks huumuse või C_{org} varu pindtiheduse muutumine. Ka D muldade puhul tuleks põhinäitajaks võtta huumuse varu. Samas iseloomustab keskmiselt ja tugevasti pealeuhutud D muldasid hästi ka deluviaalse huumushorisondi (Ad) tüsedus, sest et piir maetud ja pealeuhutud mulla vahel on morfoloogiliste tunnuste järgi nendel muldadel kergemini määratav. Nõrgalt pealeuhutud D muldade korral on tüsedusega opereerimine küsitav, sest Ad kujunemine võib olla mõjutatud sügava künniga. Kuigi tavaliselt on D muldade huumusesisaldus veidi kõrgem tänu peenestunud orgaanilise aine osiste juurdetulekule mulda, eksisteerib siin seaduspärasus, et tugevasti erodeeritud muldadele kaasnevad D mullad on tunduvalt vaesemad C_{org} poolest võrreldes vähemal määral erodeeritud muldadele kaasnevate D muldadega.

EHM huumusseisundiga on otseselt seotud nende produktiivsus, mille kaudseks näitajaks on mulla boniteet. Siinjuures saab mulla boniteedi hindamistabeleid, mis on koostatud varem katsetes saadud andmete ja nende üldistuste alusel, käsitleda kui Eesti EHM produktiivsuse mudelit (Maa-amet, 1992). Mõnede erodeeritud mullaerimite viljakuse (antuna hindepunktides) seost ja selle muutumise seaduspärasust iseloomustab joonis 5. Jooniselt selgub, et mulla viljakus väheneb oluliselt seoses erosiooniastme suurenemise ja lõimise muutumisega liivsavidelt kergemate lõimiste (saviliiv, liiv) suunas.



Joonis 5. Erosioonist häiritud muldade boniteet hindepunktides olenevalt mulla lõimisest (Maa-amet, 1992). Muldade nimetused leiab koodide järgi tabelist 1
Figure 5. *Quality of erosion-affected soils in points as dependent of their texture (Maa-amet, 1992). Compartments: a) codes, b) sand, c) loam and c) clay. For soil names after their codes see Table 1*

Jooniselt 2 selguvad hindepunktide muutumise seaduspärasused: 1) lõimiselt sl → ls (aga ka l → sl) tõuseb boniteet 6 kuni 10 punkti võrra; 2) Ek → Eo → EI väheneb boniteet 2 punkti võrra iga jaotuse kohta, ja 3) E1 → E3 alaneb boniteet 5–6 punkti võrra ühe erosiooni astme kohta. D muldade puhul suureneb boniteet reas l → sl → ls 7–8 punkti võrra ja kuivenduse mõjul reas DG → Dg → Dam puhul 4–5 punkti võrra iga astme kohta. R. Kase (1975) eksperthinnangu järgi väheneb mulla produktiivsus võrreldes vastava normaalse mullaga reas E1 → E2 → E3 vastavalt 15, 30 ja 50%. Üldise seaduspärasuse järgi suureneb erosiooni tagajärjel muldade karbonaatsus ehk on tajutav oluline mulla pH tõus. Taoline nähtus on otseselt seotud moreenküngastike lähtekivimitega, mis on valdavas osas karbonaatsed. Muldkatte pealt kulumine toob neid materjale maapinnale järjest lähemale.

Uurimisandmetega on tõestatud ka lõimiste paiknemise seaduspärasused D muldadel (Kask, 1955b; Heinsalu, 1982). Nii setivad tugevama erosiooni korral paigast nihutatud mulla korese (kruus, rähk) ja mullapeenese (jäme liiv) osised nõlva jalamite kõrgematel osadel, peene liiva ja jämeda tolmu osakesed sellest allpool, nõlva nõgusal jalamil. Samas ei seti ibe ja peene tolmu osakesed kuigi kergesti välja erosiooni põhjustavatest vetest ning nad kantakse kaugematele tasandikele või sulglohkudesse. Nimetatud nõlva- või erosiooniprotsessidest tingituna on D muldade puhul enamlevinud lõimise kateenadeks liiv → saviliiv → liivsavi → savi. Loomulikult on võimalikud erinevad kombinatsioonid sõltuvalt erodeerumisele allunud mulla granulomeetrilisest koostisest ehk lõimisest.

II Ajalooline ülevaade Eesti erosioonist häiritud muldade teaduslikust uurimisest: Olulisi momente ja isikuid

Sissejuhatuseks

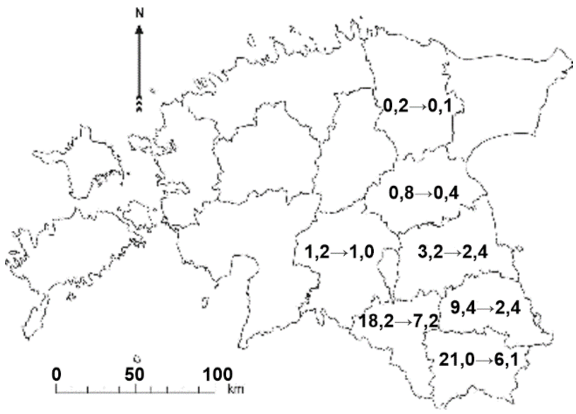
Muldade klassifikatsiooni (sh EMK) tuleks võtta kui töövahendit, mille abil määratakse mulla nimetus ja fikseeritakse sealjuures teatud hulk mulla diagnostilisi omadusi. Käesoleval ajal ametlikus kasutuses olev EHM klassifitseerimise versioon sai oma praeguse sisu ja ülesehituse juba 1980-ndate aastate alguses (EPP, 1982). Selleks ajaks oli tema üle piisavalt diskuteeritud, praktikas järeleproovitud ja täiustatud *ca* 35 aastat. EHM klassifikatsiooni arendamine toimus muidugi koos kogu EMK-ga, mille arenduse kulgu on analüüsitud mitmetes ülevaatelistes kirjutistes (Kõlli, 1998). Samas peab mainima, et ei EHM jaotus, ega kogu EMK ole midagi põlistatut, sest nad on avatud asjakohastele täiendustele kui selleks on põhjust või on kogunenud suuremal hulgal uut teavet. Teatavasti on erinevate mullaklassifikatsioonide puhul olnud heaks tavaks, et teatud aja (*ca* iga tosina aasta) tagant revideeritakse ja täiendatakse uuesti kogunenud info ja teadmiste alusel kehtivat klassifikatsiooni ja minnakse üle uuele täiustatud versioonile. Samal ajal püütakse seda lähendada globaalselt enamkasutatavatele põhimõtetele või jaotustele. Taunimist väärivaks asjaks on igal juhul rahvusliku töötluse või aspekti ignoreerimine st täielik mugandumine mingisse rahvusvaheliselt tuntumasse süsteemi (WRB, USDA, jt). Samas tuleks EMK järgi tehtud määrangud jätta avatuks rahvusvahelisele üldsusele nende (s.o EMK järgi tehtud määrangute) konverteerimisega eelpoolmainitud (WRB, USDA) globaalselt enamtuntud süsteemidesse (SSS, 2014; IUSS, 2015).

Tee tänapäeval aktsepteeritud EHM klassifikatsioonini ja välitööde metoodikateni

Kuigi EHM käsitlesid põgusalt ka Eesti vanema põlvkonna mullateaduse suurkujud Anton Nõmmik (1938) ja Alfred Lillema (1949) oli üheks väljapaistvamaks erodeeritud muldade klassifikatsiooni väljatöötajaks ja uurijaks Rein Kask (1953; 1955a; 1955b; 1960a). Tema arvukates töödes ja hiljem koos Arnold Pihoga valmisid esimesed trükised erodeeritud muldade väliuurimise metoodika (kirjeldamine, kaardistamine, proovide võtmine, omaduste süstematiseerimine jms) kohta (Piho, Kask 1960; Piho jt, 1960). Alates viiekümnendate lõpust kui moodustati mullastiku uurimise grupp (millest kujunes hiljem Eesti Põllumajandusprojekti mullastiku uurimise osakond) toimusid rohkearvulised diskussioonid nii kogu mullastikku hõlmava EMK kui ka sellesse kuuluva EHM klassifitseerimise osas (Rooma, 1984). R. Kase ja A. Piho kõrval andsid selles asjas suure panuse praktilise kaardistamise otsesed läbiviijad Igna Rooma, Ragnar Kokk, Vambola Valler, Toomas Teras jt, tehes seda selleks ajaks laekunud uurimisandmete alusel (Kokk jt, 1968; Kokk, Rooma, 1974; Kokk, 1977). Käesoleval ajal kasutatava Eesti EHM klassifikatsiooni leiab väheste täiendustega mitmetest publikatsioonidest (Maa-amet, 2001; Maa-uuringud, 2009; Astover, 2012). Olulisel määral on edasi arendatud ka välitööde metoodikat (Kõlli, 1993; Astover, 2013) ning nüüd on see üsna lähedane rahvusvaheliselt tuntumate juhendmaterjalidega (SSDS, 1993; FAO, 2006).

Erosioonist häiritud muldade levikust Eestis

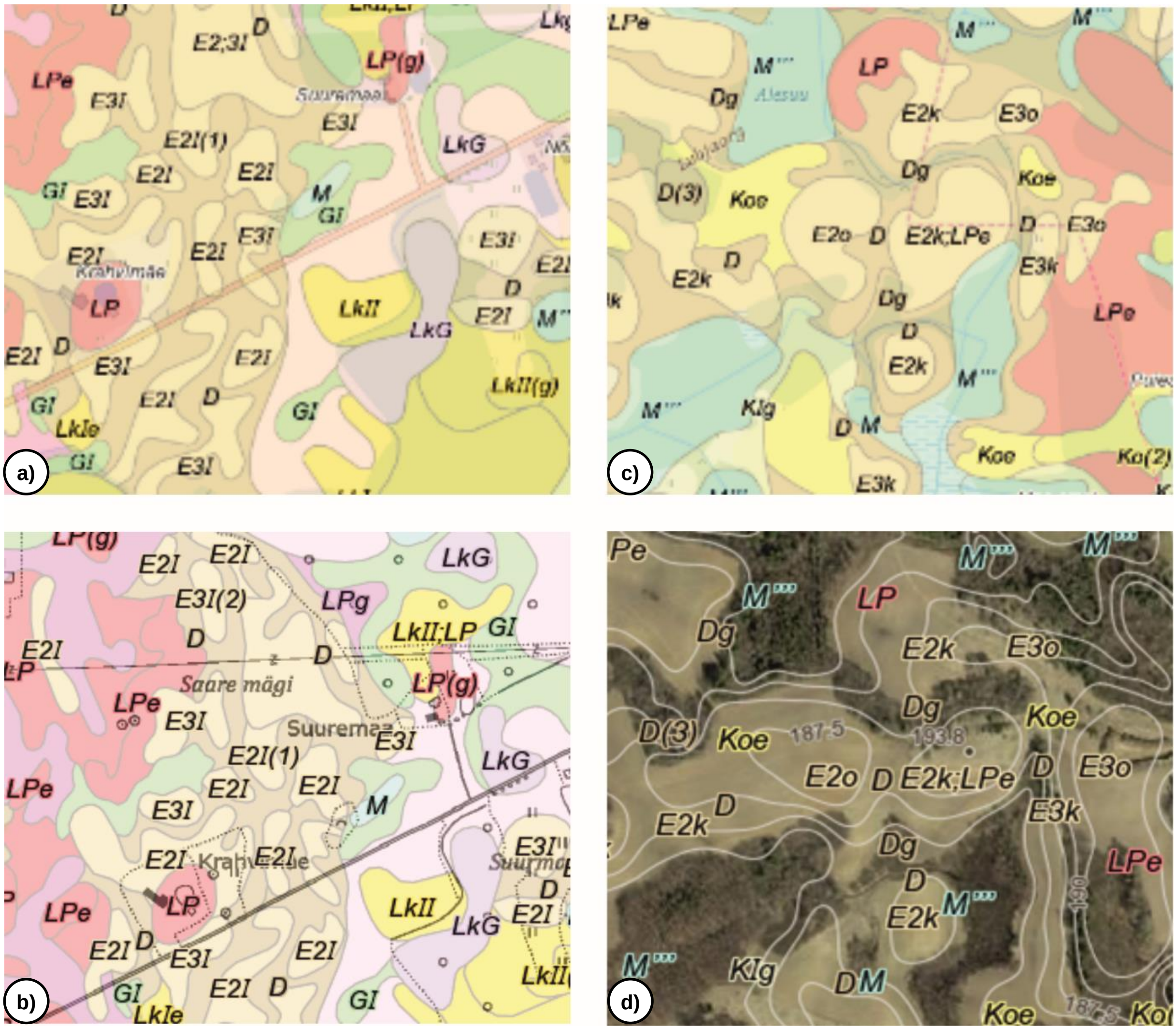
Esialgseid andmeid EHM levikust võib leida juba Eesti Vabariigi kahe- ja kolmekümnendatest aastatest (Nõmmik, 1925, 1938). Kuid esimese Eesti mullastiku valdkondadeks jaotuse skeemi, milles oli eristatud ka erodeeritud muldade valdkond, ja Eesti mullastiku kaardi koostas siiski A. Lillema (1958, 1959). Pinnalise erosiooniprotsessi levikut Eestis on uurinud R. Kask (1959). Käivitunud suuremõõtkavalise mullastiku uurimisega lisandus olulist teavet ka EHM kohta, nii et oli võimalik näidata EHM-de koosseisu kogu Eesti, eristatud agro-mullastikuliste mikrorajoonide ja maakondade (joonis 6) ulatuses (Kokk, Rooma, 1974, 1983; Kokk, 1995). Kõige täpsema ülevaate mistahes Eestimaa nurgas esinevatest EHM-dest annab interneti kaudu kättesaadav Eesti digitaalne mullastiku kaart (joonis 7; Maa-uuringud, 2009). Selle kaardi alusel on koostatud eri tehnikates ülevaatlikke skeeme EHM esinemisest Eestis (Kask jt, 2006; Köster jt, 2010; Leedu, Astover, 2019).



Joonis 6. Erosioonist häiritud muldade levik Eesti maakondade põllumajanduslikul maal (Kokk, Rooma, 1974).
Mullad: E → D, kus esimene arv näitab erodeeritud ja teine deluviaalmuldade osakaalu protsentides
Figure 6. *Percentage of eroded (first number) and deluvial soils (second number) from the total agricultural land of Estonian counties (by Kokk, Rooma, 1974)*

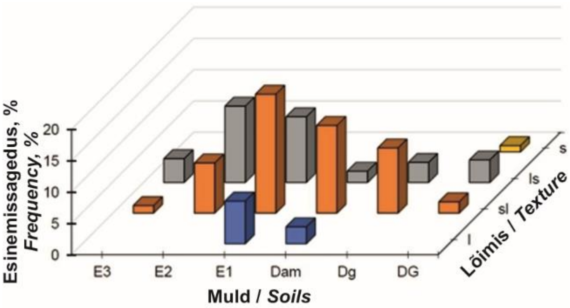
Tänuväärse arenduse on teinud maastikuteadlane Ivar Arold, kes maastiku struktuurühikute eraldamisel on võtnud arvesse ka EHM (Arold, 2005). Nii on tema poolt eristatud karbonaatse ja karbonaadivaese kattega moreenküngastike paigastikud, kus esimesel on domineerivateks Ek ja Eo mullad, mille erimite lõimiseks on karbonaatset veerist sisaldavad saviliivad ja liivsavid (vsl, vls), teistel aga leetunud mullad (EI) raudkiviveeriselised saviliivad ja liivsavid (v°sl, v°ls). Lisaks nendele on eristatud erodeeritud muldkattega voorestike paigastikud, mis on jaotatud samuti kaheks vastavalt kattekihi karbonaatsusele ja sellega seotud erodeeritud mullaliikide esinemisele. I. Aroldi (2005) maastiku paigastike kaart kätkeb endas seega ka EHM muldade levikut.

EHM levikut mullaerimite tasemel Eestis kajastab ülevaatlikult joonis 8, mis on koostatud põllumajanduslike maade kaardistamisel kogunenud andmete põhjal (Kokk, Rooma, 1974, 1983). Mitme autori arvates on EHM osakaal Eesti haritava maa muldade hulgas vähenenud seoses piirangutele maakasutuse tehnoloogiates, nende viimisega metsade ja rohumaade alla jms (Kask, 1975, 1996; Reintam jt, 2000, 2001).



Joonis 7. Väljavõtted Eesti digitaalselt mullastiku kaardilt. Asukoht ja kaardi liik: a) Krahvimäe ümbrus, b) sama põhikaardil, c) Kuutsemäe ümbrus ja d) sama kõrgusjoontega ortofotol (Maa-uuringud, 2009)

Figure 7. Excerpts from the digital soil map of Estonia. Location and kind of map: a) Environs of Krahvimäe b) the same on basic map, c) Environs of Kuutsemäe, and d) the same on orthophoto with height lines (Maa-uuringud, 2009)



Joonis 8. Eesti erosioonist häiritud muldade koosseis mullaerimite lõikes (Kokk, Rooma, 1983)

***Figure 8.** Composition of erosion-affected soils of Estonia by their varieties (Kokk, Rooma, 1983). Soil names by codes see Table 1. Texture: l – sand, sl – loamy sand, ls – loam and s – clay*

Uurimused EHM koosseisu, nende tekkeprotsesside ja seisundi kohta

Erosiooni kui kallaklikel aladel esinevat muldkatte omadusi muutvat ja diferentseerivat nähtust on Eesti olude kohta oma rohkearvuliste töödes valgustanud R. Kask. Tema töödes EHM-dega maastike kohta on käsitletud erosiooniprotsesside toimumise mehhanisme (Kask, 1955b, 1957, 1958, 1960b, 1975, 1984, 1996). Olulise panuse erosiooniprotsesside käsitlemise osas on teinud ka Alo Heinsalu (Heinsalu, 1982, 1983; Kask, Heinsalu, 1991). Käesoleva sajandi teise aastakümne üldistused Eestis toimuvate erosiooniprotsesside kohta nii mullateaduse (Astover, 2012) kui maateaduse seisukohalt (Hang, Kalm, 2014) on tehtud vastavates kõrgkooli õpikutes.

Adekvaatse ülevaate EHM omavahelistest seostest ja struktuurist on andnud tugevasti liigestatud maastikku rajatud pikiprofiilide (transektide) põhjal toimunud EHM kateenade uurimised. Taolised uurimused on andnud peale muldade koosseisu ja ülesehituse kindlakstegemise teavet ka muldade ja nende lõimiste järgnevuse seaduspärasustest (Kokk, Rooma, 1971; Heinsalu, 1983, 1988; Kõlli jt, 2010; Jandl jt, 2019). Erosiooniprotsesse, EHM-sid ja nendega seotud maakasutuse eripärasust on käsitletud nii agronoomia eriala lõputöödes (Liiva, 1992; Ellermäe, 1996), kui ka magistri (Ellermäe, 1999) ja teaduste kandidaadi (Kask, 1955b; Ratas, 1979b) väitekirjades.

Põhjapaneva töö Eestis esineva tuuleerosiooni kohta on teinud Rein Ratas oma väitekirjas (Ratas, 1979b). Tuule-erosiooni toimumisega seotud seaduspärasusi ja toimumiseks vajalike tingimuste esinemist Eesti maastikes on käsitlenud paljud erinevad autorid (Valler, 1972; Int, 1977; Ratas, 1977, 1979a; Ratas, Int, 1978; Kask, Raig, 1983; Reintam jt, 2000, 2001; Köster jt, 2010). Üldiselt on tuuleerosiooni ohtlikud taimestumata rannikualad ning liiva ja turbalõimisega külvieelsed põllud. Eesti tuuleerosiooniohtlike alade pindala on kokku 100 000 ha, millest 32% asub haritaval maal (Köster jt, 2010). Andmeid tuule ärakande kvantitatiivsete hinnangute ja granulomeetriliste fraktsioonide väljasettimise seaduspärasuste kohta leiab R. Ratase (1977, 1979a) töödest.

EHM omaduste uurimine ja kasutussoovituste andmine

EHM nomenklatuuri, leviku ja morfoloogiliste tunnuste uurimise kõrval on Eestis põhjalikumalt käsitletud EHM huumuse sisaldust ja varusid, lõimist, happesust ning produktiivsust (Kask, 1955a, 1985, 1987; Kokk, Rooma, 1971; Kõlli jt, 2010). Tagasihoidlikult on Eestis uuritud ja üldistatud käesoleva ajaperioodi kohta käivat infot nii agrokeemiliste kui ka bioloogiliste omaduste osas. Tähelepanuväärseks panuseks selles osas on R. Kase varasemad agrokeemiliste omaduste uurimused *ca* tosinal uurimisalal viiekümnendatel aastatel (Kask, 1955b).

Samas tuleb tõdeda, et EHM keskmiste omaduste kindlakstegemisel ei ole olulist kasu praktilisele põllumajandusele seoses mullaliikide suure heterogeensusega ja pideva omaduste muutustega maastikul. Tingitud muldkatte suurest heterogeensusest on mullaareaalid (kaardil kontuurid) väikese pindalaga. Lisaks sellele esinevad EHM omadustes suhteliselt suured regionaalsed erinevused. EHM majandamise aluseks tuleks võtta ennekõike mullaerimite koosseis ja huumusseisund.

EHM kirjusus on kõige suurem künklikus moreenmaastikus, kus normaalset põllupidamist häirib ebaühtlane veerežiim ja suured erinevused muldade huumusseisundis. Nimetatud asjaoludest tingituna langevad muldade harimisküpsuse saabumine ja optimaalsed külviajad erinevatele aegadele, suuresti erinevad on põllu eri osade muldade väetistarbed ja põldude saagikus. Erinevus E ja D muldade saagikuste vahel võib maksimaalselt olla kuni 9–10 kordne (Kask, 1975).

Kiirendatud vee-erosiooni ärahoidmise või vähendamise võtteid on uuritud ja soovitatud väga mitmesuguseid (Lillema, 1959; Kask, 1953, 1955a, 1960b; Valler, 1972; Lutsar 1985). Üheks oluliseks EHM erosiooni tõkestavaks võtteks on rohumaade rajamine (Sau jt, 1969; Valler, 1972). Katsetatud on õhukese turbakihiga (multš) maapinna katmist (Loid jt, 1982; Lutsar, 1982, 1989) ning soovitatud on ka kaitsepuistute rajamist (Ratas, 1977).

EHM-le agronoomilise hinnangu andmisel produktiivsuse ja kasutussobivuse aspektist ning positsioneerimisel kõigi teiste põllumajanduslike muldade hulgas lähtutakse muldade agronoomilistest rühmadest (Valler, 1973). Eesti muldade agronoomilisele rühmitamisele alusepanijaks oli V. Valler (1972), kuigi ta ise viitab ka A. Pihole (1966), kes on eelnevalt käsitlenud rühmitamist seoses külvikordade rajamisega. Eelnevalt 1972. aastale on muldade agronoomilist rühmitamist käsitletud mitmetes praktikale suunatud publikatsioonides (Rooma jt, 1966; Rooma, Valler, 1967).

Käesolevaks ajaks on Piho-Valleri-Rooma-Koka tööd tunduvalt edasi arendatud (Teras, 1992) ja selle tulemus on talletatud õppevahendis "Muldade kasutussobivus ja agrorühmad" (Kõlli, 1994). Muldade agronoomilise rühmitamise järgi on E1 mullad saviliivast savideni keskmised põllu tüüpi haritavad maad (B2 rühm). Selle rühma muldade 75 cm mullakihi veevaru on piirides 100–165 mm. E2 ja E3 mullad on rohumaa tüüpi haritavad maad. E2 muldade (rühm C4) ja E3 muldade (C5) veevarud on vastavalt alla 120 ja 110 mm. Teave Eesti muldade kasutussobivuse hinnangute kohta on leidnud kajastust ka Euroopa tasemel (Reintam jt, 2005).

Eraldi märkimist väärivad asjaolud

R. Kase uurimustest (1955b, 1975) on selgunud seaduspärasus, et E mullad on rikkamad fosfori sisalduse ja vaesemad lämmastiku poolest (P > N) võrreldes nendega koos esinevate D muldade fosfori ja lämmastiku (P < N) sisaldusega. Samas olid mõlemad mullad vaesed taimedel omastatava kaaliumi poolest. Üheks tähelepanu väärivaks asjaks oli ka põllumajandusministri Harald Männiku käskkiri teadus- ja projektasutustele ning põllumajandusvalitsustele (PM KK, 1976). See käskkiri põhines eelnevalt kogunenud uurimisandmetel ja sisaldas riiklikul tasemel antud korraldusi riigi maa- ja mullaressursside (sh EHM) parema kasutamise huvides.

Huvipakkuvaks ettevõtmiseks oli samuti Eesti Maaparandusprojekti poolt A. Lutsari juhendamisel realiseeritud väljaparanduse projekt künklikul põllumajandusmaastikul Valgjärvel (Lutsar, 1982, 1985, 1989). EHM levikuga muldkatete omaduste parandamise eesmärgil kasutati siin huumuskatte aluste kihtide tasandamist koos sellele eelnevalt kooritud huumusmulla tagastamisega. Laiemalt oli kasutusel maapinna katmine õhukese turbamultšiga ja alusmulla tihenenud kihtide sügavkobestamine. Lisaks tavaliste harimisvõtete ja väetamise kasutamisele, rajati ammendatud turbavõtu aladele veel ka erineva suurusega tiike. Et taoline looduse ümberkujundamine toimus võrdlemisi piiratud alal, tuleks seda võtta kui üht piiratud alal tehtut katset. Seoses uute kogemuste saamisega välja- või muldkatte parandamise alal, saab taolist katsetust lugeda positiivseks nähtuseks. Taolise ettevõtmise edasist laiendamist (mida õnneks ei tehtud) võinuks aga lugeda pigem negatiivseks nähtuseks.

EHM klassikaliste kateenade võrdlev uurimine Taanis, Saksamaal, Poolas ja Eestis (Valgjärve) näitas

EHM füüsikaliste ja keemiliste mullaomaduste piki kateenasid toimuvate seaduspäraste muutuste head kokkulangevust (Jandl jt, 2019). Nendel kolmeastmeliste kateenade, alates kumerast nõlva ülemisest osast (I) läbi ärakande-pealeuhte tasakaalustunud ala (II) nõlva jalami nõgusa pealeuhtelise alani (III), uurimisel Arno Kanali ja Ülo Manderi osavõtul selgitati uudse asjana mulla orgaanilise aine biokeemilist koostist ja selle muutumise seaduspärasusi erosiooni käigus. Ligikaudu tosina biokeemilise aine määramine kolmel kateena alal, tõestas olulisi erinevusi orgaanilise aine kvaliteedis seoses mulla ümberpaiknemisega erosiooni protsessides.

Erodeeritud muldkattega on seotud veel üks seaduspärasus, mida ei ole võimalik näidata mulla suuremõõtkavalisel kaardil. Selleks on ülemineku (E-D protsesside poolest tasakaalus olev) ala, mille pikkus E-D kateenades või laius E-D kontuuride vahel on alates 10−15 m (tugeva erosiooni korral) kuni 30−50 m. Taolises nn neutraalses tsoonis on A või Ak tüsedus võrdne erosioonist mõjustamata muldadega. Suhtelisel kitsa kontuuri ja väikese pindala tõttu ei ole taolised mullad kajastatud nii EMK, ega ka 1:10000 mullakaardi kaardistamisühikute nimekirjas (Valler, 1972; Kõlli jt, 2010). Erosiooniohtlikkusele hinnangu andmisel nähtub, et mõju ulatuse pindala poolest on esikohal tehnoloogiline erosioon, teisel tuule-erosioon ja kolmandal vee-erosioon. Degradeerumise astme poolt vaadates teeb kõige enam kahju vee-erosioon, talle järgnevad tehnoloogiline ja tuule-erosioon (Kõlli jt, 2006).

Eesti EHM Euroopa võtmes

Euroopa vaatepunktist muldade erosiooni osas peetakse tähtsaimaks asjaks piirkondlike (sh riikide lõikes) erisuste või sarnasuste väljaselgitamist, tehes seda 1:250000 ja veelgi üldisemate mullakaartide ja andmebaaside põhjal (Montanarella, 2003; Bullock, Montanarella, 2005; Borelli jt, 2014). Erinevate üleeuroopaliste koondandmete järgi on Eestis EHM osatähtsus ja erosiooniprotsesside intensiivsus suuresti varieeruv, kuid keskmisena suhteliselt tagasihoidlik *ca* 0,4 tonni ha^{-1} a^{-1}, ulatudes vähestel aladel piiridesse 1–2 t ha^{-1} a^{-1} (Cerdan jt, 2010; Panagos jt, 2014). Samas ulatub see näitaja tugevasti erosiooniohtlike muldkatetega riikides piiridesse 2–5 t ha^{-1} a^{-1}. Köster jt (2010) andmetel on Eesti keskmine erosiooni intensiivsus loodusliku taimkatte korral ligikaudu 0,04 t ha^{-1} a^{-1}, kuid haritavatel muldadel *ca* 0,43 t ha^{-1} a^{-1}.

Konverteerides Eesti EHM nimesid WRB süsteemi tuleb arvestada, et ei E, ega D muldade jaoks ole eristatud referentsmuldasid (IUSS, 2015). E3 mullad ja osalt ka E2 mullad kuuluvad valdavalt Regosols'ide alla, kuid E1 (osalt ka E2) ja D muldade kuuluvus on laiem. Viimased kolm EHM-da eristatakse mingi sobivaima referentsmulla hulgas kasutades EHM-s toimuvaid protsesse kajastavaid täiendsõnu (ehk kvalifikaatoreid). Olulisemad (1) ärauhet näitavad täiendsõnad on: *aric* – küntud; *entic* – algarengu seisus olev, ja (2) pealeuhet kajastavad: *colluvic* – peale uhutud; *novic* – uus kiht 5–50 cm; *transportic* – lähedalt teisaldatud; *relocatic* – ümberpaiknemine kõrvale või vertikaalselt; *aeolic* – tuulesete; *inclinic* – kallakul >5%; *pachic* – esineb >50 cm paksune Ad horisont.

Teisest küljest tuleb mullanimede konverteerimisel kasutada ka mulla põhiomadusi kajastavaid tunnussõnu, mis näitavad kas algse või praeguse mulla

(1) olemust või tekke iseärasust: *rendzic* – pehmehuumuslik tume A horisont lubjakivi koresel või pael; *cambic* – vähemuundunud horisont; *luvic* – savi sisseuhte tunnused; *retic* – heledamad kergema lõimisega keeled ja sopistused B horisondis; *spodic* – Fe, Al ja/või huumus on ülemisest mulla osast ümberpaiknenud B horisonti; *umbric* – küllastumata A horisont.

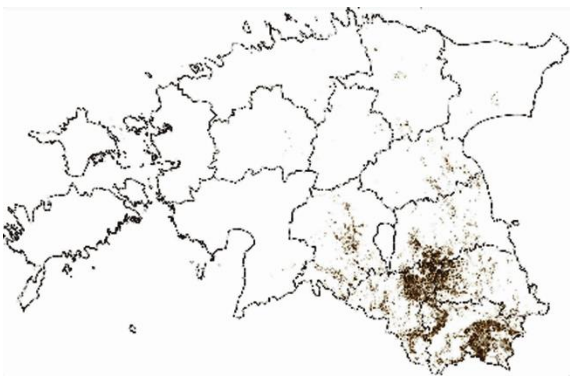
(2) lõimist*:* *skeletic* – korest >40%; *arenic* – liiv ja saviliiv; *loamic* – liivsavine; *siltic* – tolmjas; *clayic* – savine.

(3) erinevaid omadusi: *albic* – valge; *calcaric* – sisaldab $CaCO_3$; *eutric* – toiterikas; *dystric* – toitevaene; *humic* – huumust >1%; *ochric* – huumust *ca* 0,5%; *cutanic* – mulla osistel esineb savist kattekihte; *lamellic* – profiilis on õhuke savirikas kiht; *haplic* – tüüpiline. Lisaks kasutatakse veel ka täiendsõnade eesliiteid: *epi-*, *endo-*, *cumuli-*, *thapto-*, *proto-* jt.

WRB järgi antud nimed on individuaalsed, mitte aga klassifikatsiooni taksonid. Piirdume siinjuures vaid mõne näitega (EMK kood koos WRB nimetusega): **E3k** – Eutric Calcaric Skeletic **Regosol** (Aric, Arenic, Humic); **E2o** – Eutric Endocalcaric **Cambisol** (Aric, Loamic, Humic); **E3I** – Dystric Protic **Regosol** (Aric, Arenic, Ochric); **LPe** – Dystric Glossic Fragic **Retisol** (Siltic, Aric, Humic); **Dg** – Haplic Gleyic **Luvisol** (Loamic, Colluvic, Humic), **DG** – Eutric Mollic Reductic **Gleysol** (Colluvic, Loamic, Cumulinovic).

Lõpetuseks

Kiirendatud vee- ja tuuleerosioon ei ole olulisteks muldkatet degradeerivateks teguriteks Eestis üleriigiliselt. Küll aga on muldade erosioon koos EHM tekkega eluliselt tähtsad regionaalselt ja seda ennekõike Kagu-Eestis (joonis 9).



Joonis 9. Erosioonist häiritud muldade levik Eestis. Koostajad P. Penu ja T. Kikas
Figure 9. *Distribution of erosion-affected soils in Estonia. Compiled by P. Penu and T. Kikas*

Kuna peetakse igati mõistlikuks põllumajandusega tegelemist ka EHM levikuga aladel, mis tagab samas ka künkliku pinnamoega looduskaunite põllumajandusmaastike säilimise, tuleks igati toetada mullaerosiooni ärahoidvate ja/või leevendamise võtete kasutamist lokaalselt st erosiooniohtlikel aladel. Hea on tõdeda, et vastav toetuste süsteem (PRIA kaudne) ja selle rakendamise kogemus on Eesti riigil ka olemas. Loodetavasti muutub see ajapikku täiuslikumaks ja veelgi otstarbekohasemaks. Mullakaitse seisukohalt tuleks võtta erosioonist enam häiritud mullad kasutusele ennekõike rohumaadena. Samas tuleks maaelu edendamise nimel leida EHM levikualadel võimalusi ka teravilja ja rühvelkultuuride kasvatamiseks selleks enam sobivatel muldadel.

Huvitav on asjaolu, et EHM-dega alasid saab käsitleda kui C_{org} akumulaatoreid. Mehhanism seisneb siin selles, et E muldadesse iga-aastaselt sattunud uue taimse varise nii tugevasti peenestatud kui ka humifitseerunud osad kantakse koos mulla mineraalsete osistega erosiooni käigus maastiku madalametele osadele, kus nad moodustavad D mulla. Järjestikuste uute D mulla kihtide ladestumisega maetakse eelmised järjest sügavamale kuni nende väljalülitumise aktiivsest bioloogilisest aineringest. Erosiooni kiirenedes degradeerub järjest enam ka D muld, sest järjest huumusvaesemast E mullast pärinevad setted on oluliselt huumusvaesemad eelnevatest. Kõige eelöeldu tulemusel tekib paradoksaalne olukord, kus süsinikupoliitika seisukohalt on tegemist positiivse nähtusega: toodeti huumus ja maeti see aastakümneteks muldkatte alla. Agronoomia seisukohalt on taoline protsess vägagi negatiivne: väheneb mulla produktsioonivõime, suureneb heterogeensus jne ning see maa-ala ei kõlba enam põllukultuuride viljelemiseks.

Kirjanduse loetelu Eestis tehtu kohta ei sisalda kaugeltki kõiki EHM uurimist käsitlevaid publitseeritud töid. On loetletud vaid need, mida kasutati erosiooni uurimise ajaloost ülevaate tegemisel.

Erosion-affected soils in Estonian soil cover: Nomenclature of soils and their research history

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Summary

In Part I of the work with the subtitle "Overview about nomenclature and formation of influenced by erosion soils" firstly, the regularities of erosion processes and their forming conditions in the soil cover, and secondly, the agro-ecological properties and nomenclature of formed erosion-affected soils (EAS), are treated. The work is dedicated to the year 2020 soil of Estonia, for which are eroded soils. In Estonian soil classification (ESC) and the list of soil mapping units, 11 eroded and 3 deluvial soil species have been distinguished. The names and codes of EAS in the ESC are presented in Table 1. The main criteria of eroded soils determination are the intensity or stage of erosion and calcareousness of soils. But the deluvial soils are distinguished by their water regime and by the thickness of formed deluvial (colluvial) humus horizon. In Part I also the determination criteria and classification of erosion-prone soils and the agronomic quality of EAS are analysed.

In Part II with subtitle "Historic overview about scientific researches upon erosion-affected soils in Estonia: Essential facts and engaged persons", the scientific researches dedicated to the study of different aspects connected with EAS-s and happened during the last century are presented. In this overview besides main thematic issues, also the role of leading scientists in researches of most actual problems is treated. The most essential themes during studied in overview period (during last century) were very variegated. These researches started with elaboration suitable for local conditions EAS classification and methods for their field researches. For very actual problems were the distribution of EAS in Estonia and also studies upon EAS-s forming, a composition by species and actual status. As a result of above named activities was possible to form different databases on essential properties of EAS-s and to elaborate the derived from this the rules of ecologically sustainable use of EAS-s. At the end of work, the international aspects of presentation Estonian EAS and local researches are treated. The article contains one Table, 9 Figures. From the list of used literature (totally 80), entirely 70 sources are connected with treating of Estonian EAS-s.

Huvide konflikt / *Conflict of interest*

Autor kinnitab artikliga seotud huvide konflikti puudumist.
The author declares that there is no conflict of interest regarding the publication of this paper.

Autorite panus / *Author contributions*

RK, TT – artikli kontseptsioon ja planeerimine / *study conception and design*;
RK, TT – andmete kogumine / *acquisition of data*;
RK – andmete analüüs / *analysis of data*;
TT – illustreeriva materjali vormistamine / *design of figures*;
RK – käsikirja mustandi kirjutamine / *drafting of manuscript*;
RK, TT – lõpliku käsikirja toimetamine ja heaks kiitmine / *critical revision and approve the final manuscript*.

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Agraarteadus
1 • XXXI • 2020 41–46

Journal of Agricultural Science
1 • XXXI • 2020 41–46

OPTIMIZATION OF OPTIONS FOR DIFFERENTIAL APPLICATION OF NITROGEN FERTILIZERS IN THE PRECISION FARMING SYSTEM

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Saabunud: Received: 26.01.2020
Aktsepteeritud: Accepted: 12.05.2020

Avaldatud veebis: Published online: 12.05.2020

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Keywords: precision farming, differential application, nitrogen, spring wheat, hydrothermal coefficient, test sites.

DOI: 10.15159/jas.20.06

ABSTRACT. This paper aims to present the use of various treatments for the differential application of nitrogen in the precision farming system. To assess the state of the vegetation cover, both ground-based observations and associated remote sensing methods were used. Assessment of the state of plants (Menkovsky of AFI, 2009–2011) was carried out according to the phases of their growth and development using an N-tester in the field, as well as analysis of plant samples in a specialized laboratory. Remote sensing was carried out at the time of the analysis of plant samples using unmanned aerial vehicles equipped with cameras that allow shooting in different areas of the spectrum. The test sites with predetermined doses of nitrogen fertilizers for decrypt the obtained images were used. It is shown that for differential application of nitrogen fertilizers in spring wheat crops it is advisable to use the optical characteristics of the state of plants performed using calibration test sites. We have found that the maximum yield in the differentiated nitrogen applications treatment (TK-4) was 4510 kg per hectare (kg ha^{-1}). At the same time, the minimum in the TK-1 treatment was 3780 kg ha^{-1}. On average, over the years of research differentiated fertilizer application increased the collection of protein per hectare by 15–17%. In the TK-4 treatment for three years, a grain was obtained that corresponded to the first quality class (exceed 14%) in terms of protein content. Our novel research has shown that for characterizing the state of plants an assessment is given which was performed using calibration test sites.

Introduction

The technology for the precise application of fertilizers and other agrochemicals based on the results of assessing the state of soil and land cover is a very urgent task. Wherein, the economic and environmental problems of agricultural production are also important. We should be noted that the information concerning precision farming is rather large (Abler, 2004; Anselin *et al.*, 2004; Godwin *et al.*, 2003; McBratney *et al.*, 2005). Also by authors (Beluhova-Uzumova *et al.*, 2019) have been conducted an extensive review of the literature and gave an analysis of the economic efficiency of technique and technology regarding precision farming.

Nevertheless, there are still unresolved issues related to the underdevelopment of the general theory of control of such objects and systems, not to mention about high precision instruments, methods, machines and equipment, which are necessary for the implementtation of above-mentioned technology. At the same time is important the low efficiency of existing software and information support and of course relevant databases and knowledge, and adaptation of technologies to agro-climatic and other conditions of production (Report to EC Directorate, 2007; Report of GSC EU. 2019). Significantly limits the capabilities of precision farming technologies and techniques underutilization of associated remote sensing means with detailed ground-based observations. This is because there is no scientific backlog in this area, where a common methodology is not developed and reliable methods for obtaining and applying information about the state of crops. Besides, the test sites for decrypting the obtained images are not developed.

One of the most important technological operations in the precision farming system is the differential application of nitrogen fertilizers, which is made taking into account small-scale heterogeneity within the field (Blackmore *et al.*, 1994). The main task of our investigations is the optimal management of sowing to achieve an established crop and specific quality for this variety (Yakushev, 2016).

Material and Methods

The studies were carried out in the field conditions of the Menkovsky (59⁰42' up to 59⁰46' N and 30⁰18' up to 30⁰20' E) of Agrophysical Research Institute (AFI) located in the Pskov soil district (Gagarina *et al.*, 1995), where the most common are sod-weakly and medium-podzolic soils. Among these soils, light and medium loamy and loamy sand on the moraine prevail.

As for remote sensing, it was done from an unmanned aerial vehicle (UAV) using two SLR cameras, which make it possible to obtain images in the visible and near-infrared ranges using the upgraded Canon EOS Rebel T1i digital camera. To obtain images in the visible range, an Olympus E-510 camera was used. Each of the digital cameras used for aerial photography of agricultural fields was connected to a UAV remote control.

In the experiments, the following experimental treatments were used:

1. Control, without fertilizing (2.33 ha)
2. High-intensity (HIO) – fertilizer application according to the maximum need of plants for the planned yield of 5 t ha^{-1} (area 2.27 ha);
3. A treatment with differentiated fertilizer application (differentiated application was made based on a preliminary agrochemical examination of the field with map assignments, the area of the plot was 2.5 ha (Yakushev *et al.*, 2010);
4. A treatment with the introduction of nitrogen feeding in the "on-line" mode using an optical device N-sensor. In this case, the sensor was calibrated using a portable N-tester instrument directly in the crop. For brevity, this methodological treatment will be called TK-1 (the average area for 2009–2011 was 3.19 hectares);
5. Treatment with the introduction of nitrogen feeding, when the N-sensor was calibrated according to the optical characteristics of the test sites (hereinafter referred to as the TK-2 treatment, the area is 3.24 ha);
6. The treatment for introducing nitrogen fertilizing according to task cards created in advance based on the classification of the aerial photographs of crops. At the same time, the classification was carried out in two ways: automatically (hereinafter – TK-3, the average area for 2009–2011 is 3.36 hectares)
7. The treatment for applying nitrogen fertilizing using test sites as standards (hereinafter – the TK-4 treatment, the area is 3.31 hectares).

The yield for treatments TK 1 – TK 4 of the grain of the spring wheat (variety of 'Ester') was assessed. Test sites for calibration were laid before sowing plants with a given dose of nitrogen fertilizers, as follows: 0, 30, 50, 70, 90, 110 kg of the active substance (a.s.) per 1 ha (Fig. 1). The area of each test site is 100x100 m.

In this case, the experimental treatments were a variety of information in agricultural technologies. The experiments were designed in such a way as to compare not only different treatments but also a variety of technologies. So, the control treatment (without fertilizing) was an extensive technology, which is used in farms with poor financial and instrumental support. The high-intensity treatment, on the contrary, was a rich, high-intensity technology that a well-financed household could afford.

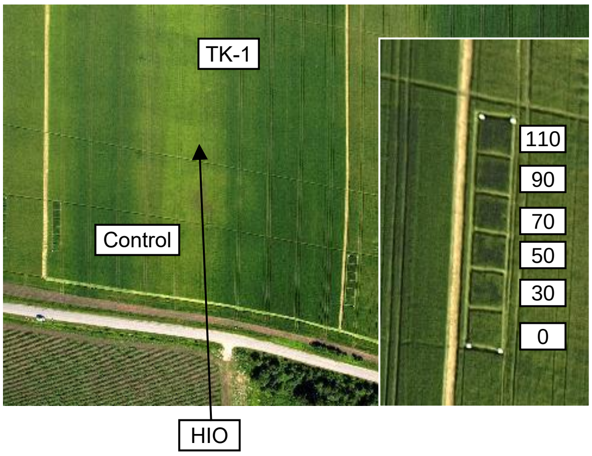

Figure 1. Test calibration sites and field with different fertilizer treatments. On the right – the test pads (100x100 m) with added doses of nitrogen: 0, 30, 50, 70, 90, 110 kg of active substance per 1 ha. On the left is a field (20.2 ha) with different doses of nitrogen fertilizers, but treatments TK-2, TK-3 and TK-4 have turned out to be outside the given image fragment

Nitrogen and potassium fertilizers were applied differentially depending on their content in the soil. In this case, fertilizers were applied in proportions N70P70K70 (in the form of nitrogen + phosphorus with N16P16K16) + N40 (in the form of ammonium nitrate) + K40 (in the form of potassium chloride).

Field experiments were carried out during the growing seasons of 2009–2011.

Statistical processing of the research results was carried out using a calculation algorithm based on data from a two-factor analysis of variance of the STAT software package (1991) of VIUA or All-Russian Research Institute of Fertilizers and Agricultural Soil Science.

Results

During the study, the climate was characterized by moderately warm summers and long winters with thaws. Spring and autumn were lingering. The average annual air temperature was +3.4 °C. The absolute maximum was +33 °C; the absolute minimum was –43 °C. The frost-free period is an average of 126 days, the largest 164 days and the smallest 101 days. The course of soil temperature repeated the course of air temperature. The maximum depth of soil freezing was observed in March (2017) and averaged 52, the largest – 112 cm, the smallest – 10 cm. The annual rainfall was 708 mm. During the warm period, 467 mm fell out, and in the cold – 241 mm. The average annual absolute humidity (***f***) or in other words the density of water vapour saturation was 7.6 g m^{3-1}, relative – 81%. In the summer ***f*** ranged from 8.0 to 14.4 g m^{3-1}, relative about 66–80%. The long-term average evaporation from land is 430 mm. The radiation balance is generally positive, but the distribution of heat throughout the year is uneven. Most of the solar heat (up to 75%) was spent on evaporation, the rest – on melting snow and ice. This is due to the position of the territory in the zone of excessive moisture.

Agro-climatic conditions for the phases of growth and development of wheat are presented in Table 1. It shows how the hydrothermal coefficient HTC changes with each year. According to our results was relatively varied annually in the phases of growth and development of spring wheat. The total amount of HTC in the 2009 year differed significantly from the results of the remaining years in comparison with other trials of field experiments.

As a result, (Table 2), it was established that in 2009 when spring wheat was cultivated using zonal technology, the productivity increased significantly in comparison with the TK-3 treatment. In 2009 and 2010, there was a tendency to increase the yield in comparison with the TK-1 treatment. Differentiated nitrogen application compared to the continuous application regardless of the year of the experiment and the methodological approach to its application significantly increased productivity by 2.0–9.4 kg ha^{-1} or by 6–26 %.

Table 1. Agroclimatic conditions of the phases for growth of the spring wheat

Year	Values of hydrothermal coefficient (HTC)					Total
	Sowing – Tillering	Tillering – Flowering	Sowing – Flowering	Flowering – Harvesting	Sowing – Harvesting	
2009	0.8	5.5	3.8	4.1	3.9	18.1
2010	1.1	4.4	3.6	0.9	2.6	12.6
2011	2.8	1.5	1.9	3.9	2.8	12.9

Among the differentiated nitrogen applications, the maximum yield in the TK-4 treatment was 4510 kg per hectare (kg ha^{-1}) regardless of the year of the experiment, and the minimum in the TK-1 treatment was 3780 kg per hectare. There were no significant differences in the grain yield between the TK-2 and TK-3 treatments. The exception is the TK-3 treatment in which in 2009 the minimum yield among the TK treatments was noted.

The yield of the grain of the spring wheat (variety of 'Esther') for treatments TK-1–TK-4 in comparison with "Control" and for treatment "HIO" was obtained in Table 2. Where is visible that the use of application fertilizers provides a significant increase in yield. During the three years, the minimum yield in the control treatment was an average of 2500 kg per hectare that is not so very much.

When the spring wheat has been cultivated in 2009 by zonal technology (HIO treatment) then the productivity of this in comparison with treatment TK-3 was significantly increased.

Table 2. The yield of grain (kg ha^{-1}) of the spring wheat (variety of 'Esther') depending on the use of different technologies in various weather conditions

Treatment	2009	2010	2011	Average (A)
Control	2840	2250	2410	2500
HIO	4690	2970	3050	3570
TK-1	4550	2950	3830	3770
TK-2	5330	2770	3750	3950
TK-3	4310	3210	4120	3880
TK-4	4780	4090	4660	4510
Average(B)	4420	3040	3640	3700
LSD 05 (AB) = 456		LSD 05 B = 698		LSD05 A = 1715

During the corresponding investigation of the influence of the technologies concerning the differentiated top-dressing application of nitrogen fertilizing it comes necessary to determine the share of the influence of random (weather conditions – influencer "Year" (A) and a fixed influencer – (technology of nitrogen application) – (B).

Statistical processing of the data showed that the influencer fertilizing (46%) made the largest contribution to the formation of spring wheat grain of 'Ester' variety. The second influencer in terms of the impact on the crop was weather conditions (40%) and the least influence on the formation of grain yield was exerted by the interaction of influencer Year (13%).

One of the important indexes of technology effectiveness is the collection of protein per unit area. Analysis of the data (Table 3) shows that irrespective of the methodological approach to their application of fertilizers is significant increases related to the collection of protein in comparison with the control treatment. An average collection protein was increased by 19–56% per hectare related over the years of research for differentiated fertilizer application compared with the high-intensity treatment. It should be especially noted that treatment TK-4 gave the largest collection of protein – 685 kg ha^{-1} (Table 4).

Table 3. The content of protein (%) in spring wheat grain depending on the use of different technologies in various weather conditions

Treatment	2009	2010	2011	Average (A)
Control	11.17	9.37	13.30	11.28
HIO	11.97	12.19	12.90	12.35
TK-1	12.37	13.23	16.10	13.90
TK-2	11.86	14.38	16.20	14.15
TK-3	11.00	14.03	15.60	13.54
TK-4	14.80	16.45	17.20	16.15
Average (B)	12.20	13.28	15.22	13.56
LSD05 (AB) = 0.80		LSD05 B = 0.46		LSD05 A = 0.33

Based on the above results we can conclude that the greatest variability (17%) of protein depending on year was in treatment TK-3 and *vice versa*, the smallest – in treatment HIO (4%), second in baseness is the treatment TK-4 (8%). The variation in the remaining treatments is also relatively high (14–15%), while it is noteworthy that the control treatment had a coefficient of variation 17%.

Data obtained from Tables 2 and 3 takes into account the content of protein in the grain yield, the visualization of the experimental results are presented in Fig. 2.

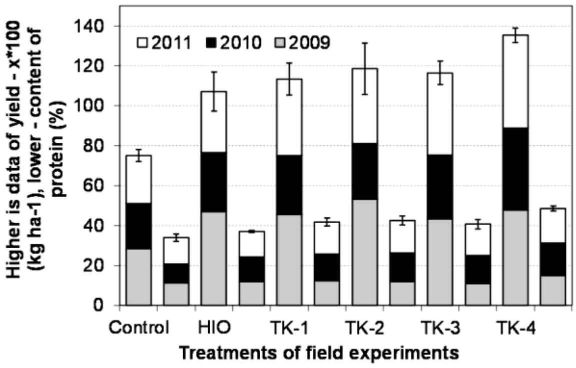

Figure 2. Content of protein in the grain yield of spring wheat (± standard deviation)

It is noteworthy that the experimental variations in their final indexes are arranged as a row in increasing order, while the results of protein (low bars in Fig. 2) correlate quite well in the same figure with the results of yields (high bars) of the crop. As noted above the total yield here of the TK-4 treatment was the largest. It also is worthy of the fact that the standard deviation of the data during the harvest of treatment TK-2 was the largest. After it, the HIO treatment is in second place, although according to the protein data of the standard deviation was the smallest with it. It seems that current analysis makes possible to get a very clear idea for comparing different varieties by year among themselves.

Discussion

All this gives the expected results if we have the appropriate sensors, corresponding software for mapping and the possibility of accurate compliance agricultural technology. It should be noted that in our case these conditions were fully met. This is warranting by the fact (Yakushev *et al.*, 2010) that treatment with differentiated fertilizer application (differentiated application) was made based on a preliminary agrochemical examination of the field with map assignments. It is also impossible to ignore the fact that precision farming represents a real opportunity for future research (Blackmore, 2003; Elipbeki, 2018).

In this case, we should pay attention to various strategies for applying nitrogen fertilizer. Commonly known strategies for applying nitrogen fertilizer a two are used:

- technology (off-line);
- technology (on-line);
- technology (off-line) has a two-stage:
  a) the use of complex nitrogen balance models or the use of dynamic nitrogen and soil models for calculating the doses of nitrogen (0, 30, 50, 70, 90, 110 kg of the active substance (a.s.) per 1 ha), compiling task maps and differential application of nitrogen (Yakushev, 2016; Ferguson *et al.*, 2011; Lekomtsev *et al.*, 2011).
  b) compilation of yield maps based on yield maps and other auxiliary means and differential application of nitrogen using injection technology or in the form of stabilized fertilizer (Larscheid *et al.*, 1997; Yakushev, 2016; Wagner *et al.*, 2007).
- Technology (on-line) usually has a two-stage:
  a) use of sensor systems, for example, Uaga N-sensor, CROP meter, *etc*., with which they evaluate the status of crops in real-time, determine the require doses of nitrogen in real-time and apply them (Feiffer *et al.*, 2007, Yakushev *et al.*, 2010);
  b) use of sensors in a real-time system with the addition of data on digital thematic maps of factors, for example, on soil properties, taking into account the goals of protecting the environment and nature, yield goals (Adamchuk, 2011; Novitski, 2017).

At the same time, we have found that the test sites have been used already (Bure *et al.*, 2017) in which noted that "a small region of the field where the qualitative indices of plants are already known", while "the main principle is that the existence of a linear relationship between the colour of plants and the dose of nitrogen must be analysed based on various qualitative factors". These studies have also found a wider application (Basso *et al.*, 2009; Shpaara *et al.*, 2009; Bure, Mitrofanova, 2016) where is to assess the level of ecological "data measured *in situ*, as well as an aerial photographic image of the object". Also, it should be noted that precision farming is a dynamically developing system of agricultural production (Shannon *et al.*, 2017). The theory and practice of its application in Russia are presented in the work of the author (Yakushev, 2016). State and prospects for the development of precision farming are reflected also in the works (Bongiovanni *et al.*, 2004; Truflyak *et al.*, 2018). The digitalization of agriculture is presented in recent works by authors (Kiryushin *et al.*, 2018).

Concerning the size of the field, some authors (Anselin *et al.*, 2004; Meyer-Aurich *et al.*, 2010) have had such opinion that economic gross advantage of site-specific management of nitrogen fertilizer depends on the type of sensor used and size of the field.

Weather analysis (Table 1) of the results related hydrothermal coefficient (HTC) is also useful where if summarize the results obtained over the years. It is clear that HTS directly affects the data of yield. We have found that between HTS and yield (Y) of spring wheat has the linear relationship (Y = 2,061HTC + 7,047) with a coefficient of representatives $R^2 = 0.85$.

According to the information in the literature (Lekomtsev *et al.*, 2011; Diacono *et al.*, 2013; Abler, 2004; Shannon *et al.*, 2017), concerning the spring wheat, our opinion is that the choice of this cereal culture was infallible. Firstly, for the above-mentioned region of Russia, the advantage of spring wheat cultivation is that planted in the early spring, grows quickly and is normally harvested in late summer or early autumn. Secondly, the simultaneous improvement of grain yield and corresponding grain protein percentage

(Löffler *et al.*, 1982). As already seen, this is well confirmed according to the above Fig. 2. Taking as a basis of a report of the National Institute of Food and Agriculture (USA) it is possible to approve with confidence that when protein content exceeds 14% then it means that increased the value of crop automatically (Ranson, 2018). According to above Table 3 mostly the protein content of the grain was exceed 14% in treatments TK-4 and TK-3, also TK-2 (excluding for them both in the year of 2009). It is still noteworthy that with TK-1 treatment in 2011 only the protein content in the grain corresponded to the expected result. It is important to note that the high-intensity treatment (HIO) of fertilizer application (Table 3) did not give us in a testing year of the field experiments the proper level of protein content in the grain. Since this question, remains insoluble then implies the logical deduction for the continuation of field experiments.

Conclusions

The results of our investigations have shown that characteristics of the state of plants. Assessment by using the calibration test plots was carried out.

Differentiated application of nitrogen fertilizers regardless of the year of the experiment and the methodological approach, significantly increased yield compared to a continuous application by 6–26%. Among the differentiated application treatments, the maximum yield was in the TK-4 treatment (4510 kg ha^{-1}). In this case, the method of applying nitrogen fertilizing using test sites as standards were used. No significant differences in the grain yield between the other treatments of precision farming were found.

Regardless of the methodological approach, with the differentiated application of nitrogen fertilizers, grain with protein content is higher than when using zonal technology by 10–24%.

Acknowledgements
This paper is connected with the project of Agrophysical Research Institute on Conducting fundamental and priority applied research, experimental design and experimental work introducing the achievements of science aimed at gaining new knowledge in the field of agriculture and crop production.
The authors express their gratitude to the machine operators who ensure the operation of all agricultural equipment used in the experiments and to the colleagues of the analytical centre for providing biochemical analysis of plant and soil samples. We are also grateful to Estonian Academic Agricultural Society and Estonian Crop Research Institute.

Conflict of interest
The authors declare that there is no conflict of interest regarding the publications of this paper.

Author contributions
DM, AK, EN, PL – study conception and design
DM, AK, PL – acquisition of data
DM, AK, EN, PL – analysis and interpretation of data
AK, EN – drafting of the manuscript
DM, AK, EN, PL – critical revision and approved the final manuscript

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Agraarteadus
1 ● XXXI ● 2020 47–52

Journal of Agricultural Science
1 ● XXXI ● 2020 47–52

LÜHIÜLEVAADE: RAVIMIJÄÄGID REOVEESETTES JA NENDE LAGUNEMINE KOMPOSTIMISEL – VIIMASE AASTAKÜMNE UURINGUD EESTIS

MINI-REVIEW: PHARMACEUTICALS IN SEWAGE SLUDGE AND THEIR DEGRADATION DURING COMPOSTING – RECENT STUDIES IN ESTONIA

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Saabunud: Received: 31.12.2019
Aktsepteeritud: Accepted: 07.03.2020
Avaldatud veebis: Published online: 07.03.2020

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Keywords: sewage sludge, pharmaceutical, plant uptake, compost.

DOI: 10.15159/jas.20.02

ABSTRACT. Pharmaceuticals are present in sewage sludge and its compost. This may cause severe health problems due to the plant uptake of pharmaceuticals by food plants when sewage sludge compost is used for fertilizing agricultural soils. Recently studies were conducted for estimating the efficiency of composting technologies in the view of the degradation of pharmaceutical residues. Experiments on plant uptake of pharmaceutical residues showed, that this phenomenon could not be ignored when using sewage sludge compost as a fertilizer. Novel approaches were developed *via* optimising the composition of the compost mixture with the aim of utilising sewage sludge compost as a nutrient-rich source for the improvement of soil properties. Sawdust as a bulking agent clearly speeded up the degradation of most of the studied pharmaceutical residues present in sewage sludge and its compost. More work in this field is needed for increasing the efficiency of the sewage sludge composting process. Efficient express methodologies should be developed with the aim of assessing the safety of sewage sludge compost.

Sissejuhatus

Reoveesete on muutunud üheks globaalseks probleemiks. Sisaldades paljusid väärtuslikke mullaviljakust parandavaid toiteaineid, on tema näol tegemist potentsiaalselt vägagi atraktiivse põlluväetisega. Paraku on aga reoveesette kasutamine põllumajanduses piiratud temas sisalduvate reoainete tõttu. Üheks üha enam esilekerkivaks probleemiks on ravimijääkide sisaldus reovees ja selle settes, mis kujutab endast tõsist ohtu reoveesette kasutamisel põldude väetamisel seoses ravimite akumuleerumisega toidutaimedes. Viimase nähtusega kaasneb aga bakteriaalne ravimiresistentsus, mille ohtlikkust on raske ülehinnata. Ravimijääkidega seotud probleemide laiahaardelisusest ja tõsidusest annavad pildi hiljutised ülevaateartiklid (Verlicchi, Zambello, 2015; Tran jt, 2018; Patel jt, 2019; Ghirardini, Verlicchi, 2019). Käesolev ülevaade kajastab konspektiivselt viimase kümne aasta jooksul Eestis läbiviidud uuringute tulemusi antud valdkonnas. Esimeseks sammuks oli Eesti suuremate linnade reoveepuhastites eraldatavas settes ravimijääkide olemasolu tuvastamine (Lillenberg, 2011). Edasine töö jätkus erinevate omadustega ravimijääkide lagunemiskiiruste väljaselgitamisega sõltuvalt kasutatavast reoveesette kompostimistehnoloogiast. Uuriti ravimite liikumist mullast toidutaimedesse ning töötati välja keskkonnaohutu turbaalade väetamise metoodika nende alade metsastamise eesmärgil. Kirjeldatud uuringud viidi läbi Tallinna Tehnikaülikooli, Tartu Ülikooli ja Eesti Maaülikooli teadlaste ühistööna. Tulemusena on kaitstud neli doktoritööd (Lillenberg, 2011; Kipper, 2012; Haiba, 2017; Järvis, 2018).

Mulla saastumine raskemetalliühendite ja orgaaniliste ühenditega, sealhulgas ravimijääkidega, kujutab tõsist ohtu toidutaimede kvaliteedile. Raskemetallide ja ravimijääkide sisalduse määramine keskkonnas on kallis ja töömahukas ettevõtmine (Wierzbowska jt, 2018; Nei jt, 2009; Davis jt, 2002; Kipper jt, 2011; Kipper jt, 2017). Õnneks on munitsipaalse päritoluga reoveesettest tulenev raskemetallidega seotud mullareostus madal (Seo jt, 2019). Tavaliselt ei ole ka ravimijääkide sisaldus põllumuldade väetamisel kasutatavas reoveesettes või selle kompostis märkimisväärne, olles µg kg^{-1} nivool (Lillenberg jt, 2009; Lillenberg jt, 2010a), kuid paraku viivad kaasneva ravimiresistentsuseni juba oluliselt madalamad kontsentratsioonid. Tulemuseks on see, et bakteriaalsete haiguste ravimiseks kasutatavad ravimid kaotavad oma toime (Carlet jt, 2011; Piddock, 2016). Reoveesettes ja settekompostis esinevad bakterid on sageli antibiootikumresistentsed, kuna on elanud pikka aega antibiootikume sisaldavas keskkonnas (Reinthaler jt, 2003; Sahlström jt, 2009). Niisuguste bakterite sattumine keskkonda põhjustab ravimresistentsuse levikut. Mullabakterite antibiootikumresistentsus kujutab endast potentsiaalset ohtu inimeste ja loomade tervisele, sest resistentsust määravad geenid võivad transformeeruda ohututelt mullabakteritelt patogeensetele bakteritele horisontaalse geeniülekande teel (Davies, 1994). Seetõttu ei ole ravimijääkide olulisust reoveesette väetusainena kasutamisel võimalik ignoreerida.

Et uurida ravimijääkide sisaldust ja käitumist reoveesettes, selle kompostis ja toidutaimedes, tuli luua vastavad metoodikad, mis võimaldasid erinevate ravimite samaaegset määramist. Vaatluse alla võeti sellised enamlevinud medikamendid nagu fluorokinoloonide hulka kuuluvad tsiprofloksatsiin (CIP), norfloksatsiin (NOR) ja ofloksatsiin (OFL), sulfoonamiidid sulfametoksasool (SMX) ja sulfadimetoksiin (SDM) ning tetratsüksiinide rühma kuuluvad tetratsükliin ((TCL) ja doksütsükliin (DOX), lisaks diklofenak (DCF), karbamasepiin (CBZ) ja metformiin (MET) ning antibakteriaalne ühend triklosaan (TCS). Sellekohase töö tulemused on põhjalikult käsitletud kolmes doktoritöös (Lillenberg, 2011; Kipper, 2012; Haiba, 2017) ning teadusartiklites (Lillenberg jt, 2009; Haiba jt, 2013a; Haiba jt, 2017; Haiba jt, 2018; Kipper jt, 2017).

Ravimijäägid reoveesettes

Eestis tekib aastas kuivainele taandatuna ligikaudu 30 000 tonni reoveesetet (Nei, Lillenberg, 2009). Kõrgeimad määratud ravimijääkide sisaldused µg kg^{-1} Tallinna veepuhastusjaama reoveesettes taandatuna kuivainele olid järgmised: CIP – 1520; NOR – 580; OFL – 134; SDM – 73; SMX – 22 ja Tartu veepuhastusjaamas: CIP – 442; NOR – 439; OFL – 157; SDM – 32; SMX – 16 (Lillenberg, 2011). TCL ja DOX jääke Tallinna ja Tartu reoveesettes ei leitud. DCF, CBZ, MET ja TCS kontsentratsioone otseselt reoveesettes ei määratud, kuid kaudse hinnangu kohaselt olid nende väärtused Tallinna reoveesettes ligikaudu DCF – 100; CBZ – 80; MET – 3; TCS – 2000, kõik µg kg^{-1} (Haiba, 2017). Euroopa Liidus puuduvad normatiivid ravimijääkide sisalduse kohta reoveesette kompostis (EU Counsil Directive 86/278/ EEC). Väetamiseks kasutatavas sõnnikus ei tohi summaarne ravimijääkide sisaldus ületada 100 µg kg^{-1} ja 10 µg kg^{-1} sõnnikuga väetatud mullas (EMEA/CVMP/055/96, 1996). Silmas pidades võimalikku mullabakterite resistentsuse arenemist tuleks vastav piirväärtus langetada kontsentratsioonideni 0.01–0.1 µg kg^{-1} (Montforts, 2005). Kuna uuritud reoveesette proovid sisaldasid ravimijääke olulisel määral rohkem kui nende lubatud piirväärtused väetamiseks kasutatavas sõnnikus, siis sellest tulenevalt töötlemata reoveesetet põllumuldade viljakuse tõstmiseks kasutada ei tohi. Samas tuleb silmas pidada, et nii Eesti kui ka paljude teiste riikide mullad vajavad väetamist ja reoveesette näol on tegemist toitaineterikka ressursiga, mistõttu nii meil kui ka kogu maailmas pööratakse suurt tähelepanu reoveesette kompostimistehnoloogiate väljatöötamisele ja edasiarendamisele.

Reoveesette kompostimine ja ravimijääkide lagunemine

Mitmete uurimistööde põhjal võib kinnitada, et paljud ravimid ja isiklikud hügieenivahendid ei eraldu reoveesette töötlemisel ning ei lagune keskkonnas täielikult (Redshaw jt, 2008; Lillenberg jt, 2009; Lillenberg jt, 2010a; Jelic jt, 2011; Rodríguez-Rodríguez jt, 2012; Borgman, Chefetz, 2013; Haiba jt, 2013b; Narumiya jt, 2013; Reichel jt, 2013; Haiba jt, 2017; Haiba jt, 2018; Lindholm-Lehto jt, 2018). Fluorokinoloonide ja tetratsükliinide aeglast degradeerumist põhjendatakse nende tugeva seondumisega tahketele osakestele (Carmosini, Lee, 2008). Walters jt näitasid fluorokinoloonide väga pikaajalist säilimist reoveesettega väetatud mullas – 994 päeva pärast väetamist oli mullas säilinud rohkem kui pool algsest CIP ja OFL sisaldusest (Walters jt, 2010). Hollandi põldudelt võetud proovides oli tetratsükliini resistentsust määrava geeni esinemissagedus mullabakteritel kasvanud ajavahemikul 1970–2008 15 korda – põhjuseks korduv väetamine tetratsükliine sisaldava sõnnikuga (Knapp jt, 2010). Kuigi mullas kauapüsivate ravimite kontsentratsioonid on üldjuhul madalad, siis nende potentsiaalset pikaajalist toimet inimestele, loomadele, taimedele ja bakteritele ei tohi ignoreerida (Lillenberg jt, 2009; Nei jt, 2014; Nei, Haiba, 2019; Van Doorslaer jt, 2014; Prosser, Sibley, 2015; Bártíková jt, 2016).

Üheks reoveesettes sisalduvate orgaaniliste reoainete toime kahandamise võimaluseks on reoveesette kompostimine. Kompostitud reoveesete on võetud laialdaselt kasutusse põllumajandusliku mulla viljakuse tõstjana. See võimaldab ühtlasi lahendada ühte väga valusat tsivilisatsiooni arenguga seotud globaalset probleemi, milleks on reoveesette koguste plahvatuslik kasv. Samas ei saa aga ignoreerida tõsiseid keskkonnaprobleeme, mis sellise lahenduse kasutamisega kaasnevad. Mulla saastumine raskemetalliühendite ja orgaaniliste ühenditega, sealhulgas ravimijääkidega, kujutab tõsist ohtu toidutaimede kvaliteedile (Raghunatha jt, 2019; Liu jt, 2010; Nolan jt, 2005; Pruvot jt, 2006).

Merike Lillenbergi doktoritöö tulemusena võib väita, et ravimite lagunemine sõltub olulisel määral reoveesette kompostimistehnoloogiast (Lillenberg, 2011). Anaeroobselt kääritatud reoveesette korral, mida segati turbaga, lagunesid uuritavad ravimijäägid CIP, NOR, OFL, SDM ja SMX 12-kuuse kompostimisperioodi jooksul täielikult, kuid anaeroobselt töötlemata reoveesette kompostimisel koos puukoortega lagunes samal perioodil täielikult ainult SDM; teised uuritud ravimid lagunesid 86–94% piires.

Egge Haiba doktoritöös (Haiba, 2017) uuriti DCF, CBZ, MET ja TCS lagunemise kiirusi kompostimisel erinevate kompostimissegude koostiste korral. Vastavad segud valmistati Tallinna reoveesette segamisel põhu, saepuru, põlevkivituha ja puukoorega. Parimad ravimijääkide lagunemise tulemused saadi reoveesette segamisel saepuruga. Reoveesette ja saepuru segamisel mahuvahekordades 1:2 lagunes ühekuuse kompostimisperioodi jooksul 92% DCF, 55% TCS ja 91% MET 1:3 segu korral olid need näitajad DCF korral 98%, TCS korral 81% ja MET korral 93%. Samas kummagi segu korral CBZ lagunemist ei täheldatud (Haiba jt, 2017; Haiba jt, 2018). Teostatud uuringud lubavad väita, et kompostimistehnoloogia optimeerimise teel on võimalik tagada CIP, NOR, OFL, SDM, SMX, DCF, MET ja eeldatavasti ka TCS efektiivne lagundamine, kuid CBZ elimineerimiseks tuleb rakendada teisi, nagu näiteks fotokatalüütilisi meetodeid (Zhang jt, 2020). Kompostimisperiood peaks kestma minimaalselt kuus kuud (Haiba, 2017).

Ravimijääkide migratsioon mullast toidutaimedesse

Hiljutised uuringud näitasid, et taimed omastavad pikaajalisel muldade reoveesettega väetamisel fosforit paremini kui sõnniku või kompostiga väetamisel, mis on eeldatavasti tingitud mulla madalamast pH-st reoveesettega väetamise korral (Glæsner jt, 2019). Paraku sisaldab reoveesette ja sellest valmistatud kompostiga väetatud muld ravimijääke, mis omakorda võivad liikuda edasi taimedesse (Nason jt, 2019). Erinevad ravimid akumuleeruvad erineval määral taimede maa-alustes või mullapealsetes osades (Tanoue jt, 2012). Eelkõige akumuleerivad ravimijääke just taimede maa-alused osad. Seepärast kasutatakse reoveesetet või selle komposti sagedamini teraviljapõldude väetamisel.

Ravimijääkide liikumine mullast taimedesse on seotud mulla omadustega. Uuringud näitasid, et sulfoonamiidide migratsioon mullast taimedesse on märgatavam kui flourokinoloonide liikumine taimedesse (Lillenberg jt, 2010a; Lillenberg jt, 2010b; Lillenberg jt, 2010c; Kipper jt, 2010; Lillenberg, 2011; Haiba jt, 2013a). See on tingitud asjaolust, et fluorokinoloonid adsorbeeruvad võrreldes sulfoonamiididega tugevamini mullaosakeste külge (Thiele-Bruhn, 2003). Ravimijääkide liikumine mullast taimedesse omab olulisemat kaalu liivmuldade korral ja on tagasihoidlikum savimuldade korral (Lillenberg, 2011). Samas on teada, et iseenesest vähendavad bioloogilised jäätmed ravimite omastamist taimede poolt (Pullagurala jt, 2018).

Uut reoveesettest valmistatud komposti kasutamisel

Reoveesette kompost on leidnud laialdast kasutamist mahajäetud põllumaade ja kaevandusalade taaskasutusse võtmisel (Järvis jt, 2017; de Andrés jt, 2007; Wu jt, 2019). 2018. aastal Tallinna Tehnikaülikooli Tartu kolledžis valminud Jüri Järvise doktoritöö (Järvis, 2018) põhirõhk oli suunatud jääkturbaalade metsastamisega seotud probleemide lahendamisele. Reoveesette kompostiga täidetud istutusaukude kasutuselevõtt võimaldas radikaalselt vähendada keskkonnareostust, mis kaasneks sellise komposti laialilaotamisega maapinnale. Kompostiga täidetud istutusaugud tagasid esimesel kasvuaastal kõrgemad tüve kõrguskasvud kontrollgruppidega võrreldes. Puuistikute kiire kasv on majanduslikult tulus ja ühtlasi tagab konkurentsieelise rohttaimestiku ees.

Kuidas edasi?

Reoveesette komposti kasutamisel peab olema tagatud toiduohutus. Kuna reoveesette kompost sisaldab arvukalt reoaineid, siis nende kõigi regulaarne määramine ei ole töömahukuse ja analüüside kõrge maksumuse tõttu põhimõtteliselt teostatav. Seetõttu oleks vaja reoained kõrvaldada juba nende reovette sattumise kohas või siis töötada välja kompostimistehnoloogiad, mis tagavad nende lagunemise ohututeks produktideks kompostimisprotsessi käigus. Edasine töö jätkub kahes suunas. Vaja on luua lihtne kompleksmeetod, mille abil saaks hinnata komposti ohutust. Kuna uuringud näitavad, et praeguste tehnoloogiate korral kulub kvaliteetse madala reoainete sisaldusega komposti saamiseks vähemalt üks aasta, siis Eesti klimaatilistes tingimustes oleks vaja protsessi olulisel määral kiirendada, et mahtuda soojema perioodi sisse. Sama probleem vajab lahendamist meiega samas kliimavöötmes asuvates teistes riikides. Revolutsiooniline läbimurre rahvusvahelisel tasandil siin tänasel päeval puudub, kuid probleemi lahendamisel on Eesti ülikoolid eesliinil: eeldatavasti on otstarbekas edasi liikuda sobiva koostisega kompostisegu väljatöötamisega. Esmased sellesuunalised katsetused on näidanud positiivseid tulemusi.

Tänuavaldused
Täname Keskkonnainvesteeringute Keskust ja Tallinna Tehnikaülikooli käesolevas ülevaates kajastatud uuringute finantseerimise eest.

Huvide konflikt / *Conflict of interest*

Autorid kinnitavad artikliga seotud huvide puudumist.
The authors declare that there is no conflict of interest regarding the publication of this paper.

Autorite panus / *Author contributions*

LN, EH, ML – käsikirja kirjutamine ja toimetamine / *writing and editing manuscript*.

Mini-Review: **Pharmaceuticals in sewage sludge and their degradation during composting – recent studies in Estonia**

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Summary

Recent years have shown intensive studies involving the fate of different widely used pharmaceuticals and four PhD theses have been conducted in this field. Based on the studies it can be claimed that sewage sludge composting is an efficient and cost-effective way of degrading sulphonamides, fluoroquinolones, diclofenac and metformin, whereas different approaches should be applied in the case of carbamazepine and preferably also for triclosan. Still, plant uptake of the last two is not of considerable scale and due to this, their presence in the compost is probably not of critical nature. The rate of degradation of pharmaceuticals present in sewage sludge remarkably depends on the composting technology. Currently, for the efficient degradation of most of the studied pharmaceuticals 12-months composting period is preferred. Unfortunately, the microbial activity sufficiently decreases during winters in Estonia. Due to this phenomenon, the following studies will be directed towards increasing the efficiency of sewage sludge composting process with the aim of cutting down the time needed for the degradation of pharmaceutical residues present in this media.

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Agraarteadus
1 • XXXI • 2020 53–65

Journal of Agricultural Science
1 • XXXI • 2020 53–65

EXPRESS-DIAGNOSTICS METHOD FOR ASSESSMENT OF SOIL COMPACTION FOR DIFFERENT CULTIVATION METHODS

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Saabunud: Received: 01.12.2019
Aktsepteeritud: Accepted: 08.05.2020

Avaldatud veebis: Published online: 11.05.2020

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Keywords: express-diagnostics method, cultivation method, modelling soil compaction, computer simulation, vegetation miniatures, guttation method.

DOI: 10.15159/jas.20.04

ABSTRACT. Soil compaction remains a concern because of the heavy tractors used in intensive agriculture. When axle loads of vehicles increase, soil compaction is affected in deeper soil layers. An efficient tool is needed to assess the impact of machines on soil. Therefore, an express-diagnostics method was developed and implemented under Estonian agricultural conditions. Since 1976, an investigation has been carried out on how wheeled or tracked vehicles (WTV) influence soil under agricultural conditions in Estonia. The main goal of the investigation was to develop a mathematical model and a corresponding computer simulation system. Uncompacted and compacted soil was modelled using a vegetation model of "guttated vegetation miniatures". The system allows soil vulnerability to compaction to be assessed by the criterion (q_{abc}) agro-empirical bearing capacity (ABC). Both field and laboratory data were used in the development of the system. We have found that at the deepest layer the bulk density was higher for tilled soil compared to no-tilled soil. Dry soil bulk density in no-tilled soil after 2 years in the deepest layer was 0.11 Mg m^{3-1} less than tilled soil, and for no-tilled soil after 3 years in the deepest layer, it was 0.12 Mg m^{3-1} less compared to the tilled field soil. The amount of agronomically preferable aggregates (2–4.75mm) was major in tilled soil compared to no-tilled soil. It means that the preferred (in an agronomical sense) soil particles K_{str} in conventionally tilled (ploughing – K2; K3) fields were significantly better compared to no-tilled (O2; O3) fields in the trial plots. These results emphasize the benefits of multifunctional modelling systems (computer simulation and simulation by vegetation miniatures) and the need to improve assessment of methodology for receiving adequate and probable results, and finally for yield prediction.

Introduction

In order to determine the cause and extent of soil compaction, one needs to carry out an analysis using special complex methodology. Usually this methodology is based on complex investigations of the "machine-soil-crop" system (Nugis, 1988). Soil tillage alongside any compacting effect caused by wheels or tracks complicates the task of solving the impact of soil compaction (Horn, Kutilek, 2009; Tullberg *et al.*, 2007). In other words, while wheels or tracks have a compacting effect on soil, any soil loosening that occurs due to digging booms will reduce soil compaction (Nugis, 1988). Research has shown that in addition to the effects of compaction, which become fixed in different soil layers (Nugis, 1988), all of the various cultivation activities also imposes long lasting impacts on the various soil layers (Håkansson *et al.*, 1987). Soil compaction problems have a multi-disciplinary character, in which complex machine/soil/crop/weather interactions all play important roles (Soane, Ouwerkerk, 1994). However, it is believed that a theoretical soil compaction model can be developed to provide a suitable method of tackling soil compaction problems (Blight, Soane., 1986).

Historically, agricultural vehicles often weighed less than 2 Mg. However, in more recent times, agricultural vehicles may weigh as much as 60 Mg. The latter applies for instance to some sugar beet harvesters in Central Europe (Horn, Fleige, 2005). The increasing weight has often led to tyres with higher inflation pressure than was needed for the lighter equipment (Blight, Soane, 1986). Therefore, there is a need to establish quantitative criteria to characterize the trafficability of heavy machines as well as their influence on soils. There have been many efforts to develop these criteria (Söhne, 1953; Skotnikov *et al*., 1982; Rydberg, 1984; Arvidsson *et al.*, 1991; Richards *et al.*, 2000; Tarkiewicz, Lipiec, 2000; Tullberg, 2000; Dawidowski *et al.*, 2000; Tijink, van der Linden, 2000; Koolen, van den Akker, 2000; van den Akker, 2001), all of which are interesting and contribute to the understanding of the soil compaction problems. However, more effort is required to develop the methodology needed to assess machinery-induced soil degradation based on soil bearing capacity and to make it possible for every farmer to avoid the potential negative influences on their soils.

If wheel pressure contacting soil (normal dynamic stress q_d) of the wheeled or tracked vehicles (WTV) is higher than the agrotechnical soil bearing capacity (q_{abc}) (which defines the limits of soil to sustain pressure of heavy tractors), then the subsoil is endangered (Horn, Fleige, 2005; van den Akker *et al.*, 2003; Jones *et al*., 2003). Since this is sometimes the case, ongoing research needs to focus on the potential environmental effects of soil compaction.

In Estonia, the potential damage to soil resources is not as common as in some other countries since there is currently no sugar-beet production, and therefore no use of heavy sugar-beet harvesters. Furthermore, in Estonian soils freeze every winter, which reduces the persistence of compaction effects. However, the remediation effects of freeze/thawing is less effective in the subsoil than in the plough layer (Håkansson, 2001; Blight, Soane, 1986). Therefore, the problems resulting from soil compaction are factors of great importance when designing and operating field vehicles and when deciding which tillage practices should be utilized.

Recently, the University of Agricultural Sciences (SLU) in Sweden has carried out an investigation related to the impacts on soil from the complex interactions from various tillage operations (ploughing 20–25 cm, versus shallow cultivation 10 cm (Rydberg, 1984). In these long-term investigations (1973–1983) by Rydberg (1984) in the southern part of Sweden, no significant decrease in yield was observed between ploughing and shallow cultivation treatments. Therefore, it can be concluded that in these areas, planting of cereals cultures without ploughing can be performed without negative impacts to production. However, the same studies demonstrated that the further north in Sweden that ploughing occurred the more important deep ploughing becomes to ensure higher yields. In this study, a yield advantage was observed through ploughing at the same parallel that would correspond to Estonia. The yield increased 5–35% (average 18%) for oat and 0–32% (average 12%) for barley with deep ploughing compared to the shallow ploughing. Similar results were found for other crops, with yield without ploughing decreasing by 14–21% for sugar beet, and decreased an average of 22% for pea and 21% for winter rape (Rydberg, 1984). The results published in these studies justifies more intensive research under the conditions found in Estonia.

Due to the complex nature of this research, investigations using multifunctional and multidisciplinary modelling systems is needed with a comprehensive view of soil conditions. This modelling system would require engineering functions that are essential to be able to carry out a quantitative assessment. This would include the investigation of current soil conditions under tractor wheel and an assessment of soil restoration afterwards. A fruitful way of studying soil processes is by simulating them in a modelling environment. Powersim v2.5 (Powersim Software AS) is a tool that can be used to create models of complex processes which involve many different parameters (Persson, 1995). The temporal dynamics of these processes can then be investigated by varying the initial parameters. Research is need to describe the state of soil after the complex interactions of direct drilling and ploughing, therefore, the objective of this investigation was to develop an express-diagnostics method to describe relationships between q_d (WTV) and q_{abc} (soil) in such a way that the functions of the machine-soil-crop system could be predicted. This research comprised of laboratory and field experiments including modelling of soil compaction by computer simulation and simulation by vegetation miniatures. This involved examination of soil conditions under fields associated with different cultivation methods.

Material and Methods

Field experiments

The field experiments were carried out on fields of permanent observation points in different regions of Estonia: South-Viljandi County at Abja-Paluoja (58º7´39´´N, 25º15´32´´E) – trial No 2 (by WRB – *GleicAlbeluvisol*); Valga County (57º56´31´´N, 26º9´17´´E) – trial No 3 (*Fragi-Stagnic Albeluvisol*); and Pärnu County (58º38´18´´N, 24º21´17´´E) – trial No 8 (*MollicGleysol*). Trial plots were located on farmers' fields in which regular crop rotation was maintained. These plots included direct drilled plots (designate as "O") and tilled plots (designate as "K"). The physical properties of soil, *i.e.* dry bulk density (Mg $m^{3\,-1}$), water content (% g g^{-1}), cone or penetrometer resistance (MPa) and volumetric water content W_v at five points (with interval 5 m) of the Z-scheme (at each point n = 3) were observed in each field. Measurements were taken in spring after seeding and in autumn after harvest, using a Percometer and Eijikelkamp Penetrologger. The Penetrologger geotagged the measurement points with an on-board GPS system. Data measured by the Percometer E_r (dielectric constant) was used to calculate the soil volumetric water content W_v using three different relationships:

1) from experimentally identified $W_v(E_r)$ graph for Estonian average loam soil;

2) by Topp *et al.*, 1980:

$$W_v = 4.3 \cdot 10^{-6} {E_r}^3 - 5.5 \cdot 10^{-4} {E_r}^2 + 2.92 \cdot 10^{-2} E_r - 5.3 \cdot 10^{-2}, (m^3 \cdot m^{-3}) \quad (1)$$

3) by Ln formula (Kadaja *et al.*, 2009):

$$W_v = 0.144 \cdot \ln(E_r) - 0.109 \quad (2)$$

The dry bulk density and gravimetric soil water content from 0–10, 10–20 and 20–30 cm layers were determined with Eijekelkmp's cylinder (100 cm^3) and compared with the Percometer results. At the same sampling locations, cone resistance was measured down to 70 cm, but only data down to 40 cm was used in the analysis because of the regular occurrence of stones below 40 cm interfered with the measurements.

During 2012–2014, electrical properties of soil were measured with a percometer (Adek LLC, EE 05500 B1) using a 28 mm diameter probe (type TVL) which can be pushed directly into soil. Percometer (abbreviation from Permittivity and Conductivity) is an electrical capacitive probe instrument which measures "*in situ*" the dielectric constant E_r of soil at 40–50 MHz frequencies and the bulk electrical conductivity (*ECa*) of soil at 1 kHz over the same sampling volume (Saue, 2008). The measurements were carried out in triplicate near each Z point at depths of 5 cm (soil layer 0–10 cm), 15 cm (soil layer 10–20 cm) and 25 cm (soil layer 20–30 cm) for a total of 45 measurements per plot.

Laboratory tests

In the laboratory, soil samples were compacted with the aid of an oedometer, in which the dynamic normal stress (q_d) was measured, and a guttating test-culture (spring-barley "Anni") was measured, where the latter reacted negatively to increases of bulk density (Fig. 1). The guttating test-culture method is based on the principle of abscission of guttated liquid at a constant temperature (23 °C) and at almost 100% air humidity, using a hydrothermostat.

Nine seeds for germination were sown into cylinders of 8 cm height and 6 cm diameter. Within 48 hours of sowing barley, 3 cm whitish colour germs spring up with dewdrops. The humidity or density of these drops varied depending on soil physical properties, *i.e.*, the guttated liquid was reduced at higher soil bulk densities (up to totally absent) due to the increased difficulty of the seed germs to develop. The gutta can easily be collected on filter paper and the area (mm^2) of the blot can be determined by weighing (mg) or by a planimeter (mm^2). Also, it is possible to scan the blot on the filter paper (treated with 5 per cent copper vitriol solution) to determine the area (kB) using the program Photoshop. In this study, the latter was used because of the simplicity of determining the relationship between etalon square in mm^2 and in kB. An oedometer was used for specifying the limit of normal strain in soil at the depth of 10 cm under laboratory conditions.

Figure 1. Results of guttation intensity (guttate liquid at sprouts, mm^2 at filter paper) of spring-barley "Anni" depending on bulk density

Evaluation of soil compaction from a practical point of view was based on data obtained from the assessment of relative guttation and crop yield. Also, research was carried out by this test-method to clarify the main soil-hydrolytic constant characteristics, including the smallest soil water content (FSM), ripping moisture of capillary connection (RMC), smallest field capacity (SFC) (virtually the same as field capacity (FC)), and the maximum molecular field capacity (MMFC) (Reppo, 1980). Our experience has shown that there is a definite relation between SFC and FC which can be defined as FC/SFC = 1.13.

In addition to laboratory experiments using the guttation method the others laboratory experiments were carried out which conducted with vegetative miniatures and which were also based on the guttation method.

Theoretical suppositions

The normal dynamic stress q_d could be measured immediately (by strain gage sensor) during motion of WTV, but the soil dry bulk density, penetration or cone resistance, water content of soil, and structural composition could only be measured before and after soil compaction. Also, the deph h_w of fresh wheel tracks of WTV should be immediately measured. However, WTV requires that an agroempirical bearing capacity (ABC) of the soil (q_{abc}) be found (Table 1).

Concerning that the main criterion is:

$$q_d < q_{abc} \tag{3}$$

First, determining q_{abc} required verification of the corresponding levels of dry bulk density (Mg·m^{-3}), penetration resistance (MPa), and water content (% g g^{-1}). The level of agroempirical bearing capacity (ABC) (specifically soil compaction) is required to determine the influence of WTV on soil providing an adequate picture of final results characterizing axle-load (Håkansson *et al.*, 1987) and for determining an express-diagnostics evaluation (Nugis *et al.*, 2014). Altogether for any WTV it is important to know the track depth h_w or final soil settlement after wheel traffic. Regarding crop growth for any specific soil type, it is advantageous for WTV when the rut h_c or final wheel traffic settlement is not very deep, and at the same time, the dry soil bulk density (γ_a) is not more than the suitable limit ($\gamma_{i(limit)}$). Therefore, an advantageous situation can be defined as:

$$\gamma_a < \gamma_{i(limit)} \tag{4}$$

This limit of dry bulk density $\gamma_{i(limit)}$ is determined in the laboratory by the guttation method (Reppo, 1980; SU 1018013 A1; SU 866471 A1; Nugis, Reppo, 1984).

Determination of q_{abc} can be made according to track depth h_w of soil using the following equation (Kacygin, Orda, 1977; Nugis, 1988):

$$h_w = \frac{1}{\beta}\ln\frac{q_d}{q_{xo}}\frac{A(\varepsilon_{max}-\varepsilon_{min})}{\varepsilon_{max}+1} \tag{5}$$

where q_d– tire dynamic normal pressure during traffic in the soil layer nearest the wheel or track (*e.g.* 0.10 m), kPa; q_{xo} – compressive normal stress in the farthest soil layer during traffic relative to the tracks where no residual settlement is observed, kPa (usually q_{xo} = 20 kPa); β – coefficient of distribution of cone resistance in the vertical direction of depth of soil after traffic WTV, m^{-1} (Eq. 13); ε_{max} – maximum void ratio of soil before WTV traffic; ε_{min} – minimum feasible void ratio of soil after traffic of WTV (for example, traffic or laboratory tests of more than 50 times by oedometer); A – index (after traffic) of soil compaction when the soil void ratio ε_i is directly found in the field as a result of determining the dry bulk density, which is calculated as described by Troitskaya (1961):

$$A = \frac{(\varepsilon_{max}-\varepsilon_i)}{(\varepsilon_{max}-\varepsilon_{min})} \tag{6}$$

If specific density γ in ε (Eq. 6) is substituted by bulk density $\varepsilon = (\delta-\gamma)/\gamma$ then the index of soil compaction is calculated as:

$$A = \frac{(\gamma_i-\gamma_{min})\gamma_{max}}{(\gamma_{max}-\gamma_{min})\gamma_i} \tag{7}$$

where, γ_{min} – dry bulk density of soil in its loosened initial state, γ_i – current value of soil dry bulk density, γ_{max} – limit of soil dry bulk density in the state of compaction at which plants are not able to grow any more.

Table 1. ABC and index of soil volume trampling K_v (if the soil moisture ratio is equal to 0.8 FC), coefficient β distribution of normal compressive stresses in the depth of soil and appropriate soil bulk densities (γ_{min} and γ_{min}) including index A of soil compaction and field capacity of soil (for main Estonian soil samples).

Soil sample	Coefficient of soil volume trampling (K_v), kN m$^{3-1}$	Coefficient (β)m^{-1}	Soil dry bulk density initial state (γ_{min}), Mg m$^{3-1}$	Soil dry bulk density maximum state, (γ_{min}), Mg m$^{3-1}$	Index of soil com-paction (A)	Soil field capacity (FC), % g g^{-1}	Soil agro-technical bearing capability (ABC) or (q_{abc}), kPa
*Fragi-Stagnic Albeluvisol**	2050	2.5	0.98	1.79	0.81	16	470
Molli-Calcaric Cambisol	2900	3.3	1.11	1.78	0.82	17	390
Endoeutri-Mollic Cambisol	2900	3.1	1.07	1.68	0.79	18	380
Sceleti-Calcaric Regosol	2800	3.2	1.11	1.79	0.85	15	410
Epigleyi-Salic Fluvisol	3300	3.4	1.15	1.78	0.89	16	440
*Gleic Albeluvisol**	2600	3.3	0.98	1.73	0.71	15	520
*Mollic Gleysol**	2400	3.3	1.05	1.50	0.69	16	190

*determined during proximate period 2012–2014

Eq. 6 describes one of the more important characteristics for determining soil compaction A and could be used as the basis for determining the following indexes of soil structure: (B_{str}) and humidity C_w.

Accordingly, after transformation of Eq. 3 and substitution of the variable, the final expression for agroempirical bearing capability q_{abc} that describes the situation immediately after traffic can be written as:

$$q_{abc} = \frac{K_v}{\beta}\left\{\frac{1}{1-A\left(1-\frac{\gamma_{min}}{\gamma_{max}}\right)} - 1\right\} \quad (8)$$

where K_v – coefficient of soil trampling volume (kN m$^{3-1}$), which could be calculated if we have the value of soil resistance in the linear part of the beginning of the cone resistance diagram of (kN) and the value of cone nozzle (area in m^2) and at the same time have the depth (m) of soil penetration; γ_{min} – dry soil bulk density (Mg m$^{3-1}$) before WTV traffic and where the properties of soil are similar to those after spring cultivation and before sowing; γ_{max} – maximum feasible of soil dry bulk density (Mg m$^{3-1}$) after WTV traffic (for example, WTV traffic of more than 50 times).

The next important index needed is the index of soil structure B_{str}. First, the ratio of soil structure K_{str} is evaluated (Nugis, 2010; Nugis *et al.*, 2014) by the USA Standard Testing Sieve and also by the method of Swedish University of Agricultural Sciences (Kritz, 1983; Håkansson, 1983). For this determination, the soil is sieved under moist conditions.

The ratio of soil structure (structure ratio) K_{str} (soil moist sieving) is calculated with the following equation:

$$K_{str} = \frac{s_{ad}}{s_{un1}+s_{un2}} \quad (9)$$

where, s_{av} – percentage of soil particles with diameter between 2–4.75 mm (agronomically preferable structural aggregates – AVSA); s_{n1} – percentage of soil particles with diameter <2 mm (not-agronomically preferable structural aggregates – N-AVSA); and s_{n2} – percentage of soil particles with diameter >4.75 mm (also N-AVSA).

During long-term investigations, it has been found that if $s_{av} = s_{n1} + s_{n2}$ then the structure ratio K_{str} is equal to 1 (denoted by $K_{str(max)}$), which means that the soil structure is in the maximum preferred condition. Also, K_{str} at levels less than 0.50 are is a completely undesirable soil condition, For example, it has been observed that after potato harvesting in Estonia, soil compaction resulted in the structure ratio of $K_{str(min)} = 0.49$. Results indicate that it is possible to characterize the common structural condition of soil through a corresponding index B_{str} of soil structure measured directly in the field as described below:

$$B_{str} = \frac{(K_{str(\max)}-K_{str(i)})}{(K_{str(\max)}-K_{str(min)})} \quad (10)$$

where, $K_{str(i)}$ – the structure ratio of soil according to the current result of field measurements.

The same principle was used for estimation of soil moisture properties characterized by a corresponding index of humidity "C_w", but with the difference that this index was subtracted from one. For example:

$$C_w = \left[\frac{(1-F_{c(\max)}-F_{c(\mathrm{i})})}{(F_{c(\max)}-F_{c(\min)})}\right] \quad (11)$$

where, $F_{c(\max)}$ – soil water content (g/g%), which is equal to field capacity (FC),

$F_{c(\min)}$ – soil water content (g/g%), which is equal to plant fading.

Since for the optimization of WTV assessment is use for corresponding tillage equipment, there is a need to know that the structure of the soil is good when it is ready for cultivation, *i.e.*, if soil humidity is in the FC range of 0.7–0.9 (or 70–90% field capacity) (Nugis, 1997; Heinonen, 1979; Revut, 1960).

Finally, a suitable model for the theoretical description of changes for the previously discussed indexes (A, B_{str}, C_w) can be developed for each index separately using the same computer simulation model (Figs. 2 and 3) with the POWERSIM system (www.powersim.no). Index C_w can be determined using the same model (Fig. 4) as indexes A and B_{str}. After substitution we can write Eq. 11 as follows:

$$C_w = \frac{1-(\mathrm{Maximum\_level\_of\_MR}-\mathrm{Moisture\_ratio\_MR})}{(\mathrm{Maximum\_level\_of\_MR}-\mathrm{Minimum\_level\_of\_MR})} \quad (12)$$

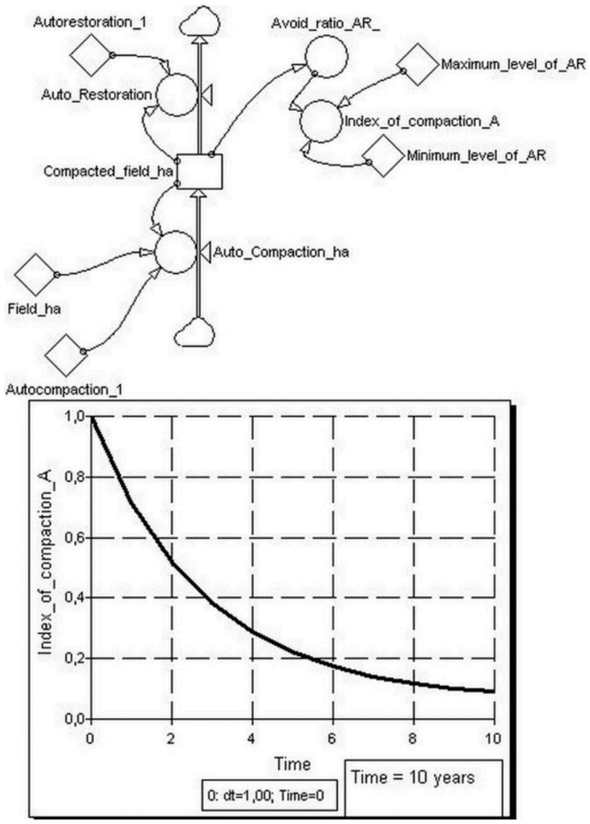

Figure 2. Relationship between index of soil compaction (A) and time (year) when soil compaction and start of spontaneous autorestoration related to changes in soil dry bulk density

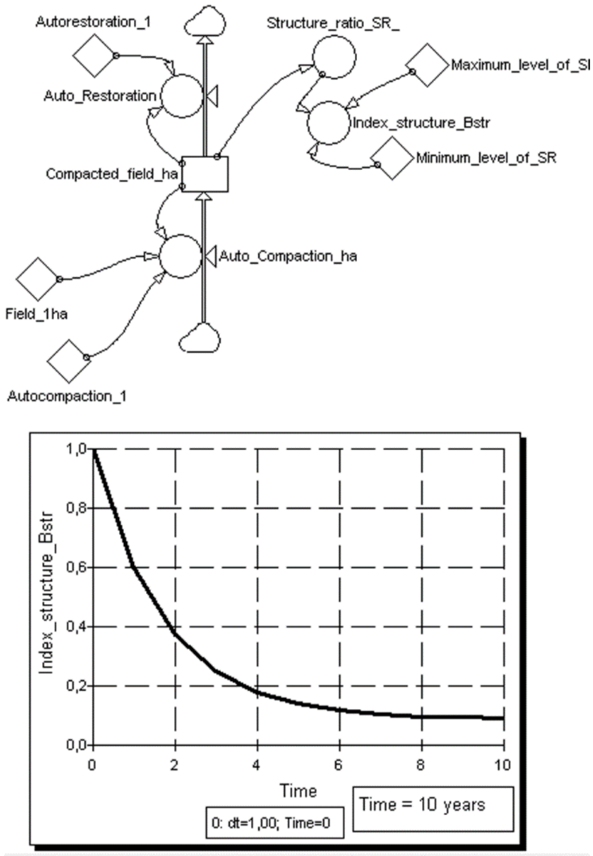

Figure 3. Relationship between index of soil structure (B_{str}) and time (up to 10 years) when MTM started spontaneous autorestoration related to changes in soil structure ratio

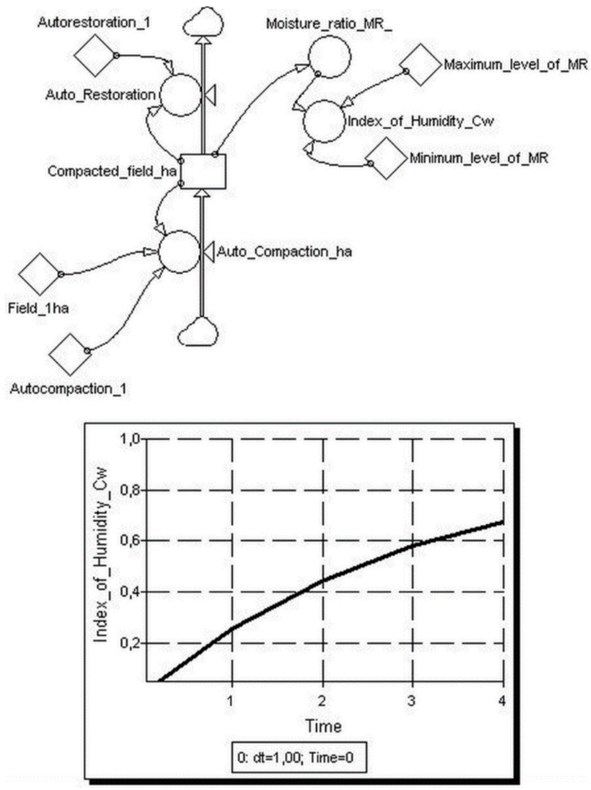

Figure 4. Relationship between index of soil humidity (C_w) and time (up to 3 years) when MTM started spontaneous autorestoration related to changes of soil moisture ratio

Concerning models (Figs. 2, 3, and 4), it should be noted that the starting-point for all of the indexes was the same, *i.e*. a compacted field 10000 m^2 (filled into the box "*Field_1ha*") and ratio 0.26 (filled into the box "*Autorestoration_1*") between width of double tracks after tractor traffic (1.31 m) and working with drill (5 m). With controlled traffic farming (CTF), to divide the distance between the two tramlines for the width of double tracks, the corresponding ratio is filled into the box "*Autorestoration_1*" (Fig. 2).

However, the model process for Figs. 2 and 3 for soil spontaneous autorestoration runs for a much longer period (about 10 years) compared to the related soil humidity (Fig. 4). Since examining the process of moisture ratio due to weather conditions of Estonia would not be appropriate without precipitations during the same period, a 4 year period (2012–2014) corresponding to the field experiments was used.

Results

Soil agroempirical bearing capability

Generally, the ratio between minimum (initial state of soil) and maximum dry bulk density, Eq. 6 and 7, varied according to soil type (Mouazen, Ramon, 2009; Nugis, 1988). On average, the minimum dry bulk density (γ_{min}) for relatively light soils of Estonia (by WRB – *Gleic Albeluvisol* including *Fragi-Stagnic Albeluvisol*) were observed to be 0.98 Mg m^{3-1} (ε_{max} = 1.65). For *MollicGleysol* (WRB) – γ_{min} = 1.05 Mg m^{3-1} (ε_{max} = 1.50). The data for maximum dry bulk density for several soil types were quite different (Table 1). For example, experiments during 2012–2014 resulted in γ_{max} = 1.73 Mg m^{3-1} (ε_{min} = 0.50) for *Gleic Albeluvisol* (South-Viljandi County) and γ_{max} = 1.79 Mg m^{3-1} (ε_{min} = 0.45) for *Fragi-Stagnic Albeluvisol* (Valga County) and for *Mollic Gleysol* (Pärnu County).

To determine the coefficient of volume trampling of soil (kN m^{3-1}), it was sufficient to have a chart of penetration or cone resistance (Fig. 5). In the diagrams shown in Figure 5, a dot corresponding to the linear part could be marked which represents each trial (h_{co} = 0.4 m; h_{cok} = 0.3 m; h_k = 0.3 m). This was necessary for calculation of the coefficient of trampling volume of soil K_v (kN m^{3-1}). Also, for each trial it was possible to fix the suitable level of penetration resistance (MPa) for each soil layer (p_{ro} = 1.17 MPa (117 kN m^{-2}); p_{rok} = 0.80 MPa (80 kN m^{-2}); p_{rk} = 0.77 MPa (77 kN m^{-2}).

The hypothesis concerning the coefficient β (Eq. 5) for distribution of cone resistance in the soil depth layer h_{ci} after traffic of WTV was defined as:

$$\beta = 1/h_{ci} \quad (13)$$

This coefficient mostly depends on soil type and moisture ratio level. It is a well-known that if soil humidity decreases then the coefficient β level will increase. Coefficient of trampling volume K_v (Eq. 6) also depends on soil humidity and at the same time soil texture classification. Because the Estonian soils are relatively light, the soil humidity plays a more important role.

In order to evaluate the soil agroempirical bearing capability q_{abc} (ABC), the corresponding results are shown in Table 1 for the most common soils of Estonia (Nugis, 1988) and for the soils evaluated in the field experiments (Tamm *et al.*, 2015). Table 1 includes the agroempirical bearing capability results of previously ploughed plots. Direct drilling increases agroempirical bearing capability, thus allowing bigger equipment usage with direct drilling technology without harmful effects to soil. However, such effects were not observed on the heavier soils of Pärnu County, (*i.e. Mollic Gleysol).*

Abja-Paluoja 2013–2014

No Till (O2) Cone res. MPa	No Till (O2) LSD <0.05	K+No Till (OK2) Cone res. MPa	K+No Till (OK2) LSD <0.05	Ploughing (K2) Cone res. MPa	Ploughing (K2) LSD <0.05
0.56	0.17	0.49	0.15	0.47	0.14
0.73	0.24	0.61	0.16	0.57	0.17
0.98	0.24	0.80	0.19	0.77	0.20
1.17	0.27	0.92	0.21	0.89	0.21
1.35	0.28	1.00	0.21	0.99	0.22
1.49	0.29	1.07	0.22	1.07	0.21
1.63	0.27	1.15	0.22	1.13	0.23
1.78	0.27	1.22	0.22	1.21	0.25
1.90	0.25	1.34	0.23	1.21	0.26
1.93	0.23	1.51	0.26	1.15	0.26
1.98	0.19	1.61	0.27	1.17	0.27
2.08	0.17	1.65	0.27	1.20	0.28
2.06	0.18	1.67	0.27	1.18	0.28
2.11	0.17	1.71	0.28	1.20	0.28
2.09	0.19	1.68	0.30	1.18	0.30
2.12	0.19	1.63	0.32	1.22	0.32
2.13	0.22	1.64	0.34	1.26	0.32
2.15	0.24	1.63	0.35	1.32	0.34
2.14	0.25	1.64	0.34	1.46	0.39
2.16	0.29	1.82	0.40	1.52	0.41
2.31	0.32	1.88	0.36	1.60	0.45
2.35	0.33	1.97	0.37	1.90	0.50
2.34	0.36	2.20	0.39	2.12	0.53
2.47	0.38	2.46	0.36	2.44	0.52
2.61	0.41	2.65	0.32	2.65	0.51
2.85	0.42	2.91	0.31	2.90	0.54
3.16	0.44	3.14	0.32	3.12	0.55
3.37	0.49	3.39	0.35	3.44	0.54
3.50	0.51	3.51	0.32	3.74	0.50
3.51	0.48	3.57	0.33	3.99	0.50
3.52	0.49	3.80	0.36	4.40	0.59
3.56	0.50	3.92	0.43	4.58	0.59
3.61	0.49	3.97	0.38	4.72	0.56
3.65	0.53	4.07	0.43	4.93	0.53
3.69	0.45	4.27	0.50	5.20	0.58
3.83	0.44	4.43	0.49	5.26	0.54
4.08	0.50	4.47	0.47	5.41	0.57
4.02	0.51	4.50	0.48	5.40	0.58
3.97	0.45	4.58	0.48	5.44	0.55
4.11	0.69	4.88	0.42	5.55	0.55

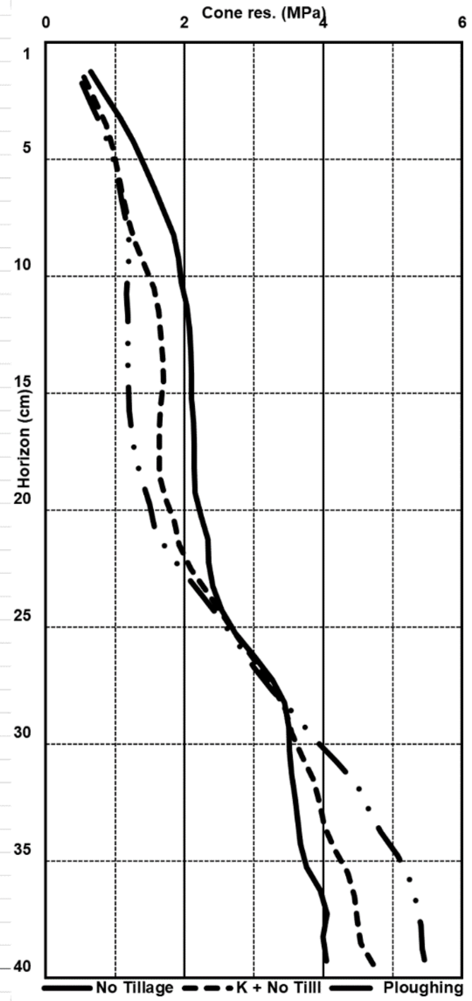

Figure 5. Example changes of average penetration or cone resistance (MPa) depending on depth (cm) of soil layer (O2 – direct drilling or no tilled; OK2 – one time is ploughing and after that every time is direct drilling; K2 – ploughing) which were measured during field experiments (2013–2014) in South-Viljandi County at Abja-Paluoja (58º7´39´´N, 25º15´32´´E) – trial No 2 (WRB – Gleic Albeluvisol)

Indexes of soil compaction, soil structure and soil humidity

In Table 2, the average values for structure ratio ($K_{str(i)}$) and for index values of soil compaction (A), soil structure (B_{str}) and soil humidity (C_w) are shown. In this table (according to equations 4, 7, 8, and 9), the minimum and maximum values are: 1) $K_{str(min)}$ = 0.10, $K_{str(max)}$ = 1.00*;* 2) ε_{min} = 0.45, ε_{max} = 1.65*;* 3) $B_{str(min)}$ = 0.01, $B_{str(max)}$ = 0.99*;* and4) $F_{c(min)}$ = 0.19, $F_{c(max)}$ = 1.00. Accordingly, it was observed that for the assessment of the best and worst structure and humidity characteristics corresponding to soil compaction, ε_{min} = 0.45, $K_{str(max)}$ = 1.0, $B_{str(min)}$ = 0.01 and $F_{c(min)}$ = 0.19 are worst and other characteristics were inversely better. It is very important for the formation of suitable POVERSIM models that the above mentioned characteristics be filled into the related ring boxes of "Avoid_ratio_AR", "Structure_ratio_SR" and "Moisture_ratio_MR", respectively (Figs. 2–4).

Table 2. Average values of ratio structure ($K_{str(i)}$), soil compaction (A), soil structure (B_{str}) and soil humidity (C_w) in results usage of several agro-technologies (no till and ploughing, *i.e*. O2 and K2; O3 and K3; O8 and K8; ploughing+no till, *i.e*. OK2) during three years (2012–2014)

Characteristics	Trial plots						
	O2	K2	OK2	O3	K3	O8	K8
$K_{str}^{1)}$	0.33	0.47	0.24	0.16	0.23	0.31	0.38
$A^{2)}$	0.71	0.59	0.74	0.81	0.90	0.69	0.61
$B_{str}^{3)}$	0.74	0.59	0.84	0.93	0.86	0.77	0.69
$C_w^{4)}$	0.13	0.21	0.13	0.12	0.36	0.05	0.09

Data in Table 2 regarding trial plots showed that the indexes of soil compaction (A) and soil structure (B_{str}) for no till versus ploughing changed quite logically in South-Viljandi County for *Gleic Albeluvisol*, but the change was not logical for the Valga County trial. This was likely due to the fact that in the Valga County trial involved a different type of soil and that shallow tillage was used instead of ploughing. The index of humidity (C_w) changed predictably at both study trials. The results of moist soil sieving ratios for the South-Viljandi County, Valga County trial shown in Table 2 indicate that the preferred (in agronomical sense) soil particles K_{str} in conventionally tilled (ploughing – K2; K3) fields were significantly better compared to no-tilled (O2; O3) fields in the trial plots.

Computer simulation in comparison with data of field experiments

Figures 6–8 show the experimental data, also data of the laboratory tests (by guttation method) and theoretical SIM curve (the same as Figs. 2–4) of the computer simulation. In 2014, the index of compaction A in comparison with SIM curve for trial plots O3 and K3 are considerably different (Fig. 6). At the same time the curve of guttation tests is located quite near with SIM curve. The same tendency (Figs. 7, 8) was observed related to the index of soil structure B_{str} and soil humidity C_w for the same trial plots in 2013 and 2014, including OK2, O8 and K8 (Fig. 7). A more careful study of several similar variants is needed and selection of other input parameters for the POWERSIM model and guttation method should be done in future research.

Fig. 8 shows a shorter modelling period because the index of humidity is mostly dependent on weather conditions. In comparison to the SIM curve (the same as Fig. 4) and to the curve of laboratory tests (by guttation method), most of the trial plots are considerably different in 2014. At the same time, trial plot K3 is not very different. Therefore, it is likely that the initial data needs to be changed for the left part of the POWERSIM model (in boxes "Autocompaction_1" and "Autoresoration_1"), but after that, changes are not needed to set the same initial conditions for the above mentioned indexes: A, B_{str} and C_w. Further investigations are planned to verify this conclusion.

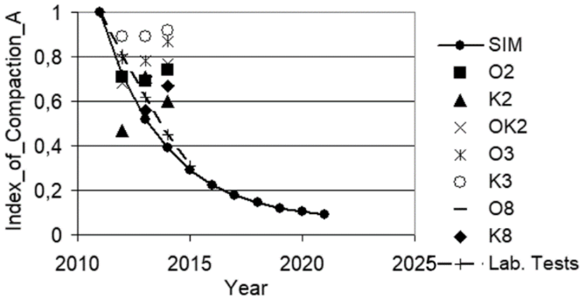

Figure 6. Results of modelling by POWERSIM system (SIM curve), curve of laboratory tests (by method of guttation) and data of indexes of soil compaction A related to different trial plots in 2012–2014.

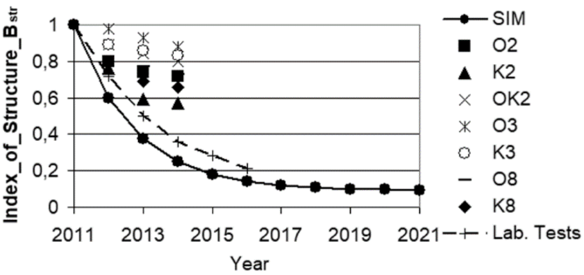

Figure 7. Results of modelling by POWERSIM system (SIM curve), curve of laboratory tests (by method of guttation) and data of indexes of soil structure B_{str} related to different trial plots in 2012–2014

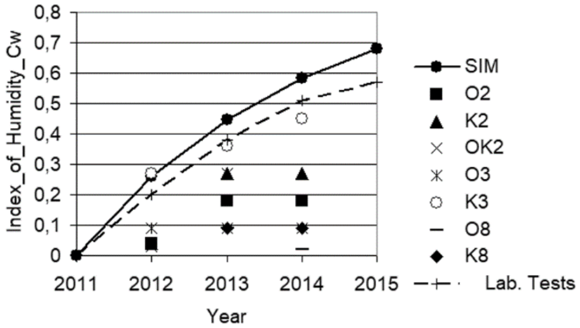

Figure 8. Results of modelling by POWERSIM system (SIM curve), curve of laboratory tests (by method of guttation) and data of indexes of soil humidity C_w related to different trial plots in 2012–2014

The comparison of all experimentally determined volumetric water content values of soil computed from E_r measurements according to different formulas (Experimental Graph – Eq. 1, (Topp *et al.*, 1980) and ln formula – Eq. 2) are presented in Figure 9. The Y-axis value – W_v of each point of "Cylinder Sampling and drying/weighing" series represents the average value of W_v of soil samples taken from the field at the same depths. The X-axis value – E_r is the average of 15 percometer measurements at the same depth as the samples were taken.

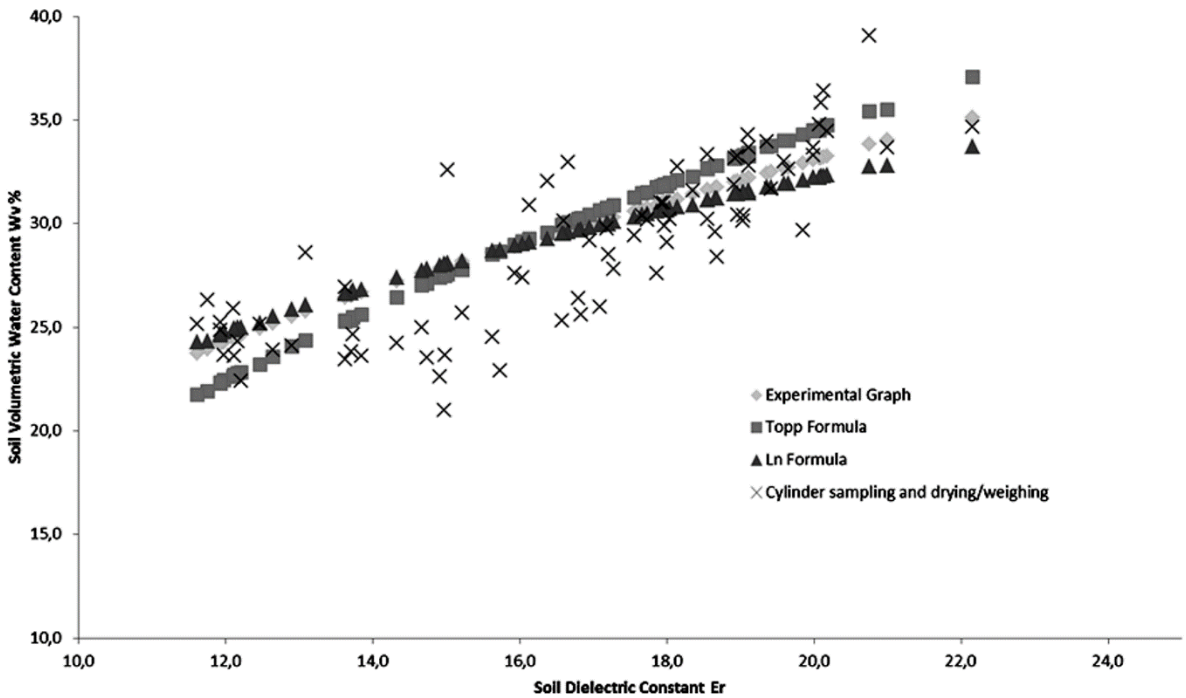

Figure 9. Comparison of experimentally determined and computed soil dielectric constant volumetric moisture values

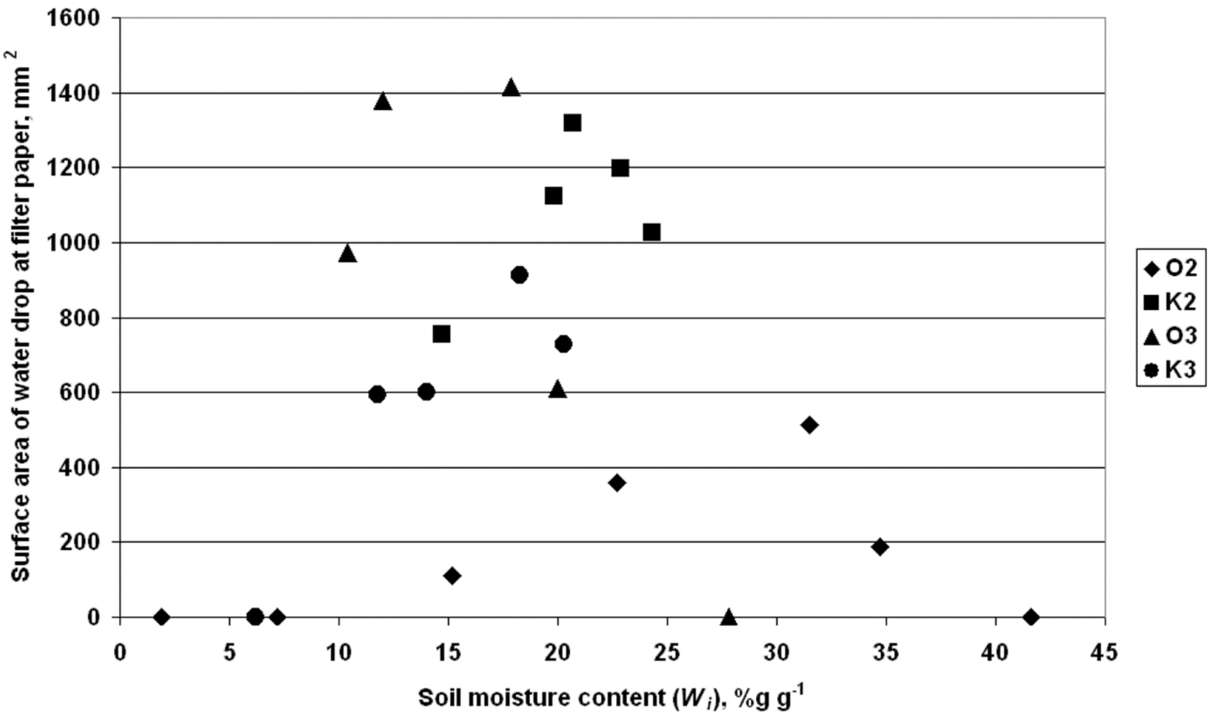

Figure 10. Results of humidity test simulation by vegetation miniatures (guttation method by Reppo (SU 866471 A1), of soils which were extracted from farmer's fields (2012–2013). Each diagram point (maximum LSD_{05} = 257 mm^2 of guttated liquid) connected with current cylinder (253.5 cm^3; diameter 62 mm and height 84 mm) was filled with the corresponding soil (middle dry bulk density 1.10±0.04 Mg $m^{3\,-1}$)

The dispersion of sampled W_v values is predictable since the samples are taken at only two places and the electrical parameters are not measured at exactly the same sample, but from the nearby soil. The natural variance of soil water content can be as high as 3 to 4% on the 2.5 m scale (Famiglietti *et al.*, 2008). The measurements at ECRI on Estonian fields resulted in a standard deviation for soil volumetric water content of 1 to 2%. The average deviation between experimental and computed W_v values given in the Figure 9 was less than 1%, which represents the natural soil variation in the field. All three means of W_v calculation from E_r data gave reasonably accurate results and the difference between the formulas used in this study were in the same order as the natural soil moisture variability.

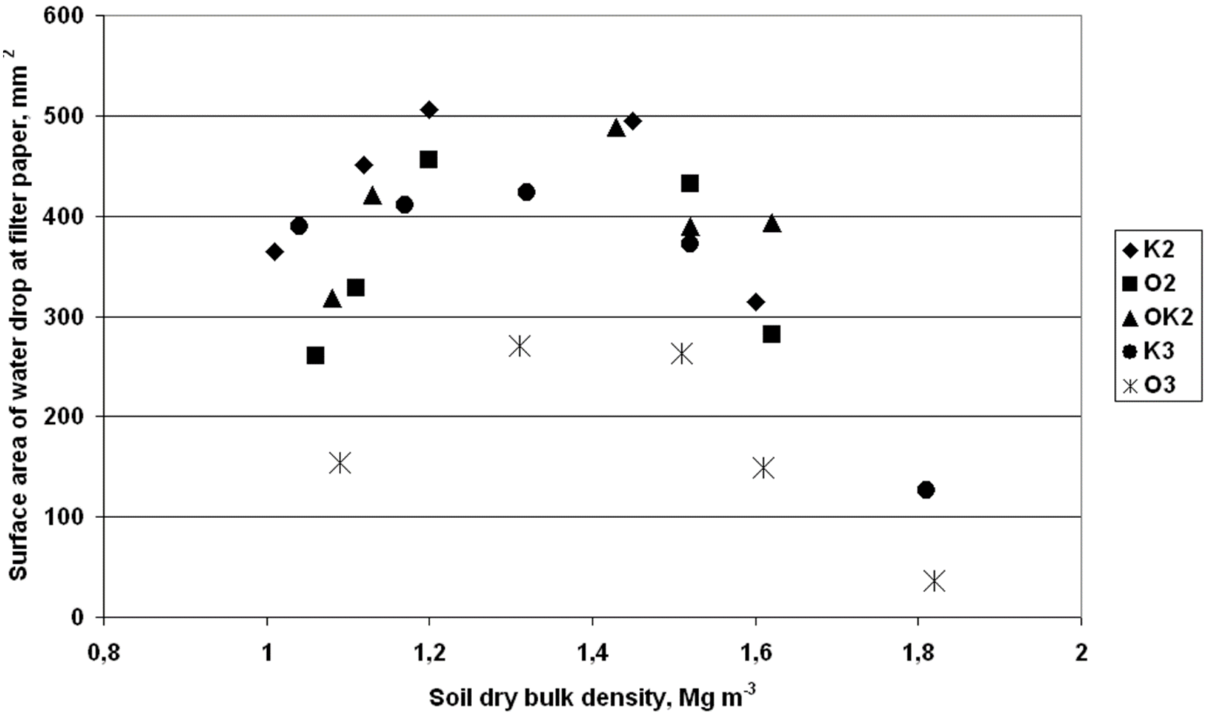

Figure 11. Results of bulk density simulation by vegetation miniatures (guttation method, SU 1018013 A1; EE 05682 B1), of soils which were extracted from farmer's fields (2012–2013) where middle soil moisture content was 20.1±1.7 % g g^{-1} (the maximum LSD_{05} = 281 mm^2 concerning the guttated liquid or water drop at filter paper)

Figures 8 and 9 show that the tendency for changes in the index for humidity (C_w), W_v,and E_r are similar. This is quite logical because the dependence between C_w and the moisture ratio (MR) or W_{MR} is linear. Therefore, from the field experiments (2012–2014), the relationship between moisture ratio W_{MR} (calculated from soil field capacity (FC)) and the index of humidity C_w can be described by the equation: $C_w = -0.599\ W_{MR} + 0.89$ ($R^2 = 0.89$).

Simulation by vegetation miniatures

Figures 10 and 11 show the results of the laboratory test with vegetation miniatures of soil humidity and soil bulk density, respectively. In Figure 10, the soil water content, smallest field capacity (SFC) is shown while Figure 11 indicates the limits of dry bulk density concerning Estonian Gleic Albeluvisol (South-Viljandi County) and *Fragi-Stagnic Albeluvisol* (Valga County). These limits are the most favourable conditions for growing cereals. Based on the dependences shown in Figures 10 and 11, the corresponding minimum and maximum limits of characteristics could be selected for computer simulation modelling of the soil physical properties.

Discussion

Our main goal was to develop an express-diagnostics method to describe the relationships between q_d (WTV) and q_{abc} (soil) in such a way that the functions of the machine-soil-crop system could be predicted. The study determined that the complex estimation of soil compaction, soil structure, and humidity could be characterize by indexes "*A*" (Fig. 6, Eq. 6), B_{str} (Fig. 7, Eq. 10), and C_w (Fig. 8, Eq. 11). Accordingly, it was determined that the main diagnostic level could be summarized for Estonian soils. It should be noted that similar results have been reported by others (Mouazen, Ramon, 2009; Mueller *et al.*, 2009; Troitskaya, 1961).

The main focus of the study was characterizing the ABC (agroempirical bearing capability, Eq. 8) with practical results that could be used by farmers. For farmers, it is necessary to immediately know the level of soil compaction for a given tractor under the specific Estonian soil conditions. Many studies report that they have solved this urgent problem (Söhne, 1953; Arvidsson, Håkansson, 1991; Richards *et al.*, 1997; Koolen, van den Akker, 2000; Dawidowski *et al.*, 2000; Tarkiewicz, Lipiec, 2000; Tullberg, 2000), but none of the publications consider the issues related to ABC.

Most of the agronomically preferable structural aggregates (macrostructure) are formed as a result of soil tillage (Soane, Bonne, 1986) in conditions of mature soil. Nevertheless, it should be noted that according to Revut (1960), in general agronomically preferable aggregates of soil are deemed to be those with a diameter between 0.25 to 10 mm, which are determined by means of dry screening in a laboratory.

In Nordic countries, an evaluation method (as described by Kritz (1983) and Håkansson (1983) is used that differs from the above widely used methods. In this method, soil aggregates between 2 to 5 mm (in our case was 2 to 4.75 mm) in diameter are deemed agronomically preferable structural aggregates and are assessed in the field by means of moist soil screening. The soil structural aggregates with diameters larger than 5 mm and less than 2 mm are considered as not agronomically preferable. Because we have evaluated soil structural elements by both the USA Standard

Testing Sieve and also by the Swedish University of Agricultural Sciences method (Kritz, 1983; Håkansson, 1983) where moist soil is sieved, it is believed that the differences between corresponding soil particle size of 2–5 mm or 2–4.75 mm are not important.

It is well established that soil is compacted by WTV during agricultural farming operations. Modern WTV are commonly very powerful units, which must be properly ballasted for maximum trailing capacity. A >50 kW unit can weigh about 4 Mg (1.8 Mg in front axle and 2.2 Mg rear axle) and carry about its own weight. Modern high power WTV can weight considerably more. For example, a typical New Holland T8.260 with 168 kW, weighs 7.2 Mg (2.7 Mg front axle and 4.5 Mg rear axle) and can carry 10 Mg on rear linkage and 3.7 Mg on the front. Total weight with all ballasts can be more than 20 Mg (>6 Mg in front axle and >14 Mg in rear axle). This type of machinery generates a considerably higher load to soil and results from this research agrees with the well-known opinion that an axle load above 10 Mg should never be used in agriculture soils (Håkansson *et al.*, 1987).

It should also be noted that the advantage of express-diagnostics method discussed in this scientific work is that it enables the specific "machine-soil-crop" functioning system to be determined without complicated laboratory and field experiments. The influence of tractor actions (and corresponding tools) on soil is passed on to the functioning of the plant, which influences crop yields either positively or negatively. Therefore, it is very important to understand the relationships between machine, soil, and crop (Pidgeon, Soane, 1977). The main question is how are changes in dry bulk density, penetration or cone resistance, soil water content, and structural composition of soil resulting from machine operations. The results of this study have indicated that information regarding the soil penetrologger including TDR (Mueller *et al.*, 2009; Bejarano *et al.*, 2010; Botta *et al.*, 2010) and data from a guttation method (simulation by vegetation miniatures (from PhD of Enno Reppo (SU 866471 A1; SU 1018013 A1) is sufficient for express-diagnostics assessment. However, the impact on soil from field ploughing for the tramline strips and in the middle of the field (both immediately during the motion of WTV and later) remain less understood. In spite of the large amount of information that has been reported about this topic (*i.e*. McHugh *et al.*, 2009; Leiaru, 2015) more research is required.

For assessment of soil compaction, it is very important to obtain adequate soil condition information. Because weather conditions are usually very variable under field conditions, long-term field experiments are required to obtain reliable results. However, results from this study have indicated that the guttation method or simulation by vegetation miniatures during a short period (only 2 days and 7 determinations of water droplets (guttate) from plant sprouts) can be used to obtain suitable results for soil compaction assessment. Thereby, if to compare the results of laboratory experiments obtained by guttation method with a theoretical curve we could be noted that we gave an encouraging result, which confirms the correctness of the theoretical approach. It is believed that difference in these methods and long term studies would be negligible, while providing easily available soil condition characteristics for yield estimation.

If the surface area of water drop on filter paper shown on the vertical axis of Figure 11 was converted into relative data then it could be compared with relative crop yield data. Results of several field studies of machines have indicated that relative guttation and relative yield did not vary more than 5%, calculated from the best (maximum) result (100%). We have found that our results were correlated with crop response curves which has been supported by many authors (Semionov *et al.*, 1980; Håkansson, 2001).

Conclusions

In this research, the soil agroempirical bearing capability for the main Estonian soil types was determined.

Indexes of soil compaction, soil structure, and soil humidity were determined and by using POWERSIM system changes to these indexes were simulated.

Results of simulation by vegetation miniatures (guttation method) could be used to determine the minimum, maximum, and limit levels of dry bulk density, and the limits of smallest field capacity (SFC).

Field experiments determined soil bulk density (in 0–10, 11–20 and 21–30 cm layers) for three field pairs. Result showed that at the deepest layer the bulk density was higher for tilled soil compared to no-tilled soil. Soil bulk density in no-tilled soil after 2 years in the deepest layer was 0.11 Mg $m^{3\,-1}$ less than tilled soil. The bulk density of no-tilled soil after 3 years in the deepest layer was 0.12 Mg $m^{3\,-1}$ less compared to the tilled field soil.

Also, the amount of agronomically preferable aggregates (2–4.75mm) was major in tilled soil compared to no-tilled soil.

Acknowledgements
The authors would like to thank the Estonian Ministry of Rural Affairs for support of this research project. Also many thanks to colleagues from the International Soil Tillage Research Organization who encouraged authors for writing this paper.

Conflict of interest

The authors declare that there is no conflict of interest regarding the publications of this paper.

Author contributions

EN, KT, TV, TP, VP – study conception and design.
EN, KT, TV, TP – acquisition of data.
EN, KT, TV, TP, VP – analysis and interpretation of data.
EN, TP, VP – drafting of the manuscript.
EN, KT, TV, TP, VP – critical revision and approved the final manuscript.

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Agraarteadus
1 • XXXI • 2020 66–69

Journal of Agricultural Science
1 • XXXI • 2020 66–69

LÜHIARTIKKEL: EESTI AJALOOLISTE MÕISAPARKIDE JA METSADE PUISTU LIIGILISE KOOSSEISU VÕRDLUSE MEETOD

SHORT COMMUNICATION: A METHOD FOR COMPARING THE TREE SPECIES COMPOSITION OF ESTONIAN HISTORIC MANOR PARKS AND FORESTS

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Saabunud: Received: 02.11.2019
Aktsepteeritud: Accepted: 25.02.2020

Avaldatud veebis: Published online: 07.03.2020

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Keywords: park, forest, species composition, dendrological inventory, forest habitat.

DOI: 10.15159/jas.20.01

ABSTRACT. The following short communication article presents a method for comparing the species composition of Estonian forests and parks, giving an overview of the data that is currently being gathered and underlining how these two datasets can be compared.
Even though both forest and park inventories are carried out throughout the country, to this day there have been no comparative studies on how the species composition of parks and forests differ from each other. This stems from the fact that the park and forest inventories are carried out using different methods.
Forest inventories classify most of the trees according to their genera, but also differentiate between the species composition of the forest canopy and sub-canopy layers. The park inventories classify all dendrological plants by their species, also measuring several other individual parameters. The main difference being that park inventories do not differentiate between different canopy layers, rather providing species composition charts that include all the dendrological plants growing in the park.
In order to compare the two datasets, it is necessary to transfer the data derived from manor park inventories to match that of the Estonian forest inventory. The first step in implementing the method is to divide the inventory data from parks into the forest canopy and sub-canopy layers. The canopy layer of parks was determined to consist of old trees (>100 years). The age of the trees in parks was modelled after growth charts compiled from the data from Estonian forests, which was then extrapolated to reach 120 years. These growth charts were compared to the breast height diameter of park trees, to determine their age. The canopy layer of parks was then analysed to provide an overview of species composition that corresponds to the same level of generalisation as the forest inventories.
The results showed that the species composition of old manor parks differs significantly from most Estonian forests with the majority of the trees in parks being broad-leaved. The proposed method is suitable for comparing forests and parks on a generalised level.

Sissejuhatus

Seniajani puudub võrdlus selle kohta, kui sarnane või erinev on parkide ja metsade puittaimede liigiline koosseis. Seetõttu ei ole teada, mil määral erineb tüüpiline mõisapargi puistu kooslus Eesti metsadest ning ei ole ka võimalik hinnata, milline on parkide roll erinevate metsaliikide elupaikadena või milliseid ökoloogilisi nišše nad aitavad täita.

Käesolevas lühiartiklis tutvustatakse võrdlusmeetodit, mille abil on võimalik läbi viia metsade ja parkide puistute liigilise koosseisu võrdlust. Esmalt antakse ülevaade puistute (mets, park) kohta kogutavatest liigilise koosseisu andmetest ja nende andmekogude sisulistest erinevustest. Seejärel tutvustatakse võrdlusmeetodit, mis võimaldab teatud aspekte arvesse võttes teostada parkide ja metsade liigilise koosseisu võrdlust. Tuuakse välja aspektid, mida tuleb meetodi kasutamisel arvesse võtta, esitatakse meetodi kitsaskohad ning edasised võimalikud arendussuunad.

Suur hulk parkide liigilise koosseisu uuringuid (Palm, 2011) on keskendunud puittaimede liigilise koosseisu uurimisele. Uuringute tulemusena on olemas põhjalik andmestik parkides kasvavatest puittaimeliikidest. Selle tulemusena on olemas hea ülevaade Eesti mõisaparkides kasvavatest puu- ja põõsaliikidest, kuid puudub võrdlus metsapuistuga. Lisaks on uuritud küll parkide liigilist osakaalu (Nutt jt, 2014) ja pargipuistu liigilise koosseisu autentsust (Nutt, 2013), kuid uuringud käsitlevad vaid väikest osa kogu parkidest. Mõisaparkide puhul on uurijate tähelepanu pälvinud ka pargid kui kunstiteosed (Sinijärv, 2013), mille puhul on hinnatud kompositsiooni ja esteetilisi väärtusi (Nurme, 2019; Nurme jt, 2014). Tähelepanu on pälvinud ka parkides kasvavate liikide invasiivsusküsimused, mille hindamiseks on kasutatud Weber-Gut riskihindamismetoodikat (Purik, Ööpik, 2013) ning uuritud nimetatud riskihindamismetoodika sobivust Eesti parkides kasvavate võõrliikide hindamiseks.

Parkide ja metsade võrdlevat uurimist on seni raskendanud tõsiasi, et puuduvad võrdlusandmed, mis võimaldaksid ühistel alustel võrrelda metsade ja parkide puistute liigilisi koosseise, mis tuleneb metsade ja parkide puittaimede hindamiseks rakendatavate meetodite erinevusest. Metsapuistute hindamisel kasutatakse statistilise metsainventeerimise meetodit SMI. Hindamise tulemused esitatakse takseerkirjes, kus esitatakse eraldi I ja II rinde koosseisuvalemid. Koosseisuvalemite koosseisukordajad kirjeldavad rinde puistuelemendi tagavara suhet kogutagavarasse kasvukohatüüpide (25 kasvukohatüüpi) kohta.

Pargipuistute hindamiseks kasutakse dendroloogilise hindamise meetodit, mille alusel määratakse puistuelementide parameetrid (liik, rinnasdiameeter, tervislik seisukord jm) üksikelemendi tasemel. Tulemuseks on üksikelemendi detailsusega liigilise osakaalu andmestik, milles on esitatud ka puistuelementide mõõdud.

Tulenevalt pargi ja metsa hindamiseks kasutusel olevate hindamismeetodite erinevusest on hindamise tulemusena moodustuvad andmestikud erinevad. Kui metsade puhul on tulemuse üldistusaste liikide protsentuaalne jaotus rinnete kaupa, siis parkide puhul kajastavad dendroloogilise hindamise tulemused kõigi pargipuude- ja põõsaste liike ja mõõtmeid ilma rinneteks jaotamata.

Materjal ja metoodika

Eesti maismaast pool ehk 51,4% on metsamaa. Kõige levinumad puistud on männikud (32,1% puistute kogupindalast), kaasikud (30,1%), kuusikud (17,5%) ja halllepikud (9,0%) (Eesti Statistikaamet, 2018). Metsi kirjeldava statistika põhiallikas on riiklik metsainventeerimine, mida alates 1999. aastast on läbi viidud statistilise metsainventeerimise (SMI) meetodil. Käesolevas artiklis esitatud näite puhul on kasutatud 2008. aasta andmeid, mis on kajastatud aruandes "Eesti metsad" tabelis 33.1. "Metsamaa koosseis tagavara järgi kasvukohatüüpide lõikes".

Metsade tüpoloogia aluseks on kasvukohatüüp ehk mullastikult ja kasvutingimustelt ühtlane metsaala. Suur osa Eestis läbi viidavatest metsade uuringutest klassifitseerivad metsad 25 kasvukohatüübi alusel ning ka puistu andmed esitatakse kasvukohatüüpide järgi. Vastavalt 2018. aastal kehtestatud määrusele "Metsa korraldamise juhend" määratakse puuliigid perekonna tasemel, välja arvatud jalakas, künnapuu, haab, sanglepp ja hall lepp, mida määratakse liigi tasemel. Eestis vähem levinud puuliikide puhul märgitakse vaid, kas tegemist on okas- või lehtpuudega (Metsa korraldamise juhend, 2018).

Parkide liigilise koosseisu analüüsimisel võeti käesoleva näite aluseks perioodil 2005–2012 läbi viidud parkide (17) dendroloogiliste inventuuride andmeid. Kokku koondati andmebaasi andmeid 13 944 puu kohta, millest 1836 olid okaspuud ja 12 108 lehtpuud. Pärismaiseid puid oli 11 902 ja eksoote 2042 eksemplari. Pärismaistest puudest valdava osa moodustasid lehtpuud (11 218 puud) ja vaid väikese osa okaspuud (684 puud). Eksootidest oli okaspuid 1152 eksemplari ja lehtpuid 890.

Selleks, et metsade ja parkide puistute võrdlust oleks võimalik läbi viia, alustati andmete ühtlustamisest. Metsade puistut kirjeldavate koosseisuvalmite üldistusaste on parkide dendroloogiliste inventuuride andmete omast suurem. Seetõttu tuleb võrreldatavuse saavutamiseks tõsta parkide andmete üldistusastet ehk kirjeldada parkide puistu koosseisu metsade puistu koosseisuvalemitega samadel alustel.

Parkide koosseisuvalemi koostamiseks jagati pargipuistu esmalt rinneteks. Parkide I rinde koosseisu loeti vanad, mõisapargi algkoosseisust pärinevad (>100 aastat) puud, kusjuures puude vanuse määramisel võeti aluseks puude rinnasdiameeter, arvestades sealjuures liigilisi iseärasusi. II rindesse arvati kõik väiksema rinnasdiameetriga pargipuud ja -põõsad.

Pargipuude vanuse hindamisskaala koostamisel võeti aluseks Eesti puistute kõrguse, diameetri ja tagavara kasvumudel. Mudel koosneb Eesti Metsakorralduskeskuse poolt koostatud 206 metskonna takseerandmete andmebaasifailidest, mis kajastavad Eesti riigimetsa seisundit ajavahemikul 1984–1993 (Kiviste, 1995, 1997). Kasvumudel on koostatud metsakasvukohatüüpide järgi metsanduses kasvatatavate liikide (MA, KU, KS, HB, LM, LV, SA, TA) kohta. Pargi puude vanuse hindamisskaala loomiseks arvutati mudelis olevatele liikidele keskmised kasvukõverad 120 aasta pikkuse perioodi kohta. 120-aastane periood valiti kuna sellisel juhul jääb nn noorte ja vanade puude üleminek (ehk vanusepiir 100 aastat) perioodi sisse. Kasvukõveraid kasutati rinnasdiameetri mõõtandmete teisendamisel vanuseks. Vanadeks puudeks määrati liikide kaupa eksemplarid, mille rinnasdiameeter oli suurem kui skaalanäit. Liikide kaupa oli see järgmine: *Alnus* *glutinosa*, *Betula pendula*, *Pinus sylvestris* 24 cm, *Picea abies* 26 cm, *Quercus robur*, *Fraxinus excelsior* 30 cm, *Populus tremula* 36 cm. Ülejäänud liikide puhul võeti määramisel kõvadel lehtpuudel aluseks *Quercus robur*, *Fraxinus excelsior (kõvad lehtpuud)* eeskujul 30 cm ja pehmetel lehtpuudel *Alnus glutinosa*, *Betula pendula* (pehmed lehtpuud) eeskujul 24 cm.

Järgnevalt teisendati liigid perekonna tasemele, välja arvatud harilik jalakas (*Ulmus glabra*), künnapuu (*Ulmus laevis*), harilik haab (*Populus tremula*), sanglepp (*Alnus glutinosa*) ja hall lepp (*Alnus incana*).

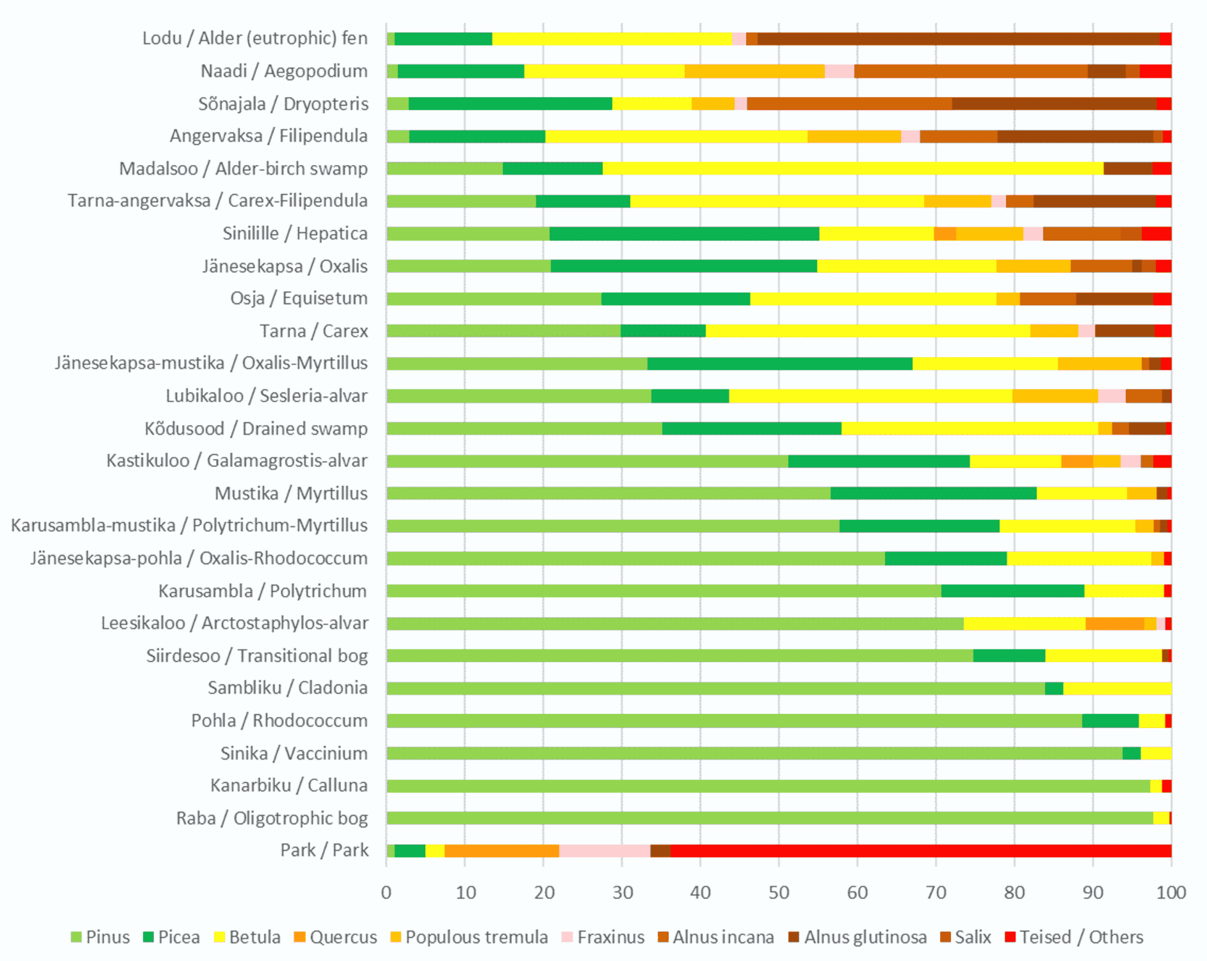
Tulemused kirjeldati analoogiliselt metsade puuliikide osakaalu kirjeldavale koosseisuvalemile.

Andmetöötluseks kasutati vabavaralist programmi R.

Tulemused

Koosseisuvalemite võrdlus näitas, et parkide liigiline koosseis erineb oluliselt metsade liigilisest koosseisust (joonis 1).

Metsades on suurem okaspuude- ning parkides lehtpuude osakaal. Parkides on lehtpuid rohkem kui okaspuid (suhe on umbes 5:1). Kui metsades on põhiliseks okaspuuliigiks harilik mänd (*Pinus sylvestris*), siis parkides esineb harilikku mändi väga vähe. Ka on pargipuistutes märgatavalt väiksem hariliku kuuse (*Picea abies*) osakaal. Üleüldiselt on okaspuude osa parkides väga väike, jäädes 10% lähedale. Parkide erinevus metsadest ilmneb ka eksootide esinemise poolest. Kui parkides on eksootide liigiline mitmekesisus suur, siis metsades eksoodid praktiliselt puuduvad. Samas on küll pargid eksootide liikide arvu poolest rikkad, kuid eksootide osakaal kogu puistust on väike, mis tähendab seda, et enamus puid on pärismaised. Parkide puistust 90% moodustavad pärismaised puud, kusjuures laialehiste puude hulk selles jääb 80–90% vahele.



Joonis 1. Puuliikide osakaal metsade kasvukohatüüpide järgi (2008. aasta andmetes on jalakas loetud "teiste liikide" hulka)
Figure 1. The species composition of trees in different forest site types (In data from 2008, *Ulmus glabra* is classified as "other species")

Arutelu

Käesolevas lühiartiklis tutvustatud võrdlusmeetodi abil saab võrrelda metsade ja parkide puuliikide proportsionaalset jaotust. Koosseisuvalmite kasutamine metsade ja parkide üldistatud tasemetel võrdlemiseks on sobilik, kuid silmas tuleb pidada koosseisuvalmite koostamise metoodikat. Kuna metsade puistute kohta koostatakse koosseisuvalemid mõlema rinde puhul eraldi, tuleb ka parkides jagada kogupuistu esmalt rinneteks ning alles seejärel on võimalik koostada

I rinde puistu osa kirjeldav koosseisuvalem. Käesolevas lühiartiklis tutvustatud võrdlusmetoodika annab esmased tulemused ja kinnituse, et tüüpilise mõisapargi puistu ja Eesti metsade koosluse proportsionaalset võrdlust on olemasolevate andmete põhjal võimalik läbi viia selleks, et hinnata, kui sarnased või erinevad on erineva kasvukohatüübi metsade ja pargi puistu (metsa I rinne ja pargi vanad puud) proportsionaalne koosseis.

Lühiartiklis tutvustatud võrdlusmetoodika edasiarendamisel on mitmeid võimalusi. Metoodika täiendamisel on vajalik parkide koosseisuvalemi koostamisel põhjalikumalt tegeleda puude vanuse määramisega, et oleks võimalik võimalikult täpselt eristada I ja II rinde piir. Teiseks aspektiks, mida tuleb eelpool esitatud võrdlusmeetodi puhul arvesse võtta on asjaolu, et metsade puistu koosseisuvalem kirjeldab ühe liigi tagavara tihumeetrites puistu kogutagavarasse hektaril ja parkide puhul näitab ühe liigi eksemplaride osakaalu kogu pargi puistus. See tähendab seda, et võrdlus näitab liikide proportsionaalset erinevust.

Kitsaskohaks on ka metsade ja parkide seire erinev katvus. Kui metsade riiklik seire katab kogu Eesti, siis pargipuistuid riigi tasandil ei seirata ning seetõttu on parkide puistu uuringud piirkonniti erineva katvusega ning täpsusastmelt erinevad.

Huvide konflikt / *Conflict of interest*

Autorid kinnitavad artikliga seotud huvide puudumist.
The authors declare that there is no conflict of interest regarding the publication of this paper.

Autorite panus / *Author contributions*

NN – katse planeerimine, andmete kogumine, analüüs ja tõlgendamine, artikli kirjutamine / *study conception and design, acquisition, analysis and interpretation of data, drafting*;
AK – andmete analüüs ja tõlgendamine / *analysis and interpretation of data*;
MKS – artikli kirjutamine, toimetamine / *drafting, editing and critical revision of the manuscript*.

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SHORT COMMUNICATION: THE IMPROVEMENT OF THE GROWTH OF TOMATO TRANSPLANTS BY BOKASHI TEA

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Saabunud: Received: 17.03.2020
Aktsepteeritud: Accepted: 25.05.2020

Avaldatud veebis: Published online: 26.05.2020

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Keywords: bokashi tea, height, number of leaves, stem diameter, tomato transplants.

DOI: 10.15159/jas.20.10

ABSTRACT. Effective microorganisms' bokashi fermentation is proposed to upcycle food waste to novel feed supplements, and to (partially) replace traditional composting of food waste (and secondary residues from industrial processes) to facilitate both plant production and soil quality as well as to reduce greenhouse gas emissions. The purpose was to assess the influence of bokashi tea treatment on the growth of tomato transplants. There were two treatments: one with bokashi tea and second without bokashi tea (control). Tomato transplants treated with bokashi tea tended to be higher than those in control; while the results were not significantly different. The number of leaves of tomato transplants treated with bokashi tea was not significantly different. The stem diameter of tomato transplants was 13% greater ($P = 0.04$) in bokashi tea treated plants than in control. Conclusion: Bokashi tea improves the growth of tomato transplants by increasing stem diameter and is allowing for plants to take up more nutrients.

Introduction

Bokashi technology is a method for treating biowaste in general and food waste in specific, using controlled lactic acid fermentation (LAF) under anaerobic conditions (Boechat *et al.*, 2013). The term is based on a traditional Japanese method of the same name. Unlike standard aerobic composting, bokashi waste treatment is performed in closed bioreactors or unaerated piles to create anoxic conditions. To control the breakdown of organic matter under LAF conditions, a mixture of biowaste is inoculated with a defined mixture of (facultative) anaerobic microorganisms (effective microorganisms – EM).

Assuming collection routines maintain nutritional quality, bokashi fermentation of food waste with an effective microbiome (EM) is a form of biological treatment that stabilizes the bio-waste and provides an animal feed (supplement), or a nutrient-rich growth-promoting fertilizer for field- and greenhouse-based food production systems. Thus, in the sense of circular economy and zero-waste, more complete utilization of food waste will be achieved. To promote the industry-scale use of this innovative technology in Europe, the end products of EM bokashi treatment have to be effective, safe for the environment and human health, and economical. EM bokashi fermentation is proposed to upcycle food waste to novel feed supplements, and to (partially) replace traditional composting of food waste (and secondary residues from industrial processes) to facilitate both plant production and soil quality as well as to reduce greenhouse gas emissions.

Effective microorganisms (EM) consist of a mixed culture of beneficial ("effective"), naturally-occurring microorganisms such as purple non-Sulphur bacteria (PNSB; *e.g. Rhodopseudomonas palustris*, *Rhodobacter sphaeroides*), lactobacilli (LAB; *e.g. Lactobacillus plantarum*, *L. casei*, and *Streptococcus lactis*), yeasts (*e.g. Saccharomyces* spp.), and *Actinomycetes* (*Streptomyces* spp.) (Olle, 2016). All microbes in EM are derived from nature (Footer, 2013). The concept of EM is based on the inoculation of substrates to shift the microbial equilibrium and thus create an improved microbiome that favours improved productivity. Besides, secondary metabolites produced by the modified microbiome (*e.g.* inositol, ubiquinone, saponin, low-molecular polysaccharides, polyphenols and chelating agents) are a relevant mode of action (Boechat *et al.*, 2013).

A couple of theories exist to justify the complex mode of action of EM, or plant growth-promoting microorganisms (PGPM), in agricultural production (Balogun *et al.*, 2016). These include the biological suppression of pathogens theory, energy conservation theory, mineral solubilization theory, microbial ecological balance theory, and biological nitrogen fixation theory. EM can thus e.g. decompose biogenous waste and residue, detoxify pesticides, suppress plant diseases and soil-borne pathogens, enhance nutrient cycling and produce bioactive secondary metabolites such as vitamins, hormones, and enzymes that stimulate plant growth/reroute C allocation. For example, it is increasingly realized that LAB, as being an important part of the EM inoculate, is powerful organic fertilizers, bio-control agents, and bio-stimulants (Lamont *et al.*, 2017).

Bokashi can stimulate microbial, meso- and macro-fauna activity, thereby increasing soil aggregate abundance and stability (Amezketa, 1999), which will improve soil drainage and aeration especially in heavy soils; in more coarse soils it increases the water holding capacity of the soil. Thereby Ginting (2019) shows that bokashi applications are improving soil fertility.

EM increases crop yield and growth Megali *et al.* (2014), because of improved plant nutrition. EM bokashi fertilization leads to greater yield increases than other growth promotors (Mohan, 2008). The fact that not all species respond positively to EM application suggests: not all plant species are responsive to EM effects on the soil/root microbiome (Hayat *et al.*, 2010) or soil amendment might not have resulted in the sufficient establishment of EM's constitutive microbial species into the local soil microbiome (Mayer *et al.*, 2010).

Therefore, the present investigation aimed to assess the influence of bokashi tea on the growth parameters of tomato transplants.

Material and Methods

The experiments were carried out in spring 2019 in a heated glasshouse at the Estonian Crop Research Institute.

In experiment tomato variety Valve was grown. There were two treatments: 1. with bokashi tea treatment; 2. without bokashi tea treatment – control. Each treatment consisted of 3 plants. The experiment had three replicates. The experiment was repeated at the same time, *i.e*. simultaneously.

Tomato seeds were sown on 17 April 2019 and transplants were grown in a heated glass greenhouse. The greenhouse lighting at a plant level was approximately 12 000 lux from high-pressure mercury lamps. The plants were additionally lighted in 18 hours (4.00–23.00). All plants were grown with a minimum day and night temperature of 20 °C and 18 °C, respectively.

Young plants were transplanted two times: at first at spacing 5 cm into larger boxes (23 April 2019), second time into an individual pot (9 cm diameter), (3 May 2019). Substrate for organically cultivated seedlings and transplants was organic vegetable soil from Matogard Ltd. Ingredients: peat, compost, organic fertilizers, humic substance, clay. Characteristics: capacity/mass <0.7 kg L^{-1}; acidity (pH KCl) 5.6–6.5; salts content 1.2–2.0 g L^{-1}.

Seeds were soaked in bokashi tea 1:500 solution (bokashi tea treatment) or water (control) half-hour before sowing. Tomato seeds were sown on in bio-vegetable soil treated with bokashi tea 1:500 solution (treatment 1) and in organic vegetable soil treated with water (treatment 2). 2 L liquid per 12.5 L peat in both treatments was used. At first spacing, larger boxes were filled with organic vegetable soil treated with bokashi tea 1:500 solution (treatment 1) and with organic vegetable soil treated with water (treatment 2). The same amount of liquid was used per 12.5 L peat in both treatments. A second spacing the pots were filled with bio-vegetable garden soil treated with bokashi tea 1:1000 solution (treatment 1) and with bio-vegetable garden soil treated with water (treatment 2). This time 4 L liquid per 25 L peat was used in both treatments. 06.05–27.05.19 the plants were watered with weekly intervals with bokashi tea 1:1000 solution (treatment 1) and with water (treatment 2). Here 4 L liquid per 32 plants in both treatments was used.

On 07.06.2019 the height, stem diameter and the number of leaves were recorded. The height was measured with measuring tape, the stem diameter was measured with a shear calliper, and the number of leaves was counted.

Analyses of variance were carried out on the data obtained using programme MS Excel 2019.

Results

The stem diameter of tomato transplants was 13% greater (P = 0.04) in bokashi tea treated plants than in control (Table 1). Tomato transplants treated with bokashi tea tended to be 5 cm higher than those in control (Table 1); while the results were not significantly different (P = 0.06). The number of leaves of tomato transplants treated with bokashi tea was not significantly different (P = 0.1) (Table 1). The standard deviation of the bokashi tea treatment for the plant height was 1.528 and for control 3.055 cm and the number of leaves, it was 0.577, while in control treatment 1.155, large variation in the control group was the reason that results were not statistically different. The examples of the tomato transplants are shown in Figure 1 and the stem diameters of tomato transplants are in Figure 2.

Table 1. The height, the number of leaves and the stem diameter of tomato transplants according to treatments: bokashi tea and control

Traits	Height of plants, cm		Number of leaves		Stem diameter, mm	
	bokashi tea	control	bokashi tea	control	bokashi tea	control
Average	31.667	26.667	8.667	7.667	9.667	8.333
Standard deviation	1.528	3.055	0.577	1.155	0.577	0.577
P-value	0.064		0.251		0.047	

Figure 1. The photo of tomato transplants according to treatments: bokashi tea (left) and control (right)

Figure 2. The photo of tomato transplants stems according to treatments: bokashi tea (left) and control (right)

Discussion

In present investigation was found that tomato transplants treated with bokashi tea tended to be higher than untreated control transplants. Earlier experiments (Olle, 2014, 2015; Olle, Williams, 2015), have been reported that tomato, cucumber and squash transplants contrary were shorter by using EM treatment. This is in agreement with Idris *et al.* (2008) results with tomato plants because they found that EM treatment increased plant height; however, they measured plant height at fruiting while in present research the height of transplants was measured.

One reason why the height of tomato transplants tended to be higher in bokashi tea treatment (bokashi tea includes also EM) is that this tea is a product of food waste fermented with bokashi containing EM. Food waste gives a lot of useful nutrients to bokashi tea, which can be the reason tomato transplants tended to be higher in bokashi tea treatment than in control.

The second reason could be that EM inoculation to both bokashi and chicken manure increased photosynthesis of tomato plants (Xu *et al.*, 2001), and increased photosynthesis gives better growth of plants.

Chantal *et al.* (2010) showed increased leaf areas in cabbages treated with EM. Although there was no significant difference in cabbage plant height, treatment with EM 'bokashi' plus an EM solution resulted in the highest diameter stems, followed by the chemical fertiliser (Nakano, 2007). The increase in stem diameter is following the results of the present investigation and results of other experiments (Olle, 2014; Olle, Williams, 2015). On other hand, Puranapong and Siphuang (2001) studied the use of a mixture of EM with chicken, quail, pig or cow manure on the growth of yard-long bean and snake eggplant, but showed no significant differences of plant growth parameters.

Bokashi tea improved the quality of tomato transplants because they tended to be higher with a greater stem diameter than untreated plants. The golden rule is that transplant with very good quality results in higher yields. Bokashi tea gives a good start to tomato transplants because EM solubilise minerals (Olle, Williams, 2013), including Ca, from the bokashi tea solution. Ca influences many processes beneficially: plants with a higher Ca content have less disease, are attacked by fewer insects, and have better transport and storage qualities (Olle, 2013). The plant protection effect is confirmed by the integrated results of Xu *et al.* (2012), who suggest that the advantage of nitrogen metabolism in EM bokashi-fertilized tomato plants accounted for the high phytophthora resistance.

Conclusion

Bokashi tea improves the growth of tomato transplants by increasing stem diameter and is allowing for plants to take up more nutrients.

Acknowledgements
NutriLoop Ltd. provided for my trials the bokashi tea.

Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Author contributions

MO contributed to the design and implementation of the research, to the analysis of the results and to the writing of the manuscript.

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REVIEW: **MANAGING WEED POPULATIONS THROUGH ALTERATION OF THE CROPPING PATTERN**

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Saabunud: Received: 17.01.2020
Aktsepteeritud: Accepted: 12.05.2020

Avaldatud veebis: Published online: 18.05.2020

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Keywords: weeds, cropping pattern, weed-crop competition.

DOI: 10.15159/jas.20.07

ABSTRACT. Alteration of the cropping pattern, such as manipulation of sowing date, increasing crop sowing rate, alteration in population density and row spacing, the use of cultivars that are more competitive and proper fertilization, particularly nitrogen application, have been the focus of many research studies. These studies aimed for the goal of boosting the crop's capacity to provide domination over weeds and surviving competitive stress. Modifications in sowing date might have tremendously influence on plants growth, but also have a prominent influence on weed infestation, crop development and yield. Changes in sowing dates are important to prevent the durations of considerable weed risks and consequently raise crop yield. High sowing rates increase the capacity of crops to overcome weeds and preserve yield loss under moderate weediness of the crop. Further, increased crop density, crop uniformity with alteration in row spacing had powerful and constant depressing outcomes on weed biomass and affirmative outcomes on biomass and yield of the crop. Competing varieties might be more efficient in the reduction of the capability of weeds throughout competitiveness for restricted sources. Finally, nutrient balance is frequently essential for crop-weed competition, and controlling the fertilizer applications in space and time might be a technique for useful weed suppression. Hence, the manipulation of certain agronomic integrated with competitive cultivar is a promising way to reduce weed interference in crops and to improve the sustainability of cropping systems through less reliance on herbicides.

Introduction

Weeds are the most severe obvious risk to sustain productive farming systems, responsible for imposing about 34% potential yield loss worldwide (Oerke, 2006). The use of herbicides is the most successful, profitable and useful system of weed control (Marwat *et al.*, 2006; Hussain *et al.*, 2008; Anwar *et al.*, 2012; Mehmeti *et al.*, 2018; Pacanoski, Mehmeti, 2018). Unfortunately, over-reliance on herbicides has led to the development of resistant weed biotypes (Moss *et al.*, 2011; Gage *et al.*, 2019; Heap, 2019), crop phytotoxicity (Begum *et al.*, 2008, El-Nahhal, Hamdona, 2017), environment pollution and public health hazard (Phuong *et al.*, 2005). The existing herbicide-founded weed control model is generally treated as unsustainable. Moreover, strict EU directives decrease the number of herbicide possibilities, and new mechanisms of action are seeming too ambitious and distant. Moreover, they increase the risk of the resistance evolvement to the remaining herbicides (Duke, 2012). Farmers are increasingly recognizing Integrated Weed Management (IWM) strategies to reinforce their weed control due to rising pressure on agriculture production from the herbicide resistance evolvement (Andrew, Storkey, 2017). Lindquist and Mortensen (1998) reported that managing weed populations throughout the modification of the cropping pattern is an important part of IWM. Several cultural practices have been investigated to increase the crop's capacity to provide an advantage concerning weeds and permanent competitive stress. This included the manipulation of sowing date (Duary, Yaduraju, 2006), increasing crop seeding rate (Chauhan, Johnson, 2011), alteration in population density (Nurse, Di Tommaso, 2005) and row spacing (Norsworthy, Oliveira, 2004), using of more competitive cultivars (Andrew, Storkey, 2017) and adequate fertilization which is particularly true for nitrogen (N) application (Blackshaw, Brandt, 2008).

Modifying sowing dates can adjust the growing season in sense of decreasing the weeds impact on crop growing, by altering the competitive superiority to the crops (Kwabiah, 2004). Berzsenyi (2000) stated that sowing date strongly relates with the preparation of the soil that has a significant effect on the weed seed dormancy and germination, whereas Williams (2006) noticed that sowing date influences crop yield losses caused by weeds. For example, delayed sowing has been reported to diminish yield losses caused by weeds in soybean (Buhler, Gunsolus, 1996) and dent maize (Gower et *al.*, 2002).

Higher sowing rate and row spacing is an important technique that facilitates crop competitive capacity about weeds (Lindquist, Mortensen, 1998; Gibson *et al.*, 2002; Chauhan, Johnson, 2011; Fahad *et al.*, 2015). Higher sowing rates promote brief canopy closure, which provides more efficiently weeds suppression. Significant decreases of relative weed density and weed biomass, as well as a significant increase of plant height, dry weight plant and seed yield of barley (O'Donovan *et al.*, 2001), wheat (Olsen *et al.*, 2005), and soybean (Place *et al.*, 2009), were recorded for the use of higher sowing rate.

For many crops, reducing row width has been found to increase the competitiveness of the crop because of an early canopy formation that results in improved yields and a reduction in the amount and frequency of herbicide use (Norsworthy, Oliveira, 2004). Murphy *et al.* (1996) observed increased corn yield and a light interception along with reduced weed biomass as row width was narrowed.

Further, diverse genotypes of the same crop acquire characteristics that may become a higher or lower competitive capacity with weeds. These characteristics are usually associated with earlier seed germination and crop plant emergence, prompt canopy development, and rapid growth in the young stages (Rasmussen, Rasmussen, 2000). Investigation of the crop capacity to suppress weeds by competition involves differences in competitive capability in cultivars and recognition of crop suppressive characteristics. This has been broadly recognized in many crops, such as wheat (Cosser *et al.*, 1997; Ogg, Seefeldt, 1999; Mason Spaner, 2006), barley (Dhima *et al.*, 2010), rice (De Vida *et al.*, 2006), and soybean (Vollmann *et al.*, 2010).

Finally, application timing and placement of N fertilizer can as well affect weed competition with crops. *Veronica hederifolia* competitive ability was greater when N was applied at the tillering than at the stem elongation stage of winter wheat (Angonin *et al.*, 1996).

Taking into account previously mentioned facts, the objective of this review is to recapitulate the existing material and to contribute for the successful weed-crop competitive interaction through modification of the cropping pattern.

Managing weeds through manipulation of sowing date

Modifications in sowing date might have tremendously influence on plants growth, but also have a prominent influence on weed infestation, crop development and yield (Hay, 1986). Changes in sowing dates are important to prevent the durations of considerable weed risks and consequently raise crop yield (Harper, 1999; Hussain *et al.*, 2017). Results of Bonis *et al.* (2010) reported that weed infestation was significantly affected by sowing date of wheat in Hungary. Spandl *et al.* (1998) detected that control of *Setaria viridis* in the spring-seeded wheat was more effective compared to fall-seeded wheat, due to the weed emergence in a single flush rather than many flushes. Delaying wheat drilling from September to the end of October decreased *A. myosuroides* populations by approximately 50% (Lutman *et al.*, 2013). As far as crop rotation is concerned, various rotations are more successful in suppressing weeds relative to simpler ones (Weisberger *et al.*, 2019). A six-year crop rotation containing lateness sowing in three years out of six caused an 87% reduction in *Avena fat* density, related to a 4% reduction in a wheat-fallow rotation only. Schoofs *et al.* (2005) found that *Avena fatua* infestations were decreased significantly by postponing sowing from early May to late May, without any crop yield consequences. Mulder and Doll (1994) reported that in row weed density decreased significantly in uncultivated treatments when corn planting was delayed from 25 April to 5 May. Delayed planting allows the corn to germinate after the peak emergence of many weed species (Regnier, Janke, 1990). Results of Rajablarijani *et al.* (2014) revealed that delayed sweet corn sowing (6 July) reduced weed dry weight by 46% (average for both years) compared with the 5 June sowing date without reducing crop yield. Similar, Williams and Lindquist (2007) reported an 80% lower weed biomass at harvest in late sown corn relative to early-sown corn. Rushing and Oliver (1998) reported a tendency for larger crop yield decrease from *Xanthium strumarium* competition in April-sowed soybean than in May or July sowings. Weed infestation is influenced by sowing time. In the study of Mubeen *et al.* (2014) higher weed infestation (51 to 59 plants m^{-2}) was noticed at late sowing compared to early sowing rice. For obtaining high yield and good kernels quality, rice sowing at the optimum time is crucial (Chauhan, Johnson, 2011). Bera *et al.* (2016) investigate four different dates of rice sowing, namely December 1st, December 15th, December 30th and January 14th. Rice sowing on December 15th showed lowest weed infestation and biomass at both of the estimations, and highest per cent of productive tillers in comparison with other sowing dates. The highest grain and straw yields (5.19 and 5.65 t ha^{-1}, respectively) was collected from December 1st sowing, it was narrowly succeeded by sowing at December 15th. Regardless of weed control techniques, the rising tendency of weed infestation and weed dry weight were recorded with delaying of sowing date.

Jadhav (2013) noticed stunted crop growth and higher weed density as a result of delaying in sowing.

Managing weeds through alteration in population density, higher seeding rate and narrow planting pattern

High sowing rates increase the capacity of crops outcompeting weeds and preserve yield loss under moderate weediness of the crop (Guillermo *et al.*, 2009). The use of higher sowing rates additionally might improve crop competition for light. The increasing sowing rate of wheat has a significant effect in decreasing the number of *Viola arvensis* and *Galium aparine* (Ona *et al.*, 2018). An increased wheat crop population had strong and persistent negative consequences on weed biomass and positive outcomes on crop biomass and yield. Kristensen *et al.* (2008) confirmed that in conditions of highest wheat plant density (721 seed m^{-2}), weed biomass was <50% than at the lowest wheat plant density (204 seed m^{-2}). It is reported that in maize through increased crops density, variety choice and sowing pattern all three factors had significant effects on both weed biomass and yield (Marin, Weiner, 2014). Also, increasing population density in sunflower crop showed practical management for weed control and higher yield (Dominschek *et al.*, 2019). Increased wheat crop density resulted in decreased weed biomass (59% and 58% for the 380 and 270 plant $m^{2\,-1}$ respectively) in comparison with crop densities of 125 plant $m^{2\,-1}$ (Korres, Froud-William, 2002). Weed population was significantly lower in wheat crop sown at higher seed rates of 150 kg ha^{-1} and 125 kg ha^{-1}as compared to the recommended seed rate of 100 kg ha^{-1} seed (Sharma, Singh, 2011). There are numerous examples where crop density manipulation has been shown to successfully reduce crop yield loss due to *A. fatua* interference (Kirkland, 1993; Wilson *et al.*, 1995). For example, Maxwell *et al.* (1994) reported that in competition with *A. fatua*, barley yield reductions were 54 and 23% at seeding rates of 67 and 134 kg ha^{-1}, respectively. Wilson *et al.* (1990) reported a lower detrimental effect from *A. fatua* on crop yield when seeding rate of both wheat and barley was increased from 135 to 337 and 134 to 443 plants m^{-2}, respectively. Evans *et al.* (1991) also reported that *A. fatua* reduced barley yield less at high than low crop densities. Furthermore, Barton *et al.* (1992), with *A. fatua* populations of 290 plants m^{-2}, observed that *A. fatua* biomass was reduced from 3,920 kg ha^{-1} to 2,460 kg $ha^{-1}$when barley seeding rate was increased from 180 to 355 seeds m^{-2}. Compared with the low seeding rate (175 plants m^{-2}) treatment, the high seeding rate (280 plants m^{-2}) reduce *A. fatua* interference and reduced percentage wheat yield loss from 26 to 32% (Stougaard, Xue, 2005). Also, O'Donovan *et al.* (2001) reported that *A. fatua* seed production was reduced when barley sowing rate was increased both with and without herbicide application. Similar, Yenish, Young (2004) noted that *Aegilops cylindrica* biomass decreased 27% per plant as sowing rate increased from 40 to 60 wheat seed m^{-2}. Tharp and Kells (2001) found that increasing corn population from 60,000 to 73,000 plants ha^{-1} reduced *Chenopodium album* L. biomass and fecundity and increased corn yield in the northern Corn Belt. In the same direction is an investigation of Nice *et al.* (2001) who found that increasing soybean populations from 245,000 plant ha^{-1} to 481,000 and 676,000 plants ha^{-1} coupled with reduced row spacing reduced *Senna obtusifolia* density and growth. The sowed single corn with higher plant population decreased weed occurrence and weeds has a low value of weed dry matter (Melo *et al.*, 2019). Increasing corn population from 33,000 to 133,000 plants ha^{-1} reduced *Cyperus esculentus* growth (Ghafar, Watson, 1983). Same, *Amaranthus retroflexus* vegetative biomass was reduced by increased corn population (McLachlan *et al.*, 1993). In aerobic rice systems sowing rates of 100–300 germinating seeds, m^{-2} increased rice yield significantly over weed biomass (Zhao *et al.*, 2007). According to Phuong *et al.* (2005), in lowland rice higher sowing rates advantaged rice towards weeds increasing yields under weedy conditions. When the rice sowing rate increased from 20 to 100 kg ha^{-1} weed biomass reduction ranged between 41 and 60%, and 54 and 56% at 35 days after sowing and at crop anthesis, respectively (Ahmed *et al.*, 2014).

Some researchers (Weiner *et al.*, 2001; Olsen, Weiner, 2005; Olsen *et al.*, 2012) noted that increased crop uniformity harmed weed biomass. Acciaresi and Zuluaga (2006) and Blackshaw *et al.* (1999) found that narrow row square planting pattern suppressed weed growth more effectively than wide-row planting pattern in beans. Moreover, Mashingaidze *et al.* (2009) reported that narrow rows in cornfields reduce biomass and seed production of weeds. Furthermore, weed biomass (Mickelson, Renner, 1997) and the total leaf area of *Amaranthus retroflexus* (Legere, Schreiber, 1989) were reduced by 20% when soybean was planted in a 19 cm compared to 76 cm row spacing. The increasing the soybean sowing rate in 76 cm rows, from 185,000 to 432,000 seeds ha^{-1} significantly reduced *Solanum ptycanthum* dry weight (Rich, Renner, 2007). Soil residual herbicides or sequential applications of glyphosate to control late-emerging weeds may not be necessary for narrow-row soybean because shade inhibits the growth of many, but not all weeds (Ritchie *et al.*, 1997; Ateh, Harvey 1999).

Managing weeds through crop genotype choice

One of the key elements of an IWM strategy is to promote crop cultivars with increased capacities either to compete with or tolerate weeds (Mohler, 1996). Competitive cultivars are a possibly interesting choice because they do not acquire any extra costs. These types of cultivars are more competent in reducing the capability of a weed species throughout the struggle for restricted resources (Christensen, 1995), may excrete allelochemicals that disturbed weed growth (Wu *et al.*, 1999; Olofsdotter, 2001; Pacanoski, Mehmeti, 2019) and lessen the economic stress of weeds by resisting crop loss (Vandeleur, Gill, 2004). Competitive cultivars can lessen the weed seed getting back into the soil and allow moderate to durable weed management programs, decreasing the pressure on chemical and mechanical weed control methods (Christensen *et al*., 1994; Blackshaw *et al.*, 2006) and promoting the sustainability of agro-ecosystems. For instance, in Greece, it has already been demonstrated that the use of competitive cultivars alone reduced recommended rates of herbicides in wheat by 50% (Travlos, 2012). The differences in competitive capacity among varieties of winter wheat and spring barley have been described contrary to volunteer oilseed rape (Christensen *et al*., 1994; Christensen, 1995). Similar results have been reported in wheat contrary *Aegilops cylindrica* (Ogg, Seefeldt, 1999), *Lolium rigidum* (Lemerle *et al*., 2001), *Galium aparine* (Mennan, Zandstra, 2005b) and weed mixtures (Cosser *et al*., 1997; Korres, Froud-William, 2002). Winter wheat varieties altered in their capacity for detrimental influence on the appearance and following growth of *Portulaca oleraceae*, *Amaranthus retroflexus*, *Eragrostis ciliogenesis*, and *Echinochloa crus*-*galli* (Wicks *et al*., 1986). In this research, reduction of weeds was between 59 and 96% compared to treatments where the winter wheat had been eliminated by cultivation before May. Choosing more competitive cultivars could decrease *A. myosuroides* heads $m^{2\ -1}$ by 22% (Lutman *et al.*, 2013). Furthermore, some wheat cultivars could provide enhanced *A. myosuroides* suppression (Andrew, Storkey, 2017). Further, high wheat tillering capability provided suppression of dry matter production in mixed weed flora population (Korres, Froud-William, 2002). In that context, Challaiah *et al.* (1986) approved the negative correlation between several wheat tillers and *B. tectorum* seed production. Similar, in Australia higher wheat tillering capacity also reduced *L. rigidum* seed production (Lemerle *et al*., 1996). Tastan (1988) concluded that wheat cultivars 'Haymana 79' and 'Kunduru 79' can suppress *Bifora radians* more effectively than other wheat cultivars in the Central Anatolia region of Turkey. *Bifora radians* biomass and seed numbers were reduced not only by an increase in the wheat seeding rate but also by cultivars. *Bifora radians* seed production in Bezostaja, Kate A-1, Momtchill, and Panda were diminished 60, 53, 54, and 46%, respectively, at the seeding rate of 250 kg ha^{-1} compared with *Bifora radians* alone at a density of 350 plants m^{-2} (Mennan, Zandstra, 2005a).

Wicks *et al.* (1986), Lemerle *et al.* (1996) and Grundy *et al.* (1997) agreed that height is a major characteristic contributing to cultivar competitiveness. This aspect is associated with light penetration within the crop canopy and shading ability (Blackshaw, 1994; Seavers, Wright, 1995). Although in weed-free fields their yield is usually lower, taller varieties commonly tolerate higher weed pressure and, in the same time, enhance reduction of weed growth (Ogg, Seefeldt, 1999; Vandeleur, Gill, 2004). The benefit of height, in terms of shading weeds, has been reported in *Bromus tectorum*-infested wheat (Challaiah *et al*., 1986), in winter wheat in competition with *A. cylindrica* (Ogg, Seefeldt, 1999), spring barley against *B. napus* (Christensen, 1995) as well as oats, barley and wheat in relation with *G. aparine* (Brain *et al*., 1999).The tall wheat 130 cm reduced mature *A. cylindrica* biomass 46 and 16% compared with short 100 cm wheat in years 1 and 2 of the experiment, respectively (Yenish, Young, 2004).

Managing weeds through adequate fertilization

Nutrient balance is frequently essential for crop–weed competition (Lintell-Smith *et al.*, 1992), and controlling the fertilizer applications in space and time might be a technique for useful weed-suppressing (Angonin *et al.*, 1996; Liebman, Mohler, 2001). Crop fertilization management is a favourable cultural practice to decrease weed infestation in crops (Di Tomaso, 1995; Evans *et al.*, 2003; Jiang *et al.*, 2018). Application of fertilizers influences on competitive interactions crop–weed of interest in the oat crop (Blackshaw, Brandt, 2008) and emphasizes oats as a usually competitive and resourceful crop. Nitrogen (N) is the major nutrient added to increase crop yield (Raun, Johnson, 1999; Wang *et al.*, 2016). Pre-seeding N application might enhance competing crop capacity compared to weeds in high growth rate crops at early stages, but this outcome depends on the dominant weeds in the crop. For example, Paolini *et al.* (1998) noticed that pre-planting N fertilization in sunflower improved the suppression of summer-emerging weeds such as *Solanum nigrum*, *Xanthium strumarium*, and *Chenopodium album*, in comparison with the split application (50% pre-planting and 50% top-dressing). Also, early or delay top-dressing with N fertilizer improved sugar beet competitive capacity against of early- or late-emerging weeds, respectively (Paolini *et al.*, 1999). Study of Evans *et al.* (2003) showed that weeds have a lower consequence on crop yield when N is applied in early growth stages whiles at amounts lower than recommended for optimum yield. N use in early growth stages also led to a reduction of weed biomass than N applications occurring in advanced growing stages (Hoeft *et al.*, 2000; Sweeney *et al.*, 2008). *Avena fatua*, *Sinapis arvensis*, *Chenopodium album*, and *Setaria viridis* density and biomass in wheat crop were at times reducing with spring than with autumn-applied N (Blackshaw *et al.*, 2004). According to the same authors, the technique of N application usually had bigger and more permanent outcomes than the timing of application on weed biomass and wheat yield. With subsurface banded or point-injected N, shoot N concentration and weed biomass were often reduce than with surface broadcast N, and concomitant growth in yield of spring wheat generally followed with these N placement applications. As a conclusion of the 4-year research project, without taking into account the weed population, the reduction of weed seed bank was between 25% and 63% with point-injected compare to broadcast N fertilization. Nitrogen fertilizer placed as narrow in soil bands, rather than surface broadcast, has been documented to reduce the competitive ability of several grass weed species (Blackshaw *et al.*, 2000; Mesbah, Miller 1999; Rasmussen 1995). Hodge *et al.* (1999) suggested that there may be competitive advantages to nutrient placement through a localized increase in root-length density of the competing species. Uptake of N by *Setaria viridis* in competition with wheat was greater when N was surface broadcast compared with surface pooling or point injection of ammonium nitrate solution (Blackshaw *et al.*, 2002). Nitrogen formulation also influences the outcome of the weed–crop competition (Blackshaw *et al.*, 2002; Di Tomaso, 1995; Kirkland, Beckie, 1998). For example, differences in the growth of corn and *Amaranthus retroflexus* were greater when N was applied as nitrate, $Ca(NO_3)_2$, than as ammonium, $(NH_4)_2SO_4$ (Teyker *et al.*, 1991). Ammonium exhibited some detrimental effects on *Amaranthus retroflexus* such as leaf chlorosis and crinkling, reduced shoot dry weight, and reduced total N accumulation.

Conclusion

The highest diversification of the cropping system (*i.e.* growing more competitive cultivars integrated with a range of other cultural control strategies) designed on agro-ecological fundamentals is crucial for successful weed management in any circumstances. In this relation, a strategy based on the manipulation of sowing date, increasing crop sowing rate, alteration in population density and row spacing, using of more competitive cultivars and adequate fertilization can improve the sustainability of cropping systems through less reliance on herbicides. This approach also provides an environmentally friendly substitute for mechanical weed control, decreasing soil erosion, nutrient loss, labour, traffic on the field, fuel consumption, and CO_2 emissions. This indicates that education of growers is obliged to gain a higher rank of proficiency and technical competence. Unilaterally decisions, like mechanical weed control and over-reliance on herbicides as the simply direct weed-control techniques may be effective in the short term but are never productive in the long term. Nowadays, many different models are used to search cropping system scenarios and to predict their effects on weed populations. Applying these measures to control weeds will reduce the use of herbicides, and this will have a greater impact on the protection of the environment which is in line with EU directives. Also, by reducing the use of herbicides and applying the measures included in the IWM, the biotypes of resistant weeds can be avoided. Therefore, alteration of the cropping pattern is very important in the development of sustainable and environmentally safe strategies for weed control.

Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Author contributions

ZP and AM – contributed equally to the preparation, creation and/or presentation of the manuscript.

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Agraarteadus
1 ● XXXI ● 2020 84–95

Journal of Agricultural Science
1 ● XXXI ● 2020 84–95

SISEÕHU KVALITEET PÕHU- JA PILLIROOPAKKIDEST SEINTEGA ELUMAJADES

INDOOR AIR QUALITY IN RESIDENTIAL BUILDINGS WITH STRAW- AND REED-BALE WALLS

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Saabunud: Received: 11.02.2020
Aktsepteeritud: Accepted: 08.05.2020
Avaldatud veebis: Published online: 12.05.2020

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Keywords: mould, indoor air, straw-bale walls, reed-bale walls, propagules.

DOI: 10.15159/jas.20.05

ABSTRACT. Straw and reed are natural local insulation- and construction materials, which properties allow them to replace energy intensive building materials. In general, straw and reed as building materials are considered harmless to the environment and human health. Unfortunately, the use of these materials may bring about mould growth in buildings which may result in different diseases (for example irritation of eyes, nose and throat, allergic rhinitis, conjunctivitis, and asthma) in people with weaker immune systems. No research has been carried out on the topic of microbiological community in straw and reed houses in climatic conditions similar to Estonia, although buildings made of natural materials are becoming more and more popular. The aims of the study were to investigate the indoor climate of buildings with straw and reed-bale walls and to determine the factors influencing indoor air quality. In order to fulfil the set aim: (1) air quality was tested in the bedrooms of the studied houses, and the microbial species in air and walls were determined; (2) the indoor air quality parameters (CO_2, RH%, and temperature) in air and at two different heights in the walls were measured. The results enable to conclude that the walls of straw or reed-bale house are suitable in Estonian climatic conditions, which as a result of professional design, usage of materials suitable for building, and high-quality craftsmanship provides a healthy and environmentally friendly housing.

Sissejuhatus

Inimesed veedavad erinevatele uuringutele tuginedes 80–90% oma ajast siseruumides (Horr jt, 2016; Katsoyiannis, Cincinelli, 2019) ning umbes kolmandik inimese eluajast veedetakse magades (Strøm-Tejsen jt, 2015). Viimastel aastatel on publitseeritud hulgaliselt siseõhu kvaliteeti käsitlevaid uuringuid, kuid magamistoad, kus inimesed veedavad 7–8 järjestikust tundi oma päevast, leiavad sellistes uuringutes väga vähe käsitlemist (Strøm-Tejsen jt, 2015, Canha jt, 2019).

Pilliroog ja teraviljapõhk on materjalid, millest ehitamine on viimasel kümnendil järjest enam populaarsust kogunud. Sellistest materjalidest ehitamine on säästlik nii keskkonnale kui võimaldab kokku hoida ka energiat, mida on vaja hoonete kütteks ja jahutamiseks (Milutiené jt, 2012). Olgugi, et põhk ja pilliroog on lihtsasti hangitavad ja naturaalsel kujul ka odavad materjalid, on tegemist materjalidega, mis võivad olla potentsiaalseteks ohuallikateks inimese tervisele. Koosnedes tselluloosist, hemitselluloosist ja ligniinist, on looduslikud materjalid heaks elupaigaks mikroorganismidele. Pidev eksponeeritus hallitusseentele võib põhjustada probleeme nõrgenenud immuunsüsteemiga inimestele, kroonilistele haigetele, lastele ja vanuritele (Portnoy jt, 2005, Hernberg jt, 2014).

Looduslike materjalide kasutamine ehituses kogub üha enam populaarsust. Uuringud näitavad, et võrreldes roopakist elamutega nõuab kivihoonete kütmine ja jahutamine rohkem energiat (Barreca jt, 2019). Pilliroo lisamine betoonisegule vähendab oluliselt materjali soojusjuhtivust (Shon jt, 2019). Rooehitised olid tuntud juba Sumeri kultuuris 5000 aastat tagasi ja Iraagi aladel on nad laialdaselt kasutusel ka tänasel päeval (Al-Jumeily jt, 2018). Need paistavad silma tervisliku sisekliima poolest ja roo kõrge ränisisaldus muudab selle materjali ebaatraktiivseks putukatele ning teistele loomadele (Al-Jumeily jt, 2018). Puudustena tuleb aga välja tuua tuletundlikkust ja madalat survetugevust, mistõttu saab ehitada kandvate seintega ainult ühekordseid hooneid (Al-Jumeily jt, 2018). Kui roog on lõigatud valel aastaajal, siis võib see kaasa tuua materjali lagunemise (Al-Jumeily jt, 2018). Seentel on oluline roll orgaaniliste ehitusmaterjalide lagundamisel (Raamets jt, 2017). 20–40% Euroopa ja Põhja-Ameerika hoonete sisekliima on mõjutatud hallitusest, millega kaasnevad erinevad terviseprobleemid (Laborel-Préneron jt, 2018). On leitud, et roog on tundlik mädaniku suhtes, kuid lagunemisprotsessi on võimalik olulisel määral alla suruda termilise töötlemise abil (Brischke, Hanske, 2016).

Mitmed autorid on oma uurimustes näidanud, et hallitusseened põhul võib jagada vee vajaduse järgi kolme rühma. Primaarsed koloniseerijad kuuluvad perekondadesse *Wallemia*, *Penicillium*, *Aspergillus* ja *Eurotium*, sekundaarsed koloniseerijad perekondadesse *Cladosporium*, *Ulocladium ja Alternaria* ning tertsiaarsed koloniseerijad perekondadest *Stachybotrys, Chaetomium, Trichoderma* ja *Auraeobasidium* (Grant jt, 1989; Gravesen jt, 1994, Nielsen jt, 2004). Eesti päritolu teravilja tüüpilised hallitusseened kuuluvad perekondadesse *Cladosporium, Alternaria, Aspergillus, Fusarium, Penicillium, Helminthosporium, Mucor ja Rhizopus* (Lõiveke jt, 2008). Perekonda *Aspergillus* kuuluvate liikide esinemine on iseloomulikum just Lõuna-Eestile (Lõiveke, 2008). Ka siseõhus on seeneperekonnad *Alternaria, Aspergillus, Cladosporium* ja *Penicillium* levinuimad (Zorman, Jeršek, 2008, Bernasconi jt, 2010).

Esimesed teadaolevad põhupallidest hooned püstitati 19. sajandi lõpul Nebraskas, põhjuseks eelkõige elanike vaesus (Henderson, 2007). Üks vanemaid sealseid põhupallidest hooneid, pärineb aastast 1903 (King, 2006). Sellist pikaealisust põhjendatakse kuiva kohaliku kliimaga (Henderson, 2007). Tänapäeval leidub põhupallidest tehtud maju Ameerika Ühendriikides, Euroopas, Kanadas, Austraalias ja Aasias (Holzhueter, Itonaga, 2010). Holzhueter ja Itonaga väidavad, et hallituse tekkimise oht on põhuelamute korral ülepaisutatud. Hallituse tekke vältimisel annavad eriliselt positiivset efekti vihmatõkked (Holzhueter, Itonaga, 2017). Siiani ei ole meie kliimavöötmes tehtud arvestatavaid uuringuid selle kohta, millised mikroobid põhul ja pillirool kui ehitusmaterjalil elutsevad, milline on siin ehitatud põhu- ja roopakkidest seintega elamute sisekliima ning käesoleva töö eesmärgiks uurida kompleksselt Eesti roo- ja põhuelamute sisekliimat ning seda mõjutavaid tegureid.

Materjal ja metoodika

Püstitatud eesmärgi saavutamiseks:

- Võeti õhuproovid uuritavate elamute magamistubadest ning välisõhust ja materjaliproove välispiiretest. Määrati nii sise- kui ka välisõhus ning piiretes leiduvad seened perekonna tasemeni;
- Määrati sisekliima näitajad (RH% ja temperatuur) elamute siseõhust (määrati lisaks ka CO_2) kui ka kahelt erinevalt kõrguselt (0,2 ja 1,2 m) välisseintes;
- Hinnati välisseinte niiskuskoormust ja hallituse ohtu.

Ülevaade uuritud objektidest

Uuringu käigus võeti proove ja koguti andur-andmesalvestitega andmeid neljast põhu- ja neljast roopakkidest ehitatud seintega elamust. Osa elamutest (kaks põhu- ja üks roopakkidest seintega) oli ehitatud Nebraska stiilis, osa karkassiga (üks põhu- ja kolm roopakkidest seintega), ühe põhupakkidest seintega elumaja puhul on ehitusel kasutatud tehases valmistatud mooduleid. Kõik uuritud elamud on projekteeritud ja ehitatud vastava kogemusega projekteerijate ja ehitusettevõtete poolt. Visuaalsel vaatlusel niiskuskahjustusi ja hallituse kasvu ei tuvastatud. Uuritud elamute vanus jäi 2–7 aasta vahele.

Elamute keskmine välisseina paksus oli 50 ± 5 cm, erandiks oli elumaja, mille seina paksus oli 100 cm. Kõik seinad olid krohvitud nii seest kui ka väljast. Krohvikihi paksus oli enamasti nii sees kui ka väljas 5 cm, erandiks olid kaks elamut. Ühe elamu seinte krohvikihi paksus oli nii seest kui ka väljast 7 cm (lubikrohv), teisel elamul oli välisseina sisepinnal 10 cm krohvi, välisseinas 12 cm krohvi. Krohvimiseks oli kasutatud enamasti savikrohvi, kahe elamu puhul oli kasutusel nii sise- kui ka välisviimistlusel lubikrohv. Kõigil uuritud elamutel oli küllaltki kõrge sokkel, lai räästas (joonis 1), mis on oluline abinõu vähendamaks seinte niiskuskoormust.

Vundamendina kasutati nii madalvundamenti (viis elamut) kui ka postvundamenti (3). Kõikide põrandate konstruktsioon oli puidust. Katusekattematerjaliks on kolme elamu puhul laast, kolme elamu puhul rullmaterjal/PVC, ühel elamul kivi ja ühel elamul on rohekatus.

Kasutatud metoodika

Töös peeti oluliseks uurida elamuid kompleksselt, katsed viidi läbi perioodil oktoober 2014 – oktoober 2016, kogudes paralleelselt sisekliima parameetrite (temperatuur, RH, CO_2) ning mikrobioloogia andmeid (pesa moodustavate ühikute arv ja taksonoomiline koosseis) nii õhust kui ka välispiirde (seinte) materjalist.

Elanikel paluti kuus tundi enne proovide võtmist magamistube mitte tuulutada. Söötmed (linnasesööde (MEA) ja dikloraan 18% sööde (DG18)) valmistati ja proovivõtuprotseduur viidi läbi ISO standardist 16000-18 juhindudes (ISO 16000-18:2011). Söötmekomponendid kaaluti analüütilise kaaluga (ABJ 120-4M, Kern & Sohn, Balingen, Saksamaa). Söötmed autoklaaviti, kasutades HMT 260 MB autoklaavi (HMC Europe, Tüssling, Saksamaa). Proovid koguti õhuanalüsaatoritega Mirobio MB2 (Cantum Scientific, Dartford, Ühendkuningriik) 9 cm Petri tassidele neli korda aastas (kevadel, suvel, sügisel ja talvel) magamistubadest ühe meetri kõrguselt põrandapinnast. Proovivõtu aeg oli üks minut ja õhu kogus 100 liitrit proovi kohta. Igalt alalt koguti kokku neli paralleelproovi mõlema söötmega. Referentsina koguti õhuproovid nelja paralleelina ka välisõhust 1,5 m kõrguselt maapinnast. Kogutud proove töödeldi, lähtudes EVS-ISO standardist 16000-17 (EVS-ISO 16000-17:2012.). Proove inkubeeriti 25 ºC juures seitse päeva, peale mida loeti pesa moodustavad ühikud (PMÜ). Puhaskultuuride saamiseks teostati edasised külvid. Seened määrati morfoloogiliste tunnuste alusel mikroskoobi abil (SP100, Brunnel Microscopes LTD, Chippenham, Ühendkuningriik). Värvimiseks kasutati laktofenool-puuvillasinist. Väljakülvid identifitseeriti perekondadeni, kasutades selleks erinevaid määrajaid (Domsch jt, 1980; Kilch, 1988; Samson jt, 1996; Bergey jt, 2000; Larone, 2002; Winn, Koneman, 2006; Watanabe, 2010).

Joonis 1. Näited uuritud elamute soklist (vasakpoolne pilt) ja räästast (parempoolne pilt)
Figure 1. *Examples of plinths (left image) and eaves (right image) of the studied buildings*

Välispiiretest (seinast) võeti ka põhu- ja roomaterjali uurimiseks proove, kasutades selleks varem välja töötatud metoodikat (Raamets jt, 2016). 10-grammise mahuga proovid plaaditi otse linnaseagarile (MEA), kuhu oli lisatud klooramfenikooli. Proove inkubeeriti 32 °C juures 72 tundi ning seejärel loendati kokku pesa moodustavad ühikud (PMÜ).

Lisaks koguti taustandmeid ühe andur-andmesalvestiga süsihappegaasi sisalduse, temperatuuri ja õhuniiskuse kohta uuritavate elamute magamistubadest (andur paiknes 1,2 m kõrgusel põrandapinnast, salvestades 30-minutilise intervalliga). Andmeid koguti ka temperatuuri ja õhuniiskuse kohta piiretes 20 cm sügavusel sisepinnast. Selleks puuriti piiretes kahele kõrgusele (0,2 ja 1,2 m) 7 mm läbimõõduga augud. Aukudesse asetati 20 cm sügavusele andur-andmesalvestitega mõõtepead ning automaatmõõtmisi teostati 10-minutilise intervalliga. Aukude sulgemiseks kasutati krohvi ja mingil määral vajus kinni ka kõrreline materjal ise.

Väliskliima andmetena kasutati Riigi Ilmateenistuse poolt mõõdetud andmeid uuritud elamutele lähimast automaatjaamast (Tallinna, Lääne-Nigula, Türi, Väike-Maarja). 2014. aasta november oli tavaliselt soojem (2,4 °C (norm 1,2 °C)). Nii 2014–2015 kui ka 2015–2016 aasta talv oli normist soojemad. 2015. aasta oli viimase poole sajandi kõige soojem aasta (keskmine õhutemperatuur 7,6 °C (norm 6,0 °C)) (Riigi Ilmateenistus, 2020).

Piirete niiskuskoormuse hindamiseks kasutati valemit 1, mis pärineb standardist EVS-EN ISO 13788 (EVS-EN ISO 13788:2012). Niiskuslisa Δv (g $m^{3\,-1}$) arvutati valemist:

$$\Delta v \; (g\; m^{-3}) = v_i - v_e \tag{1}$$

kus:

v_i – siseõhu veeaurusisaldus / *water vapour content (indoor air)*, g $m^{3\,-1}$;
v_e – välisõhu veeaurusisaldus / *water vapour content (outdoor air)*, g $m^{3\,-1}$.

Hallituseohu hindamiseks kasutati Hukka ja Viitaneni (1999) poolt avaldatud matemaatilist mudelit, mis kasutab nii suhtelise niiskuse kui ka temperatuuriandmeid hallitusindeksi arvutamiseks.

Kemikaalid ja töövahendid

Kõik tööks vajalikud kemikaalid ja reagendid osteti ettevõttest HNK Analüüsitehnika OÜ (Tallinn, Eesti). Soja baasil toodetud peptoon (≥99%, Fluka), kaaliumdivesinikfosfaat (KH_2PO_4) (puhtusaste ≥99%, Sigma Aldrich), magneesiumsulfaat heptahüdraat ($MgSO_4$ $7H_2O$) (puhtusaste ≥99,5%, Sigma Aldrich), D-(+)-glükoos (≥99,5%, Sigma Aldrich), dikloraan (2,6-dikloro-4-nitroaniliin) (puhtusaste ≥96%, Sigma Aldrich), klooramfenikool (puhtusaste ≥98%, Sigma Aldrich), glütserool (puhtusaste ≥99,96%, Sigma Aldrich), vesi (deioniseeritud, Sigma Aldrich). Agar (Sigma Aldrich), linnaseekstrakt (Sigma Aldrich), laktofenool-puuvillasinise (hallitusseente värvimiseks, Sigma Aldrich) vastasid standardis (ISO, 2011). Mikrobioloogilisteks külvideks vajalikud vahendid (Petri tassid (9 cm), inokulatsiooninõelad, alus- ja katteklaasid) osteti KRK OÜ (Tartu, Eesti).

Söötmekomponendid kaaluti analüütilise kaaluga ABJ 120-4M (mõõtetäpsus ±0,2 mg, tootja: Kern & Sohn, Balingen, Saksamaa). Söötmed autoklaaviti, kasutades HMT 260 MB autoklaavi (HMC Europe, Tüssling, Saksamaa). Söötmeplaadid valati tõmbekapi all (vastab ISO 13150 standardile, Retent AS, Nõo, Eesti). Proovid koguti õhuanalüsaatoritega Mirobio MB2 (Cantum Scientific, Dartford, Ühendkuningriik). Laboris valmistati destilleeritud vett seadmega RO01033 (ROWA, Heimsheim, Saksamaa).

Andmeid koguti igas magamistoas ka süsihappegaasi (CO_2) sisalduse, õhutemperatuuri ja niiskusnäitajate kohta andur-andmesalvestitega Green-Eye mudel 7798 (mõõtetäpsus süsinikdioksiidi mõõtmisel ±50 ppm, temperatuuri mõõtmisel ±0,6 °C, õhuniiskuse mõõtmisel ±3% (10–90%), tootja: TechGrow, Haag, Holland). Piiretest temperatuuri ja niiskusandmete kogumiseks kasutati Hobo UX100-023 andur-andmesalvesteid (mõõtevahemik –20°C kuni +70 °C, 5 kuni 95% RH, täpsus vastavalt ±0,35 °C ja ±2,5% RH, tootja Onset Computer Corporation, Bourne, Ameerika Ühendriigid).

Tulemused

Hallitusseente arvukus ja dünaamika sise- ja välisõhus aastaaegade lõikes ning hallitusseente koosseis perekondade lõikes

Sesoonne pesa moodustavate ühikute dünaamika on nii põhust kui ka roopakist ehitatud elamute magamistubade puhul sarnane (tabelid 1 ja 2). Erinevused esinevad moodustavate ühikute arvus. Kõige arvukam oli siseõhu mikroobikooslus põhupakkidest seintega elamutes suvel (tabel 1) (juuni–august), mil siseõhust kultiveeritavaid kolooniaid linnaseagarilt (MEA) oli keskmiselt 537 ± 102 PMÜ m^{3-1}. Sama seos esines ka roopakkidest seintega elamute puhul, mil suvel siseõhust kultiveeritavaid kolooniaid linnaseagarilt oli keskmiselt 858 ± 106 PMÜ m^{3-1}. Välisõhus (tabel 2) registreeriti samal ajal põhupakkidest seintega elamutel linnaseagarilt 289 ± 32 PMÜ m^{3-1} ja roopakkidest seintega elamutel 353 ± 41 PMÜ m^{3-1}. Kevadel ja sügisel jäid nii sise- kui ka välisõhust linnaseagarile võetud proovide puhul tulemused võrreldavale tasemele. Diglütserool 18% söötmele (DG18) võetud proovid olid samuti kõrgemad nii sise- kui ka välisõhus just suveperioodil ning madalaimad talvel.

Uuringu käigus identifitseeriti siseõhu hallitusseeni perekonna tasemeni (tabel 3). Talveperioodil kuulus kõige enam identifitseeritud seentest põhupakkidest seintega elamutes perekonda *Penicillum* (74%), järgnesid perekondadesse *Aspergillus* (17%), *Alternaria* (1%) ja *Cladosporium* (1%) kuuluvad hallitusseened, 7% hallitusseentest ei kuulunud eelnevalt mainitud perekondadesse. Roopakkidest seintega elamute puhul oli järgnevus perekondade lõikes sama ning erinevused esinesid osakaaludes *Penicillum* – 70%, *Aspergillus* – 19%, *Cladosporium* – 6%, *Alternaria* – 1%; 4% leitud hallitusseentest ei kuulunud eelnimetatud perekondadesse.

Tabel 1. Sesoonsed muutused pesa moodustavate ühikute (PMÜ) arvukuses siseõhus näidatuna aastaaja keskmisena elamute lõikes koos keskmise veaga (±SE) proovide lõikes m^{3-1} õhu kohta

Table 1. *Seasonal variation in culturable airborne fungi indoors shown as mean with standard error (±SE), range of CFU m^{-3} air*

Proovivõtu koht *Sampling site*	Talv *Winter*	Kevad *Spring*	Suvi *Summer*	Sügis *Autumn*
Põhk (MEA) *Straw (MEA)*	149 ± 29	298 ± 100	537 ± 102	307 ± 99
Roopakk (MEA) *Reed (MEA)*	380 ± 136	518 ± 145	858 ± 106	548 ± 155
Põhk (DG18) *Straw (DG18)*	14 ± 8	29 ± 9	46 ± 12	20 ± 11
Roopakk (DG18) *Reed (DG18)*	22 ± 13	23 ± 9	36 ± 11	22 ± 10

MEA – linnaseagari sööde / *Malt Extract Agar media;* DG18 – diglütserool 18% sööde / *18% Dichloran glycerol agar (DG18) media*

Tabel 2. Sessoonsed muutused pesa moodustavate ühikute (PMÜ) arvukuses välisõhus näidatuna aastaaja keskmisena elamute lõikes koos keskmise veaga (±SE) proovide lõikes m^{3-1} õhu kohta

Table 2. *Seasonal variation in culturable airborne fungi outdoors shown as mean with standard error (±SE), range of CFU m^{-3} air*

Proovivõtu koht *Sampling site*	Talv *Winter*	Kevad *Spring*	Suvi *Summer*	Sügis *Autumn*
Põhk (MEA) *Straw (MEA)*	94 ± 19	197 ± 43	289 ± 32	168 ± 34
Roopakk (MEA) *Reed (MEA)*	118 ± 15	198 ± 48	353 ± 41	212 ± 34
Põhk (DG18) *Straw (DG18)*	18 ± 7	30 ± 9	50 ± 11	22 ± 10
Roopakk (DG18) *Reed (DG18)*	24 ± 9	27 ± 11	45 ± 12	23 ± 9

MEA – linnaseagari sööde / *Malt Extract Agar media;* DG18 – diglütserool 18% sööde / *18% Dichloran glycerol agar (DG18) media*

Kevadel kuulus põhupakkidest seintega elamutes kõige enam identifitseeritud hallitusseeni perekonda *Cladosporium* (79%). Järgnesid perekonnad *Penicillum* (8%), *Aspergillus* (8%) ja *Alternaria* (3%). 2% hallitusseentest ei kuulunud eelnevalt mainitud perekondadesse. Roopakkidest seintega elamutes oli perekondade järjestus kevadel sama mis põhuelamutes: erinevused esinesid vaid esinemisprotsentide lõikes – *Cladosporium* (81%), *Penicillium* (7%), *Aspergillus* (7%) ja *Alternaria* (3%). 2% leitud seentest ei kuulunud eelnevatesse perekondadesse.

Tabel 3. Perekonna tasemeni identifitseeritud hallitusseente jaotumine perekondadesse aastaaegade ja ehitusmaterjali lõikes. Esimene näitaja tähistab pesa moodustavate ühikute (PMÜ) arvu ja teine protsenti koguhulgast

Table 3. *Distribution of molds identified by genus, by season and building material. The first figure represents the number of colony forming units (CFU) and the second percentage of the seasonal total*

Hallitusseened *Molds*	Talv / *Winter*		Kevad / *Spring*		Suvi / *Summer*		Sügis / *Autumn*	
	põhk / *straw*	roopakk / *reed*	põhk / *straw*	roopakk / *reed*	põhk / *straw*	roopakk / *reed*	põhk / *straw*	roopakk / *reed*
Alternaria	1 (1)	4 (1)	9 (3)	16 (3)	32 (6)	43 (5)	25 (8)	49 (9)
Aspergillus	25 (17)	72 (19)	24 (8)	36 (7)	11 (2)	9 (1)	71 (23)	110 (20)
Cladosporium	1 (1)	23 (6)	235 (79)	420 (81)	451 (84)	738 (86)	92 (30)	142 (26)
Penicillum	110 (74)	266 (70)	24 (8)	36 (7)	38 (7)	51 (6)	95 (31)	203 (37)
Teised / *Others*	10 (7)	15 (4)	6 (2)	12 (2)	5 (1)	15 (2)	25 (8)	44 (8)

Suvel kuulus kõige enam identifitseeritud seentest põhupakkidest seintega elamutes siseõhus perekonda *Cladosporium* (84%), järgnesid *Penicillium* (7%), *Alternaria* (6%), *Aspergillus* (2%); 1% leitud hallitusseentest ei kuulunud eelnevalt mainitud perekondadesse. Roopakkidest seintega elamute siseõhu puhul oli järgnevus sama: kõige enam leiti perekonda *Cladosporium* (86%) kuuluvaid hallitusseeni, järgnesid perekonnad *Penicillum* (6%), *Alternaria* (5%) ja *Aspergillus* (1%). 2% leitud hallitusseentest ei kuulunud eelnevalt mainitud perekondadesse.

Sügisel kuulus kõige enam põhuelamute siseõhus identifitseeritud hallitusseentest perekonda *Penicillum* (31%), järgnesid perekonnad *Cladosporium* (30%), *Aspergillus* (23%) ja *Alternaria* (8%). 8% põhuelamutest leitud seentest ei kuulunud eelnevalt mainitud perekondadesse. Roopakist elamute siseõhu puhul kuulus kõige enam hallitusseeni sügisel perekonda *Penicillium* (37%), järgnesid perekondadesse *Cladosporium* (26%), *Aspergillus* (20%) ja *Alternaria* (9%) kuuluvad hallitusseened. 4% hallitusseentest ei kuulunud ühegi eelnevalt mainitud perekonna hulka. Välisõhust võetud proovidest identifitseeritud hallitusseente perekondade jaotus oli vastavuses elamute siseõhust võetud proovidega.

Materjaliproovid seintest ning identifitseeritud hallitusseened perekondade lõikes

Uuringu käigus koguti materjaliproove välispiiretest (seinast) sügisel. Kogutud proovidest kasvatati välja vaid üksikuid kolooniaid (min 6 PMÜ, max 14 PMÜ). Kolooniate perekondadesse jaotumine oli sarnane siseõhust kultiveeritud proovide perekondadesse jaotumisega sügisesel perioodil. 36% identifitseeritud hallitusseentest kuulus perekonda *Cladosporium*, 32% perekonda *Penicillium*, 25% perekonda *Aspergillus*, 2% perekonda *Alternaria*. 3% hallitusseentest ei kuulunud eelpoolmainitud perekondadesse.

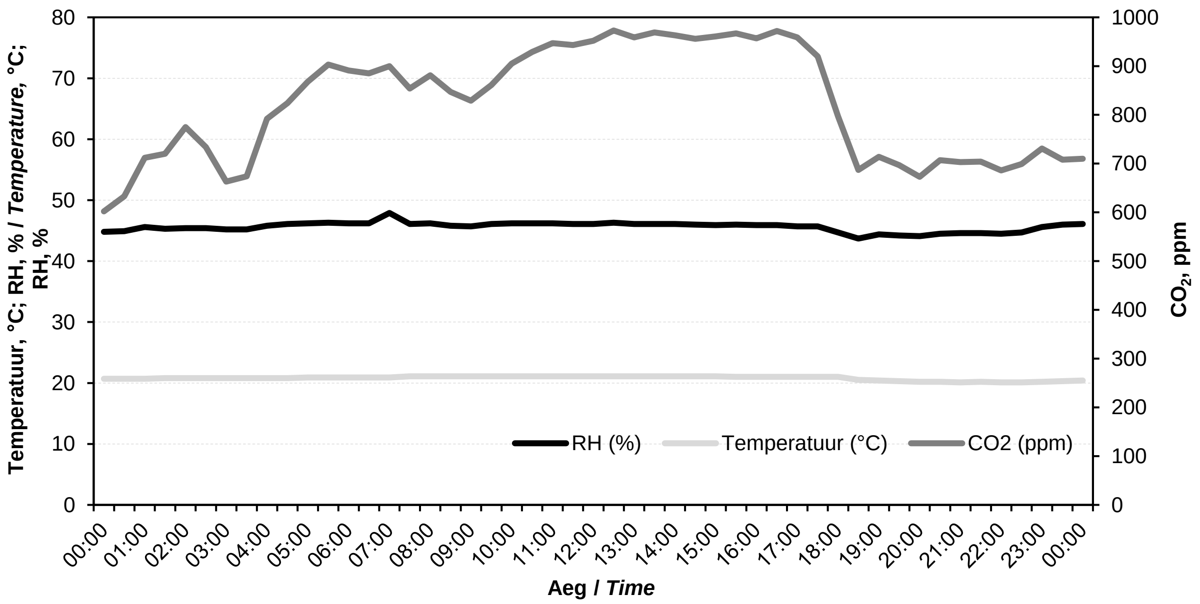
Sisekliima näitajad (CO_2, RH% ja temperatuur) elamute siseõhus ja kahel erineval kõrgusel piiretes

Kogu uuritud perioodi jooksul oli nii põhu- kui ka roopakkidest seintega elamute süsihappegaasi keskmine tase (tabel 4) madalaimal tasemel suveperioodil (põhupakkidest seintega elamutes 607 ± 26 ppm, roopakkidest seintega elamutes 568 ± 48 ppm). Kõige kõrgem oli süsihappegaasi keskmine tase põhupakkidest seintega elamutes kevadel (636 ± 26 ppm) ja roopakkidest seintega elamutes sügisel (626 ± 65 ppm).

Ühte juhuslikult valitud päeva roopakkidest seintega elamus kirjeldab joonis 2. Joonisel toodud päeva keskmine süsihappegaasi tase oli 822 ± 17 ppm. Vastavad väärtused olid madalamad öösel, maksimumväärtus (973 ppm) registreeriti päeval. Antud tuba oli kasutusel nii magamistoana kui ka laste mängutoana.

Tabel 4. Sisekliima keskmised näitajad näitajad (CO_2, RH% ja temperatuur) põhu- ja roopakist seintega elamut magamistubades esitatuna koos standardveaga (±SE)
Table 4. *Average parameters describing indoor climate (CO_2, relative humidity to temperature) in the bedrooms of buildings with straw-bale and reed-bale walls shown as a mean with standard error (±SE)*

Näitajad / *Parameters*	Talv / *Winter*		Kevad / *Spring*		Suvi / *Summer*		Sügis / *Autumn*	
	põhk *straw*	roopakk *reed*	põhk *straw*	roopakk *reed*	põhk *straw*	roopakk *reed*	põhk *straw*	roopakk *reed*
Süsihappegaas (CO_2), ppm *Carbon dioxide (CO_2), ppm*	618 ± 28	574 ± 46	636 ± 26	573 ± 55	607 ± 26	568 ± 48	616 ± 27	626 ± 65
Temperatuur, °C / *Temperature, °C*	19,0 ± 0,5	19,0 ± 0,5	19,0 ± 0,4	19,3 ± 0,9	19,0 ± 1,3	20,6 ± 1,8	20,4 ± 0,6	20,7 ± 0,9
RH, %	36 ± 2	41 ± 2	36 ± 2	42 ± 2	36 ± 2	43 ± 2	39 ± 2	44 ± 3



Joonis 2. Süsihappegaasi taseme, temperatuuri ja õhuniiskuse (RH) dünaamika 24 tunni jooksul roopakkidest seintega elumajas
Figure 2. *Dynamics of carbon dioxide, temperature and humidity (RH) over a 24-hour period in a reed-bale wall building*

Keskmine õhutemperatuur (tabel 4) jäi uuritud elamute magamistubades 19–21 °C vahele. Vastavad näitajad olid ühtlased, olles talvel ja kevadel mõlema elamutüübi korral keskmiselt 19,0–19,3 °C. Suvel oli roopakist elamute siseõhutemperatuur keskmiselt 1,6 °C võrra kõrgem kui põhust seintega elamutes. Keskmine õhutemperatuur oli kõige kõrgem nii põhupakkidest seintega elamutes (20,4 ± 0,6 °C) kui ka roopakkidest seintega elamutes (20,7 ± 0,9 °C) sügisel.

Uuritud magamistubades (tabel 4) jäi keskmine õhuniiskus 36–44% vahele, olles madalam põhupakkidest seintega elamute (36–39%) ja kõrgem roopakkidest seintega elamute magamistubades (41–44%) Roopakkidest seintega elamute puhul oli niiskusnäitaja kevadel 41 ± 2%, nii suvel kui ka sügisel oli see protsendi võrra eelnenud aastaaja väärtusest kõrgem (vastavalt 42 ± 2% ja 43 ± 2%).

Keskmine temperatuur piiretes 1,2 meetri kõrgusel (tabel 5) oli põhupakkidest seintega elamutes madalaim talvel (17,5 ± 1,3 °C), roopakist seintega elamutes aga kevadel (15,6 ± 1,5 °C). Kõrgeimad olid keskmised temperatuurinäitajad 1,2 meetri kõrgusel välispiirdes nii põhust (20,6 ± 0,8 °C) kui ka roopakist seintega elamutes suvel (19,3 ± 1,1 °C). Põhupakkidest seintega elamute puhul oli 1,2 m kõrgusel temperatuur välispiirdes (17,3–20,6 °C) kõrgem kui roopakkidest seintega elamutes (15,6–19,3 °C). Erinevus oli palju suurem 0,2 m kõrgusel, kus põhupakkidest seintega elamute keskmine õhutemperatuur varieerus vastvavalt 14,4–19,2 °C ja roopakkidest seintega elamute temperatuur vastavalt 7,3–16,3 °C. 0,2 meetri kõrgusel välispiirdes oli keskmine temperatuur madalaim nii põhu- kui ka roopakkidest seintega elamutes talvel (vastavalt 14,4 ± 2,4 °C ja 7,3 ± 2,5 °C). Kõrgeim oli keskmine temperatuur suveperioodil – põhupakkidest seintega elamutes 19,2 ± 1,0 °C ja roopakkidest seintega elamutes 16,3 ± 1,6 °C.

RH% keskmised näitajad olid 1,2 meetri kõrgusel piiretes nii põhu – kui ka roopakkidest seintega elamutes madalaimad talvel (vastavalt 33 ± 12% ja 33 ± 14%), kõrgeimad aga suveperioodil (põhupakkidest seintega elamutes 53 ± 7%, roopakkidest seintega elamutes 57 ± 1%). Üldiselt on suhtelise õhuniiskuse väärtused sarnased – vastavalt 33–53% ja 33–57%.

Keskmine RH% oli 0,2 m kõrgusel piiretes madalaim talvel (vastavalt 38 ± 4% põhupakkidest seintega elamutes ja 45 ± 6% roopakkidest seintega elamutes), kõrgeimad olid keskmised näitajad suveperioodil (põhupakkidest seintega elamutes 54 ± 2%, roopakkidest seintega elamutes 58 ± 1%). Roopakkidest seintega elamutes on tendets, et suhteline õhuniiskus on 0,2 m kõrgusel kõrgem (42–58%), kui põhupakkidest seintega elamutes (38–54%).

Välispiirde niiskuskoormus ja hallituse ohu hindamine

Temperatuuri ja niiskusenäitajaid piiretes iseloomustab joonis 3. Piirdes registreeriti ka kõrgemaid õhuniiskuse ja temperatuuri väärtusi kui siseõhus, kuid tõenäosus, et tingimused on hallitusseente kasvuks piirdes sobilikud, on väga madal.

Siseõhu niiskuslisa hinnati nii talve- kui ka suveperioodil ühe konkreetse päeva põhjal. Roopakkidest seintega elamute niiskuslisa varieerus suvel 0,46 g m^{3-1} kuni 3,42 g m^{3-1} ja talvel 0,62 g m^{3-1} kuni 2,73 g m^{3-1}. Põhupakkidest seintega elamute niiskuslisa varieerus suvel 2,1 g m^{3-1} kuni 1,99 g m^{3-1}, talvel – 0,06 g m^{3-1} kuni 1,43 g m^{3-1}. Negatiivne oli niiskuslisa päevasel ajal, mil elanikud ruumides ei viibinud. Tulenevalt Hukka ja Viitaneni (1999) poolt loodud mudeliga võrdlemisest, oli hallituse oht kõikides uuritud elamutes madal.

Hoonete kompleksne hindamine

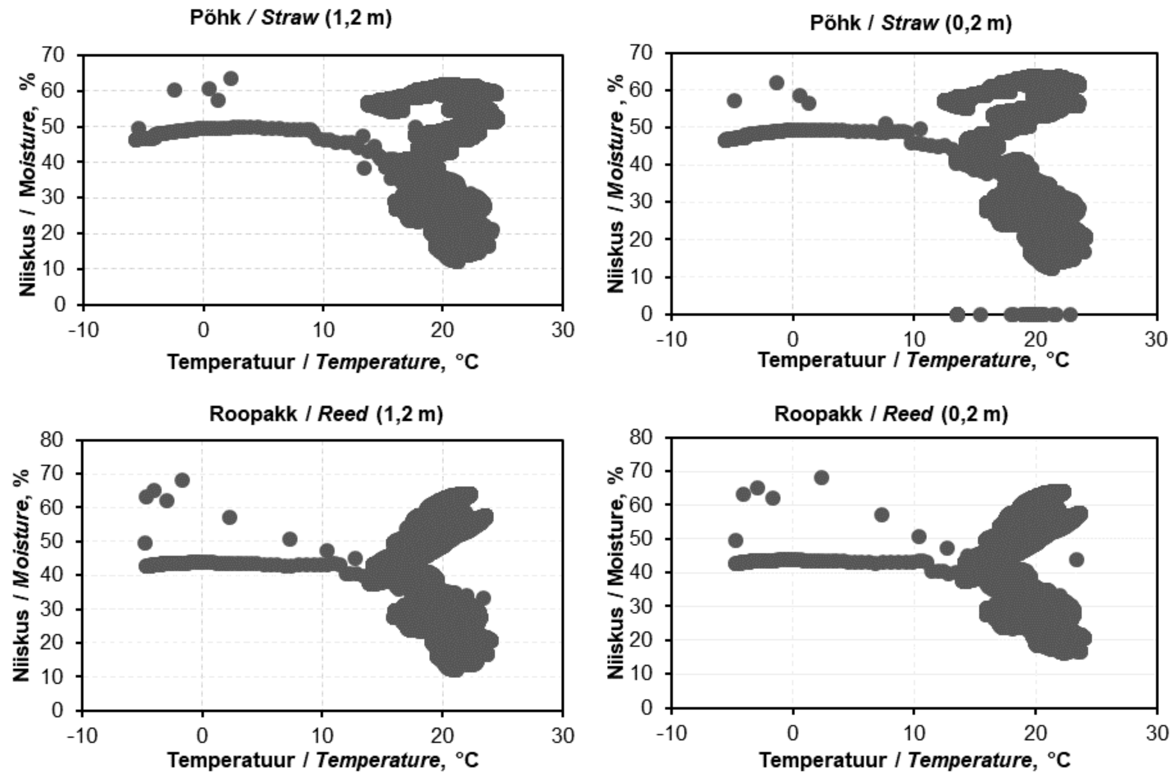
Töös uuriti elamute siseõhu kvaliteeti kompleksselt, kogudes paralleelselt sisekliima parameetrite (õhutemperatuur, RH, CO_2) ning mikrobioloogia andmeid (pesa moodustavate ühikute arv ja taksonoomiline koosseis) nii õhust kui ka välispiirde (seinte) materjalist. Interdistsiplinaarses uuringus vaadati kompleksselt põhu- ja roopakkidest seintega elamute sisekliimat, kasutades selleks andur-andmesalvesteid, õhu- ja materjaliproove. Kaks andur-andmesalvestit paiknesid piirdes ligikaudu 20 cm sügavusel – üks 0,2 m kõrgusel põrandast, et tuvastada võimalikke probleemkohti sõlme lähedal (kapillaartõus, vundamendi ehitusvead, võimalikud külmasillad) ja teine 1,2 m kõrgusel põrandast stabiilses seinaosas.

Tuginedes andur-andmesalvestitega kogutud teabele ning õhu- ja materjaliproovide tulemustele leiti, et nii põhust kui ka pilliroost elamute seintes on hallituseoht väike. Roopakkidest seintega elamute puhul väärib märkimist erakordselt madal temperatuur (7,3 ± 2,5 °C) piirdes 0,2 m kõrgusel põrandast talvisel perioodil, mis viitab roopakkide madalale tihedusele. Korstnaefekti tõttu on alumises sõlmes sissetõmme ning niiskustase ei ole kõrge.

Tabel 5. Keskmine õhutemperatuur ja õhuniiskuse (RH) piiretes 1,2 ja 0,2 m kõrgusel põhu – ja roopakist elumajade magamistubades esitatuna koos standardveaga (±SE)

Table 5. *Average air temperature and humidity (RH) within the ranges of 1.2 and 0.2 m for straw bale and reed buildings, shown with standard error (±SE)*

Näitajad / *Parameters*	Talv / *Winter*		Kevad / *Spring*		Suvi / *Summer*		Sügis / *Autumn*	
	põhk *straw*	roopakk *reed*	põhk *straw*	roopakk *reed*	põhk *straw*	roopakk *reed*	põhk *straw*	roopakk *reed*
Temperatuur (°C) 1,2 m kõrgusel *Temperature (°C) at 1.2 m*	17,3 ± 2,2	16,3 ± 4,6	17,5 ± 1,3	15,6 ± 1,5	20,6 ± 0,8	19,3 ± 1,1	18,2 ± 1,2	17,0 ± 1,8
Temperatuur (°C) 0,2 m kõrgusel *Temperature (°C) at 0.2 m*	14,4 ± 2,4	7,3 ± 2,5	15,7 ± 1,0	11,3 ± 3,7	19,2 ± 1,0	16,3 ± 1,6	16,7 ± 1,5	13,9 ± 2,6
RH (%) 1,2 m kõrgusel *RH (%) at 1.2 m*	33 ± 12	33 ± 14	41 ± 7	47 ± 2	53 ± 7	57 ± 1	41 ± 4	45 ± 4
RH (%) 0,2 m kõrgusel *RH (%) at 0.2 m*	38 ± 4	45 ± 6	42 ± 3	47 ± 1	54 ± 2	58 ± 1	42 ± 2	51 ± 2



Joonis 3. Temperatuur (°C) ja niiskusnäitaja (%) piiretes 1,2 ja 0,2 meetri kõrgusel nii põhu- ja roopakkidest elamute välisseintes
Figure 3. *Temperature (°C) and humidity (%) in outer boarders at 1.2 and 0.2 meters in buildings with straw- and reed-bale walls*

Arutelu

Ehitussektor on suurim ressursside tarbija kogu maailmas, mis aitab olulisel määral kaasa kliimamuutusele (Dutil jt, 2011; Iacovidou, Purnell, 2016). Kasvav nõudlus ehitiste ja infrastruktuuri järele suurendab nii materjalide kaevandamist kui ka emissioone (Krausmann jt, 2017). Süsiniku emisoonide vähendamiseks kogu olelustsükli jooksul on võimalik kasutada leevendusmeetmeid nii projekteerimisel kui ka ehitamisel (Pomponi, Moncaster, 2016), kasutada saab aga ka süsinikneutraalseid materjale (Chel, Kaushik, 2018). Looduslikel materjalidel on keskkonnale väike mõju, samuti pakuvad sellised materjalid elanikele/kasutajatele tervislikku elukeskkonda (Brojan jt, 2013).

Põhk ja pilliroog on materjalid, mis kasvamise käigus kasutavad fotosünteesiprotsessis süsihappegaasi ning nende kasutamine ehituses on kasvutrendis. Kuna tegemist on biolagunevate materjalidega, on oluline olla informeeritud selliste materjalide ehitamisel kasutamisega kaasas käivast mikroobipopulatsioonist ja selle võimalikust ohtlikkusest nii siseõhule kui ka piirdetarinditele.

Mikroorganismid, kes elavad suure niiskustasemega keskkonnas, vajavad oma elutegevuseks sobivat temperatuuri. Lawrence jt (2009) toovad välja, et sobiv temperatuurivahemik on 20–70 °C, madalam kui 10 °C temperatuur aga pärsib mikroorganismide elutegevust. Köetavates ruumides peab inimese pikemaajalisel ruumis viibimisel temperatuur olema vähemalt 18 °C, optimaalne, luues inimesele soojatunde ning aidates kaasa tervisliku ja nõuetele vastava sisekliima tekkimisele ja püsimisele (Kalamees jt, 2011). Keskmine siseõhu temperatuur jäi mõõteperioodil 19–21 °C vahele vastates standardi EVS-EN 16798-1:2019 (EVS-EN 16798-1:2019) alusel sisekliimaklassile III. Suveperioodil, mil temperatuurid ja niiskustase on hoonetes kõrgem, on ebasoodsate olude kokkulangemisel (kõrge temperatuur, piisav suhteline niiskus (üle 75%)) võimalik mikroobne kasv (Hukka, Viitanen, 1999; Johansson jt, 2012). Otseselt materjali hallitus ei kahjusta, kuid see viitab liiga kõrgele niiskustasemele konstruktsioonis ning võimalikele sellest põhjustatud riskidele (kõdunemine) (Lelumees, 2016).

Lisaks sobivatele temperatuuridele on mikroorganismide kasvu seisukohalt oluline roll ka ruumi õhuniiskusel ning toitainetel (Rajasekar, Balasubramanian, 2011). Eluruumide kohta kehtiva määruse kohaselt võiks optimaalne niiskus olla 40–60% (Arundel jt, 1986). Kriitiline õhuniiskuse tase mikrobioloogilise kasvu seisukohalt on 75–95%, sõltudes nii temperatuurist kui ka ehitusmaterjalist (Johansson jt, 2012). Hukka ja Viitanen (1999) toovad oma hallituse kasvu iseloomustavas mudelis välja keskkonnatingimuste ajalise kestuse, mis on vajalik mikrobioloogilise kasvu alguseks. Uuritud elamutes jäi õhuniiskus 36–44% piiridesse ja temperatuur 19–21 °C vahele. Süsihappegaasi taseme näitajad jäid soovitatud piiridesse (ühes liitris ruumiõhus on lubatud CO_2 kontsentratsioon kuni 1000 ppm (RT I, 2011)) kuuludes kõikide uuritud magamistubade puhul ISO standardi EVS-EN 16798-1:2019 (EVS-EN 16798-1:2019) alusel sisekliima klassi II (≤800ppm). Käesoleva töö raames uuritud elumajade magamistubade puhul on õhu niiskuse ja temperatuurinäitajad liiga madalad, et eeldada hallitusseente kasvu.

Roopakkidest seintega elamutes olid pesa moodustavate ühikute (PMÜ) väärtused kõrgemad kui põhupakkidest seintega elamutes ning see võib viidata võimalikule mikrobioloogilisele kasvule ülemise sõlme läheduses.

Õhu suhteline niiskus mõjutab nii hoonepiirete niiskusrežiimi kui ka hoone sisekliimat (Kalamees jt, 2011). Kui niiskuskoormus on suur, võib see halvendada nii sisekliimat kui ka põhjustada niiskusprobleeme piirdetarinditele (Kalamees jt, 2010). Siseõhu niiskuslisa oli üsna madal, olles kõrgem roopakkidest seintega elamute puhul (0,46 g m^{3-1} kuni 3,42 g m^{3-1} suvel ja talvel 0,62 g m^{3-1} kuni 2,73 g m^{3-1}) ning kuuludes standardi EVS-EN ISO 13788 alusel II klassi (EVS-EN ISO 13788:2012). Põhupakkidest seintega elamud kuulusid oma niiskuslisa poolest standardi EVS-EN ISO 13788 alusel I klassi (EVS-EN ISO 13788:2012). Põhupakkidest seintega elamute puhul oli niiskuslisa negatiivne talveperioodil tööpäevadel päevasel ajal, mil elanikud kodus ei viibinud.

Talveperioodil oli roopakkidest seintega elamute puhul keskmine temperatuur 0,2 meetri kõrgusel vaid 7,3 ± 2,5 °C. Sellises olukorras eeldame, et suhteline õhuniiskus on kõrge, kuid antud olukorras oli see keskmiselt 41 ± 2%. See viitab võimalikule hõredusele ehitussõlmede puhul, ning tänu korstnaefektile toimub selles piirkonnas külma õhu sissevool. Kuna piirdes teostati mõõtmisi ainult kahel kõrgusel (0,2 ja 1,2 m), siis korstnaefekti tõttu on oht, et piirde ülemises servas on tõenäoline ülerõhu tõttu (sooja niiske) õhu väljavool, mis on otsene oht hallituse tekkeks. Antud leid on murettekitav, sest piirdetarind on ohustatud niiskumisest ja roopakk sobivate tingimuste korral ka mikrobioloogilisest kasvust. Linnaseagarile (MEA) siseõhust võetud proovid näitavad kõrgemaid väärtusi kõikide aastaaegade lõikes, võrreldes välisõhust võetud proovidega.

Erinevatel riikidel on kasutusel erinevad standardid pesa moodustavate ühikute lubatud tasemete suhtes, kuid ühtne rahvusvaheline standard puudub (Jyotshna, Helmut, 2011). WHO ekspertrühma uurimuses leiti, et pesa moodustavate ühikute kogus sisetingimustes ei tohiks ületada 1000 PMÜ m^{3-1} (Nevalainen, Morawaska, 2009). Eestis puuduvad hallitusseentele sisekeskkonnas piirnormid. Soovituslikud piirnormid on kehtestatud Soomes ning seal tuuakse välja, et talveperioodil on soovituslik kuni 500 PMÜ m^{3-1}, suveperioodil kuni 2500 PMÜ m^{3-1} (Kosteusvauriot työpaikoilla, 2009). Antud uuringu puhul jäid siseõhus pesa moodustavate ühikute kogu uuringuperioodi hõlmavad keskmistatud kontsentratsioonid põhust seintega elamute puhul tasemele 323 ± 80 PMÜ m^{3-1} ning roopakkidest seintega elamute puhul tasemele 576 ± 94 PMÜ m^{3-1}. Ühest roopakkidest seintega elamust 2015. aasta suvel võetud proovid (1060 ± 8 PMÜ m^{3-1}) ületasid sisetingimustesse sobivaid WHO ekspertrühma poolt toodud soovituslikku kontsentratsiooni (1000 PMÜ m^{3-1}), kuid jäid alla Soome soovituslike piirnormide (kuni 2500 PMÜ m^{3-1}).

Hallitusseente kontsentratsioonid olid kõikidel aastaaegadel siseõhus kõrgemad kui välisõhus. Elamute siseõhust võetud proovidelt identifitseeritud hallitusseente perekonnad ei erinenud välisõhust võetud proovidelt identifitseeritud seeneperekondadest. Varasemad uuringud on näidanud, et välisõhust kultiveeritavad seeneliigid on kultiveeritavad ka siseõhust (Hoseini jt, 2012; Kalawasinska jt, 2012; Raamets jt, 2019). Piiretes olid kontsentratsioonid mõõdetud piirkondades väga madalad ning hallitusseente perekondlik jaotus oli sarnane sise- ja välisõhust identifitseeritud perekondadega. Olulisi erinevusi hallitusseente perekondlikus ja protsentuaalses jaotuses ei leitud, sügisesed konsentratsioonid olid kõrgemad kui talvised kontsentratsioonid (Hameed jt, 2012). Põhjuseks on hallitusseente kasvuks ja arenguks sobiv temperatuuri ja õhuniiskuse tase, samuti hulgaliselt taimset materjali, mis on substraadiks (Awad jt, 2018). Sarnast dünaamikat siseõhuproovide puhul aastaaegade lõikes, nagu leiti selle uuringu tulemusena, on leitud ka varasemates hoone sisekliimat puuduta¬vates uuringutes (Medrela-Kuder, 2003; Haas jt, 2007; Frankel jt, 2012).

Kompleksne lähenemine põhu- ja roopakkidest seintega elamute sisekliima uurimisele aitas tuvastada probleemse koha roopakkidest seina konstruktsioonis, mis on ilmselt tingitud ebapiisavast roopakkide tihedusest. Kahtluse kontrollimiseks on vajalik teostada edasised uuringud ning andur-andmesalvesti tuleks paigaldada ka piirdesse lae (ülemise sõlme) lähedale.

Järeldused

Töös uuriti ja mõõtmised viidi läbi põhu- ja roopakkidest elumajades, mis olid vastava eriala spetsialistide poolt projekteeritud ja ehitatud. Lahendusi töös lähemalt ei analüüsitud, kuid näiteks võib tuua nii laiad räästad, mis kaitsevad seinu vihma eest, kui ka hästi isoleeritud ja üsna kõrge sokliosa. Üheski hoones ei tuvastatud niiskuskahjustusi ega nähtavat hallituse kasvu. Kõiki elamuid uuriti kompleksselt. Sisekliima andmetest nähtub, et õhutemperatuur oli küll pigem mõnevõrra madalam, kui eluruumides tavaliselt (21 °C). Suhteline õhuniiskus oli optimaalses vahemikus ning silma ei registreeritud ka väga madalaid temperatuuriväärtusi, mis on talvisel ajal tavaline probleem keskküttega ja hästiventileeritud hoonetes. CO_2 kontsentratsioon ei ületanud soovituslikku piirväärtust.

Siseõhu niiskuslisa oli väike, siseõhust ega piiretest ei leitud hallituse arenguks sobivaid tingimusi vastavalt hallitusindeksile.

Kõrgemad pesa moodustavate ühikute (PMÜ) väärtused registreeriti mõõtmisperioodi jooksul roopakkidest seintega elamutes. Põhupakkidest seintega elamutes olid vastavad väärtused madalamad. Sesoonsed muutused esinesid mõlemal juhul. Läbiviidud uuringute põhjal võib öelda, et põhu- ja roopakkidest seintega elamute siseõhus esineb rohkem kolooniaid võrreldes välisõhuga. Uuringu käigus ei tuvastatud visuaalsel vaatlusel hallituse koldeid.

Töö käigus määrati nelja perekonda kuuluvaid hallitusseeni (*Alternaria, Aspergillus, Penicillium* ja *Cladosporium*), mis on leivnuimad teraviljal leiduvad hallitusseente perekonnad. Eelmainitud perekondadesse kuuluvad hallitusseened võivad kujutada endast riski inimestele (allergia, krooniline nohu, köha, hingamisteede haigused).

Kompleksne lähenemine võimaldas tuvastada ühe probleemse koha roopakkidest hoonete puhul. Nendes hoonetes oli ka hallitusseente hulk mõnevaõrra suurem. Vastavat lähenemist võib soovitada ka teiste analoogsete uuringu puhul, mis võiks anda aluse selle meetodiks arendamisele.

Uuritavate elamute sisekliima hindamisel saadud tulemused lubavad järeldada, et roo- või põhupakkides seintega ehitatud elamu on Eesti klimaatilistesse tingimustesse sobiv ehitis, mis asjatundliku planeerimise, ehituseks sobiva materjali kasutamise ja kvaliteetse ehitustegevuse tulemusena on tervislik ja keskkonnasõbralik eluase. Kindlasti tuleks läbi viia vastavad uuringud hoonetes, kus on mingil põhjusel niiskuskahjustused tekkinud. Kuivõrd niiskuskahjustusi hoonetes ikka esineb kasvõi veeavariide tõttu, siis on tarvis välja selgitada, milline on olukord ja töötada välja taastamiseks vajalikud meetmed.

Tänuavaldused
Autorid tänavad põhu- ja roopakist seintega elamute omanikke, kes lubasid oma eluruumides vajalikke mõõtmisi teostada.

Huvide konflikt / *Conflict of interest*

Autorid kinnitavad artikliga seotud huvide konflikti puudumist.
The authors declare that there is no conflict of interest regarding the publication of this paper.

Autorite panus / *Author contributions*

JR, AR – uuringu kava ja planeerimine / *study conception and design;*
JR – Proovide kogumine ja analüüs / *acquisition of data*;
JR, AR, MI, LN, KM – andmete analüüs ja interpretatsioon / *analysis and interpretation of data;*
JR, AR, MI, LN, KM – käsikirja koostamine / *drafting of manuscript;*
AR, MI, LN – käsikirja ülevaatamine ja lõplik heaks kiitmine / *critical revision and approve the final manuscript*.

Indoor air quality in straw bale and reed buildings

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Summary

Straw and reed buildings are item or synonyms for "ecological building" from healthy, reusable and renewable materials and energy efficient buildings. On the ohter hand there are legends about mould and asthma problems as common problem in straw and reed buildings.

To describe the indoor environment and building boarders (wall) long term studies (over 2 years) were carried out in the bedrooms of eight buildings (4 straw bale and 4 reed houses). This interdisciplinary study focuses to building as whole system. Air temperature, relative humidity (RH) and CO_2 concentration, temperature and RH inside the boarders (walls) at two heights (0.2 and 1.2 m) from floor level were measured. Holes were closed with plaster. To describe the microbiology in buildings and find out microbiological problems two kinds of tests were performed. Microbiological samples from indoor air and outdoor air (reference value) were collected in every season with air samplers. Residents were asked not to ventilate the houses at least 6h prior to measurements. Sampling media and procedure was designed according to ISO standard 16000-18: Detection and enumeration of moulds – Sampling by impaction. Malt Extract Agar (MEA) and 18% Dichloran glycerol agar (DG18) media were used. The sample plates were incubated at 25 °C for seven days, colony forming units (CFU) were counted and fungi were determined morphologically and microscopically following staining with lactophenol blue. For the identification to the genus level standardized identification keys were used.

Microbiological samples from building materials mounted in boarders (walls) were collected at two heights (0.2 and 1.2 m) by hand at the same points, where the holes for the temperature and RH loggers were made. Malt Extract Agar (MEA) and 18% Dichloran glycerol agar (DG18) media were used for direct plating. The sample plates were incubated at 32 °C for 72 hours, colony forming units (CFU) were counted and fungi were determined morphologically and microscopically following staining with lactophenol blue. For the identification to the genus level standardized identification keys were used.

Higher values of Colony Forming Units (CFU) were recorded during the measurement period in reed houses. The values were lower in straw houses. Seasonal changes occurred in both cases. Studies have shown that there are more colonies in the indoor air of straw and reed buildings compared to outdoor air. No mold growth was identified during this study. A complex approach to indoor climate of straw and reed habitats helped to identify a problematic site in reed buildings,

probably due to inadequate density of reed bales. Further investigations are needed to verify the suspicion and the data recorder should also be installed in the enclosure near the ceiling.

In the course of the work, four families of molds (*Alternaria*, *Aspergillus*, *Penicillium* and *Cladosporium*) were identified that may pose a risk to human health (allergy, chronic rhinitis, cough, respiratory disease). The results of the indoor climate assessment of the buildings under investigation allow us to conclude that a house made of reed or straw is a building suitable for Estonian climatic conditions, which, as a result of expert planning, use of building materials and quality construction, is a healthy and environmentally friendly housing solution.

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AKADEEMILISE PÕLLUMAJANDUSE SELTSI 2019. AASTA TEGEVUSARUANNE

Mittetulundusühingu Akadeemiline Põllumajanduse Selts tegevuse eesmärk on kaasa aidata Eesti maaelu, põllumajanduse ning põllumajandus- ja keskkonnateaduste arengule. Seltsi liikmeteks on isikud, kes on tasunud sisseastumismaksu ning täidavad seltsi põhikirjast tulenevaid kohustusi. Seltsi asukohaks on Tartu linn. Selts on 1920. aastal Tartu Ülikooli juures asutatud Akadeemilise Põllumajandusliku Seltsi poolt algatatud tegevuse jätkaja.

Akadeemilise Põllumajanduse Seltsi tööd korraldab eestseisus (juhatus), kuhu kuulub kuni 13 liiget. Eestseisusesse kuulusid kuni 2019. aastakoosolekuni tehnika-dr Arvo Leola, pm-knd Peep Piirsalu, pm-dr Maarika Alaru, pm-dr Ants Bender, pm-dr Merike Henno, pm-dr Toivo Univer, PhD Evelin Loit, pm-dr Enn Lauringson, pm-dr Alo Tänavots (Agraarteaduse peatoimetaja), PhD Matti Piirsalu ja PhD Marko Kass. Alates 6. mail toimunud üldkoosolekust kuuluvad eestseisusesse PhD Marko Kass (president), PhD Evelin Loit (asepresident), pm-mag Ingrid Bender, pm-dr Jaan Kuht, MSc Katrin Laikoja, pm-dr Peep Piirsalu, PhD Matti Piirsalu, pm-dr Ülle Tamm, pm-mag Avo Toomsoo, PhD Marina Aunapuu. Seltsi eestseisusesse kuulub ametist tulenevalt ka Agraarteaduse peatoimetaja pm-dr Alo Tänavots ning seltsi sekretäri ametis jätkab pm-dr Heli Kiiman.

Seltsi ridades oli aruandeperioodi lõpul 219 liiget, kellest koosolekutel ja sündmustel osaleb aktiivselt ligikaudu paarkümmend liiget. 2019. aastal täienes selts kahe liikme võrra (Andre Veskioja, Priit Pechter). Seltsi liikmeskonnast arvati välja üks liige isikliku sooviavalduse alusel (Kadri Rand). Seltsil on 31 auliiget, sh kolm aupresidenti. Viimati valiti seltsi auliikmeks tehnikateadlane ja õppejõud pm-dr Arvo Leola, keda tunnustati aupresidendi tiitliga.

Traditsiooni kohaselt annab president aasta lõpus üle Presidendi Rändkarika tiitliga Aasta Tegija, mille 2019. aastal pälvis olulise panuse eest seltsi ettevõtmistesse pm-mag Sirje Tamm.

2019. aastal toimus kuus eestseisuse koosolekut (30.01., 10.04., e-koosolek 17.04., 25.09., 23.10., 27.11) ning neli ettekandekoosolekut (kaheksa ettekannet). Eestseisuse koosolekutel on olnud peamisteks aruteluteemadeks ürituste korraldamine, seltsi ajakirja väljaandmine, ruumiküsimus (seltsi raamatukogu endiselt Kr 56 ruumides kastides), liikmete tunnustamine ja tegevuskava juubeliaastaks. 25. septembri eestseisuse otsusega luuakse seltsi juurde ajalootoimkond. Mitmel korral on eestseisuse päevakorraväliste teemade hulgas olnud põllumajandusteaduste rahastamine. Ühtlasi oli päevakorras emakeelse põllumajandusalase kõrghariduse 100. aastapäeva tähistamine, mida vedas Eesti Maaülikool. Kavas olid visioonikonverents, näitus, muud kohtumised. Seltsi president tegi korraldajatele ettepaneku (1.02.2019) anda juubeli puhul välja Agraarteaduse erinumber.

Seltsi eestseisuse juures tegutses seltsi 100. juubeli tähistamiseks kaks töörühma, millest esimese ülesandeks on visioonikonverentsi korraldamine ning teine koostas näituse ja juubeliraamatu.

Lisaks osalesid seltsi liikmed Eesti Teaduste Akadeemia ja teiste (teadus)seltside poolt korraldatud sündmustel.

9. jaanuaril toimus väljasõit Räpina Aianduskooli tutvumaks õppeasutuse tegevusega. Kooli tegemistest rääkis direktor Kalle Toom ning ringkäigu tegi õppemajandi juht Urmas Roht. Samas toimunud pidulikul õhtusöögil võeti kokku möödunud aasta ja anti üle pm-dr Ants Benderile "Aasta Tegija 2018" tiitel koos seltsi presidendi rändkarikaga. Osales 36 liiget.

30. jaanuaril toimus seltsi ettekandekoosolek maaülikooli tehnikainstituudis, kus ettekande tegid taimekasvatuse instituudi teadur Lea Narits "Tuntud ja uued kaunviljad Eesti põldudel" ja dotsent Peep Piirsalu teemal "Kaera lisasöötmine, uttede toitumus ja jõudlus ning vere metaboliitide sisaldus". Osales 24 liiget.

20. veebruaril toimus K.E. von Baeri majas (Veski 4, Tartu) Eesti Vabariigi 101. aastapäevale pühendatud seltsi aktus. Pärast presidendi tervitust pidas akadeemilise kõne Tallinna Ülikooli teadur Piret Peiker teemal ""R a h w a kasu pärast" – Lydia Koidula ühiskondlikkust mõttest 1860ndatel". Osales 23 liiget ja kutsutud külalist.

4. aprillil edastas seltsi president liikmetele õnnitlused seoses Akadeemilise Põllumajanduse Seltsi taasasutamise 30 aastapäevaga. Oma õnnitlustervituses tänas seltsi president kõiki neid, kes on aastate jooksul aidanud läbi seltsi tegevuste arendada kodumaist põllumajandusteadust. Seltsi asutamiskoosolek toimus 1989. aastal, kus kuulati ettekandeid pm-knd Meinhard Karelsonilt Akadeemilisest Põllumajanduslikust Seltsist, pm-knd Arnold Rüütlilt põllumajanduse ja professor Olev Savelilt põllumajandusteaduse probleemidest. Üliõpilasaja seltsi liikmed professorid Jüri Kuum ja Richard Toomre tegid ettepanekuid seltsi tuleviku suhtes.

6. mail peeti Tartus seltsi aastakonverentsi teemal "Riik ja teadus. Inimene ja teadus", kus ettekande tegid maaülikooli prorektor Ülle Jaakma "Tulevik, teadus ja Maaülikool", tehnikainstituudi direktor Margus Arak "Inseneeria hetkeseis ja edendamine", maaeluministeeriumi teadus- ja arendusosakonna juhataja Sirli Pehme "Maaeluministeeriumi teadus-, arendus- ja innovatsioonimeetmed", Tartu ülikooli peaspetsialist Randel Kreitsberg "Teaduse populariseerimine. Miks ja kellele?" ning Tartu ülikooli juhtivteadus ja Eesti Noorte Teaduste Akadeemia liige Leho Tedersoo teemal "Noored teaduses". Noorteadlaste sektsioonis esinevad Katrin Kaldre "Invasiivsed vähi võõrliigid" ja Andres Jäärats "Metsa uuendamist mõjutavad tegurid". Seltsi üldkoosolekul tehakse kokkuvõtteid eelnevast tegevusaastast. Üldkogu otsusega valiti seltsi aupresidendiks tehnikateaduste doktor Arvo Leola. Seltsile valitakse eestseisus ja president. Üldkoosoleku otsusega jätkab Agraarteaduse peatoimetajana Alo Tänavots

ja seltsi sekretärina Heli Kiiman. Revisjoni komisjoni liikmeteks valiti Maarika Alaru ja Sirje Tamm. Osales 25 liiget.

17.–18. mai toimus seltsi väljasõit Läti Vabariiki, mille raames külastati sealset taimekasvatuse uuringute keskust Priekulis. Samuti külastati Riias asuvat AS Integrētās Audzēšanas Skolat, kus võõrustajaks oli kooli üks juhte Inga Gaile ja Läti Agronoomide Seltsi liige Iveta Gūtmane. Teine reisipäev möödus suuresti Dobeles P. Upītis'e muuseumis koos sealse sireliaia uudistamisega. Lisaks tehti lühemaid ja pikemaid peatusi (Vabadussõja mälestusmärgi juures Võnnus) teistes põnevates kohtades. Osales 15 inimest.

23. juunil külastas seltsi president seltsi aupresident Arvo Leolat tema kodus Supilinnas, et üle anda seltsi liikmete õnnitlused tema 75. juubeli puhul.

28. augustil toimus suvine väljasõit Jõgevamaale, kus külastati Luua Metsanduskooli ja parki. Sealt edasi mindi Palamuse O. Lutsu Kihelkonnamuuseumi. Räägitakse siiani, et Palamuse koolimaja klassiruumis kogunes esmakordselt seltsi segakoor. Pärast kosutavat lõunat Vaiatu rahvamajas olid reisisihiks C.R. Jakobsoni tubamuuseum Tormas ja Kalevipoja muuseum Kääpal. Tormas lepiti kokku, et tulevikus osaleb seltsi eestseisuse esindaja kooli iga-aastase Jakobsoni kõnevõistluse žüriis. Sisukasse päeva jäi ka peatus Mõisakülas, riigimees Jaan Poska sünnikohas, meenutamaks Tartu rahulepingule allakirjutaja elu ja tööd. Osales 23 liiget.

18. septembril väisas seltsi eestseisuse delegatsioon koosseisus Evelin Loit ja Marko Kass Eesti Taimekasvatuse Instituuti, kus avati teraviljade aretuskeskuse uus hoone Jõgeval. Oma tervitussõnavõtu järel kinkis president seltsi poolt majarahvale hariliku pihlaka, et see uut maja kaitseks ja selle töötajaid hoiaks.

25. septembril toimus maaülikooli Tehnikainstituudis ettekandekoosolek, kus ettekande tegid taimekasvatuse instituudi vanemteadur Ülle Tamm "Kuidas aretada uusi odrasorte?" ja vanemteadur Margit Olle "Efektiivsete mikroorganismide mõju köögiviljadele ja kasutus laiemalt põllumajanduses". Osales 21 liiget.

18. oktoobril toimus Eesti Rahva Muuseumis emakeelse ülikooli juubelile pühendatud visioonikonverents "Tarkus toidab – 100 aastat emakeelset põllumajanduslikku kõrgharidust". Konverentsi eel avati juubelile pühendatud näitus, kus oli kajastatud ka Akadeemilise Põllumajanduse Seltsi rolli valdkonna arengusse. Juubelil osalejatele esitleti ja jagati tähtpäevale pühendatud Agraarteaduse erinumbrit.

23. oktoobril toimus maaülikooli Tehnikainstituudis ettekandekoosolek, kus kõnelesid zooloog Randel Kreitsberg teemal "Kuidas käib kalade käsi Eestis ja maailmas – merereostuse mõju?" ning seltsikaaslane Ellen Pärn "Constance Kalm – 'Sangaste' rukki hoidja". Osales 27 liiget.

22. novembril teatas Jyrki Wallin Agronomiliitto tegevdirektor, et paneb 16 aastat kestnud ameti maha. Tema ameti Soome Akadeemilises Agronoomide Ühenduses võtab üle agronoomiaharidusega Ilkka Pekkala.

27. novembril toimus maaülikooli Tehnikainstituudis ettekandekoosolek, kus kõnelesid taimekasvatuse instituudi nooremteadur Merili Toom teemal "Vahekultuurid – väärt abilised nii mahe- kui tavaviljeluses" ning seltsikaaslane Alo Tänavots "Searümpade (väärtuse) hindamine suuremates lihatööstustes". Osales 23 liiget.

Seltsi teadusajakirjal Agraarteadus ilmus 2019. aastal lisaks põhinumbritele ka kaks erinumbrit – juunis ja detsembris. Esimene pühendatud emakeelsele põllumajanduslikule kõrgharidusele. 29. novembril ilmus Agraarteaduse teine erinumber, mis oli pühendatud põllundustehnika õpetamise 100-ndale aastapäevale Eestis. Ajakirjas avaldatud teadusartiklid indekseeritakse SCOPUS® andmebaasis.

Selts kasutab alates uudiste ja informatsiooni edastamiseks meililisti ja sotsiaalmeediat. Seltsi sissetulekuallikateks on liikmemaksud ja annetused. Lisaks toetab rahaliselt seltsi tegevust Eesti Teaduste Akadeemia. Ka on ühekordseid sissetulekuid seoses mittevaraliste lepinguliste tegevustega. Ebaregulaarselt on seltsi ajakirja väljaandmist rahastanud Eesti Maaülikool. Seltsil palgalisi ametikohti ei ole. Võlgnevusi pole.

Marko Kass, president
Heli Kiiman, sekretär

MINEVIKUST

AKADEEMILINE PÕLLUMAJANDUSLIK SELTS 15-AASTANE

Prof dr agr P. Kõpp APSi kauaaegne esimees

5. novembril 1930 a täitus 15 aastat sellest, kui registreeriti Tartu Ülikooli juures Akadeemiline Põllumajanduslik Selts – lühendatud nimetusega APS. "Agronoomial" on põhjust seda päeva märkida esiteks seepärast, et APS on alates 1926. aastast üks "Agronoomia" väljaandjaid, teiseks aga seepärast, et APSi elu on olnud kõige lähedamas ja tihedamas sidemes meie iseseisvuspõlve agronoomkonna kujunemisega. APSi mõju sellele on olnud nii silmapaistev, et selles põlves täie õigusega kõneldakse "APSi koolist" ja "APSi vaimust". Tartu Ülikooli on agronoomidiplomiga lõpetanud seni ligi 200 (täpsamalt 181) inimest, lisaks palju neid, kes õiendanud ainult kõik eksamid, aga ka neid. kellede stuudiumitöö jäänud pooleli, neist kõigist saame inimestehulga, kellel õpinguteajal sidemeid olnud APSiga. Umbkaudsete arvestuste järgi võiks see hulk tõusta 600–700-le. Suur osa neist on jäänud praegugi kõige ligemasse kontakti APSiga eluaegsete liikmetena. Akadeemiliste Seltside peres on APS oma töö laadilt ja ulatuselt kujunenud omapärasemaks ja aktiivsemaks.

"Agronoomia" lugejaid on pidevalt informeeritud APSi tööst enese liikmeskonnast väljapoole, kodumaa põllumajanduse hääks Seda tööd mille tippsaavutuseks on ajakirjade "Agronoomia" ja "Taluperenaise" väljaandmine ning suure koguteose "Põllumehe käsiraamat" toimetamine ja kirjastamine, on varemini avalikkuses hinnatud. Märgitagu siin veel lisaks et APSi teeneks pole mitte ainult kõigi nende teoste koostamine, toimetamine ja kirjastamine, vaid APS on osanud need viia ka kõik rahva sekka. "Taluperenaise" tiraaž on kasvanud ajakirjadest suurimaks, "Põllumehe käsiraamatu" meil ennekuulmatu eksemplaride arvuga trükk on müüdud üksikutel osadel läbi. – Kõige selle avaliku töö kõrval on väljaspool vähem käsitlust ja hinnangut leidnud see nn "APSi kooli" mõju meie iseseisvuspõlve agronoomkonnale, mida aga ei saa sugugi alahinnata APSi muu kõrgeväärtusliku töö kõrval.

APSi, tema alaorgane ja üksikliikmeid iseloomustab juba algusest pääle suur tööind ja aktiivsus. Selles tundub algaastail nooruse tormi ja tungi ajajärku, nooruse laiajoonelisi unistusi, ometi igati väga positiivseid. Seda kõike on aga juba algusest pääle osatud tasakaalustada vanemale elukogemuste ja tarkusega. APSis kohtame algusest pääle tihedat koostööd vanemate ja nooremate, õpetajate ja õpilaste vabel. Teisest sem pääle asutamist alates on Seltsi esimehena juhtinud prof dr agr Peeter Kõpp, kelle tasakaalukas optimism suurel määral on iseloomustavaks jooneks kogu APSi tegevuses. Teistest õppejõududest, kes pikemat aega seltsi tegevusest juhatusliikmeina osa võtnud, mainitagu prof dr agr Leo Rinnet, prof dr agr Nikolai Rootsit, dots dr agr Mart Järvikut (Gross), eradots õp agr Jaan Metsa ja rida ülikooli assistente. – Kõikide nende kaastöö ja koostöö noorematega on olnud aktiivsele tööle virgutamisel ja juhtimisel suure tähtsusega Töövaimu kasvatamisel on töö toimkondadel, mida APSi eluea kestel asutatud 20 ümber, väga hinnatav seisukoht.

Meie agronoomilist tegelast, kes tuleb rahva seast ja läheb taas rahva sekka, peab iseloomustama elulähedus ja reaal-põllumajanduslik mõtlemisviis. Akadeemia oma õppetöö iseloomuga pole sellele arengule igakord soodustav. Siin on akadeemia ja elu vabel vahelüliks saanud APS, kus igakolmapäevastel kõnekoosolekutel käsitletakse küsimusi esijoones põllumajanduse ala juhtivate isikute poolt.

Kolmandana võiks "APSi kooli" iseloomustava joonena märkida haruldast üksmeele ja ühistöö vaimu ning leplikkust teisitimõtlejate vastu. Meie akadeemilist elu nii lihti iseloomustavad organisatsioonide vahelised Vargamäe-iseloomulised vägikaikavedamised pole pääsenud APSi tööd kunagi häirima.

15. töörohke tulemusterikka aasta möödudes on samuti kui väga paljudel agronoomilistel tegelastel ka K-k "Agronoomial" põhjust õnnitleda APSi, ühtlasi soovida edu, õnne ja jõudu kõikide nende ülesannete teostamiseks järgnevail aastail, millised APS oma ülesandeks võtnud.

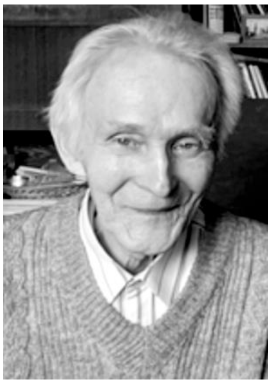
Elmar Järvesoo (Gerberson)

Artikkel on ilmunud ajakirjas "Agronoomia" 1930, 11:520.

Autor oli APSi sekretär aastatel 1932–1937. Ajakirja "Agronoomia" toimetuse abijõud (1932) ja sekretär (1932–1935).

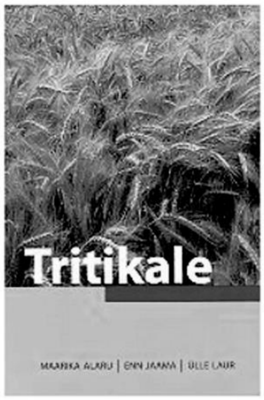
Autori kirjaviis muutmata.

PROFESSOR ENN JAAMA – 85



25. juunil 2019. aastal sai 85-aastaseks emeriitprofessor Enn Jaama. Ta sündis 1934. a Tartumaal, Rõngu vallas Korustel talupidaja perekonnas. Sealsamas sai ta ka oma esimesed talutööde kogemused ja alustas ta ka haridusteed, lõpetades seejärel kohaliku 7-klassilise kooli. Üldse on Koruste küla ja selle lähiümbrus rikas Eestis tuntust kogunud isikute poolest. Seal on sündinud, koolis käinud või elanud kunstnik Elmar Kits, skulptor Juhan Paberit, luuletaja Ernst Enno ja helilooja Aleksander Läte. Jaamade suguvõsast on Korustel sündinud ja üles kasvanud Enn Jaama mõlemad onud – loomakasvatusteadlane Kristjan Jaama ning tuntud puuviljandusteadlane ja sordiaretaja Arthur Jaama. Nende eeskujul hakkas maamehest teadlase teed sammuma ka Enn, kui ta asus õppima Jäneda Põllumajandustehnikumi ja selle lõpetamise järel jätkas õpinguid Eesti Põllumajanduse Akadeemia (EPA) agronoomiateaduskonnas. Kohusetunne ja huvi teadmiste vastu oli tal sedavõrd suur, et ta lõpetas need mõlemad õppeasutused kiitusega. Juba üliõpilasena sai kinnituse tema huvi teadustöö vastu kui ta osales aktiivselt Üliõpilaste Teadusliku Ühingu (ÜTÜ) tegevuses. Innuka üliõpilasteadlasena valiti Enn Jaama agronoomiateaduskonna ÜTÜ nõukogu esimeheks.

Jätkas õpinguid aspirantuuris, misjärel kaitses 1968. a talirapsi agrotehnika teemalise põllumajandusteaduste kandidaadi väitekirja. Enn Jaama on üks õppejõude, kelle töökohaks on olnud ainult Maaülikool ja kus ta läbis kõik ametiredeli astmed. Juba üliõpilasena alguse saanud töötegemine jätkus taimekasvatuse kateedri laborandi ja seejärel vanemlaborandi ametikohal. Õppejõu karjääri alustas ta assistendina, seejärel vanemõpetajana, dotsendina ja lõpuks sai temast taimekasvatuse õppetooli professor. Tema käe all on õppinud taimekasvatust ja söödatootmist erinevate teaduskondade üliõpilased. Oli tudengite hulgas populaarne ja hinnatud õppejõud, kes oskas ka igavate ja tüütutena tunduvad õppeainete peatükid huvitavaks ja atraktiivseks rääkida, tuues lisaks näited ka omaenda oskustest ja kogemustest. Sageli esitas ta tööde kaitsmistel ja konverentsidel esinejaile nn "kiusuküsimusi", nagu ta ise neid nimetas. Enamasti olid need jututeemaga seotud sellest vaatenurgast, mida ei oodatud ja tekitasid seetõttu humoorikat elevust. Enn Jaama juhendamisel on valminud sadakond diplomi- ja lõputööd, doktoritöö ja magistritöid. Osales ka ülikooli õpikute koostamisel ja kirjutamisel. Ta on kolme kasutusel oleva taimekasvatust käsitleva õpiku kaasautor. Õppejõu ameti kõrvalt täitis Enn Jaama taimekasvatuse kateedri juhataja kohustusi ning oli aastatel 1971 kuni 1978 EPA kaugõppeteaduskonna prodekaan ning aastatel 1978–1984 juba selle dekaan. Teadustööd alustas Enn Jaama 1961 aastast rapsiga. Ta tegi katseid ja uuris talirapsi agrotehnika probleeme ning selgitas talirapsi kasvatusvõimalusi Eesti tingimustes. Avaldas ka töid ka teiste õli- ja eeterlike õli kultuuride, rüpsi ja söödakapsa kohta. Rapsi uurimisega kujunes Enn Jaama üheks selle ala arvestatavamaks agronoomiateadlaseks Eestis. Kuid temalt võib leida uurimisandmeid ja artikleid, mis on seotud ka teiste kultuuridega nagu kartul ja söödakapsas. Lisaks neile on rida publikatsioone ka teraviljade kohta ja on ilmunud artikleid segaviljadest. Alates 1995. aastast hakkas ta selgitama talitritikale kasvatamisvõimalusi Eestis. Ta juhtis sellealast uurimistegevust Eesti Maaülikoolis ja tegi projektipõhist koostööd Tallinna Tehnikaülikooli toiduainete instituudiga. Koos oma õpilastest kolleegidega uuris ta kasvufaktorite mõju tritikale biomassi formeerumisele, saagile ja selle kvaliteedile, toite- ja söödaväärtusele. Identifitseeriti Eestis kasvatamiseks perspektiivseid sorte ja selgitati sobivaid genotüüpe tritikalejahu kasutamiseks pagaritööstuses. Tulemuste alusel valmis hulk artikleid ja 2012. a veel 109 leheküljeline raamat "Tritikale". Teda võib õigustatult pidada talitritikale Eestisse maaletoojaks. Enn Jaama tutvustas oma töö tulemusi laiemale avalikkusele konverentsidel ja ajakirjanduses. Näiteks 23. novembril 2000. a Sakus toimunud TÜ Eesti Teravili korraldatud konverentsil esines ta ettekandega talitritikale sortidest, saagipotentsiaalist ja kasutamisotstarbest ning ajalehele "Postimees" 15. juunil 2001. a antud intervjuus "Saaki ähvardab ikaldus", et erakordselt külma ilma jätkudes pole sügisel head saaki loota ning esitas seal oma asjatundlikud põhjendused.



1. septembril 1999. a omistati Enn Jaamale emeriitprofessori nimetus ja samal aastal autasustati teda Maaülikooli teenetemedaliga.

Soovime juubilarile tugevat tervist ja jaksu edaspidiseks.

Endiste ja praeguste kolleegide nimel
Jaan Kuht
Maarika Alaru
Evelin Loit

MULLATEADLANE PROFESSOR RAIMO KÕLLI – 80

Eesti Vabariigi aastapäeval, 24. veebruaril 1940. a nägi Võrumaal Orava vallas Kõliküla külas Vanatare talus ilmavalgust poisslaps, kellele pandi nimeks Raimo. Alghariduse omandas ta Luuska ja Hanikase koolis. Maapoisina läks Raimo edasi õppima Räpina Aiandustehnikumi, selle lõpetamise järel loogilise jätkuna EPA agronoomiateaduskonda. Pärast EPA lõpetamist õpetatud agronoomina 1963. a asus ta tööle RPI Eesti Põllumajandusprojekt mullastiku uurimise osakonnas esmalt inseneri ja edasi vaneminsenerina. Tõsisema huvi tõttu muldade uurimise vastu astus ta 1967. a aspirantuuri mullateaduse erialal Loit Reintami juhendamisel. Ratsionaalse-eesmärgipärase töö tulemusena valmis Raimol metsa- ja põllubiogeotsönooside fütomassi hulkasid, dünaamikat ja keemilist koostist käsitlev kandidaadiväitekiri. Põllumajandusteaduste kandidaadidissertatsiooni kaitses ta 1971. a Moskvas V.V. Dokutšajevi nimelises mullainstituudis. Aastatel 1970–1977 töötas Raimo EPA mullateaduse ja agrokeemia kateedris vanemõpetajana ja aastatel 1977–1989 dotsendina. Selle aja sees jõudis Raimo ühe aastaga Moskvas selgeks õppida prantsuse keele ja aastatel 1980–1982 töötada õppejõud-eksperdina Guinea Vabariigi Kankani Polütehnilises Instituudis. Aastatel 1984–1986 oli Raimo vanemteadurina EPA doktorant. 1988. aastal kaitses ta NSVL Siberi Osakonna Mullateaduse ja Agrokeemia Instituudis Novosibirskis bioloogiadoktori dissertatsiooni ning 1991. aastast on ta professor mullateaduse erialal. Õpetanud on ta mullateaduse põhikursust, Eesti mullastikku ning ökoloogiat ja keskkonnakaitset.

Väljaspool Eestit on Raimo end täiendanud aastatel 1978–1979 Moskva Veterinaaria Akadeemias prantsuse keele erialakursusel, 1993. aastal Fulbrighti vahetusprogrammi raames Ameerikas Wisconsini Ülikoolis ning 1996. aastal Rockefelleri fondi ja Roberto Celli memoriaalfondi toetusel Itaalias Bellagios. Raimo on osalenud ettekandega Mullateaduse 16. Maailmakongressil 1998. a Montpellieris ja 17. Maailmakongressil Bangkokis 2002. aastal.

Teadusorganisatsioonilise ja administratiivse tegevuse raames oli Raimo aastatel 1987–1990 Agronoomiateaduskonna teadusprodekaaniks. Aastatel 1992–2005 oli ta mullateaduse ja agrokeemia kateedri (õppetooli, instituudi, osakonna) juhatajaks. Aastatel 1991–2005 oli Raimo EPMÜ Loodusteaduste doktorinõukogu ning Põllumajandusteaduste ja majandusteaduse doktorinõukogu liige, 1992–2004 ka EPMÜ põllumajandus- ja loodusteaduse magistrinõukogu esimees ning aastatel 1996–1999 EV Valitsuse Säästva Arengu Komisjoni liige. Ta oli üks Eesti Mullateaduse Seltsi taasasutajatest.

Erialastest ühendustest kuulub Raimo Eesti Teadlaste Liitu, Akadeemilisse Põllumajanduse Seltsi alates 1989. a (olles 1990–1995 selle eestseisuses), Eesti Agronoomide Seltsi 1992. a, Rahvusvahelisse Mullateadlaste Seltsi 1993. aastast, on Eesti Teadusfondi Geo-bioteaduste ekspertkomisjoni, Põhjamaade Põllumajandusteadlaste Ühingu (NJF), Euroopa Mullakaitse Seltsi (ESSC) ja selle nõukogu liige, Mulla ja Veekaitse Ülemaailmse Assotsiatsiooni liige ning Eesti esindaja, Rahvusvahelise Turbaseltsi (IPS) III komisjoni liige.

Aastate jooksul on ta olnud 14 erineva baasfinantseerimise, sihtfinantseerimise, Eesti Teadusfondi granti ja mitmete Poola-Eesti ühisprojektide Eestipoolne juhendaja või vastutav täitja ja mitmete rahvusvaheliste konverentside korralduskomisjoni liige ning esimees. Aastast 1999 on ta osalenud real rahvusvahelistel teadusfoorumitel Leuvinis, Readingis, Vila Realis, Prahas, Valencias, Madridis, Münchebergis, Tartus, Sofias, Brasilias, Krakovis, Budapestis, Freiburgis ja mujal.

Aastatel 1994–2007 juhtis Raimo EMÜ mullateaduse ja agrokeemia osakonna mullamuuseumi arendamist ja renoveerimist.

Tunnustustest on Raimo saanud Eesti NSV Metsamajanduse ja looduskaitse (1979) ja Põllumajandusministeeriumi (1989 ja 1990) aukirjad. Toetusena on ta saanud stipendiumid Fulbrighti (Wisconsin, Madison, 1993), Põhjamaade Ministrite Nõukogult osavõtuks NJF seminarist (Rootsi, Knivsta, 1994) ja NJF XX kongressist (Reykjavik, Island, 1995). Rocefelleri fondi, Roberto Celli memoriaalfondi (Itaalia, Bellagio, 1996) ja ETA teadlaste vahetusfondi toetused on ta saanud tutvumiseks RISSAC-i ja Pannon PÜ-ga (Ungari, 1996) ning tegemaks koostööd muldade orgaanilise aine uurimise alal Poola TA Põllu- ja Metsamajandusliku uurimiskeskusega (Poznan, Poola, 2002–2003).

Raimo teadustöö põhisuundadeks on pika aja jooksul olnud muldade fütoproduktiivsus, lämmastiku ja tuhaelementide biogeokeemiline ringe, mulla orgaanilise aine voog läbi muldkatte, põllumuldade huumusseisund ja selle seire, muldkatete geneetilis-produktsiooniline areng, Eesti muldkatte koosseis ning muldade metsa- ja põllumajanduslik kasutussobivus, mullastikukaartide kasutamine muldade kasutussobivuse hindamiseks, Eesti muldade klassifitseerimine, mullataksonoomia ja lokaalsete mullaklassifikatsioonide konverteerimine rahvusvahelistesse süsteemidesse ning kaasaegsed muldade saastumise ja kaitse probleemid. Eestis olemasolevat detailset ja pidevalt täienevat mullastikulist teavet on vaja lokaalsel tasemel loodust säästva maakasutuse arendamisel tasakaalustatud keskkonnaseisundi tagamisel ja efektiivse loodushoidliku põllu- ja metsamajanduse korraldamisel. Aastate jooksul on Raimo koostanud 12 nimetust õppevahendeid muldade kogude, muldade määramise ja iseloomustamise, kasutussobivuse, väliuurimise jms kohta. Raimo poolt on välja töötatud ja pidevalt täiendatud muldade määramist ja mullaomaduste mõistmist lihtsustavad muldade määramise ja iseloomustamise maatrikstabelid, kuhu on lisatud järjest uusi mullaomadusi. Tema poolt on koostatud ka Eesti muldade digitaalne kogu (https://mullad.emu.ee/).

Raimo on olnud juhendajaks viie magistritöö ja ühe doktoritöö valmimisele ning tegeleb kahe doktorandi juhendamisega, kelle doktoritööde lõpetamine on laste kasvatamise tõttu edasi lükkunud.

2004. a tunnustati Raimo Kõllit EPMÜ teenetemedaliga ning alates 1. septembrist 2005 on ta EPMÜ põllumajandus- ja keskkonnainstituudi vanemteadur ja samas ka emeriitprofessor. Peale emeriteerumist on ta saanud pöörata suuremat rõhku kogutud teadusandmete läbitöötamisele, üldistamisele ja tulemuste avaldamisele. Aktiivselt osaleb ta Euroopa muldade huumusvormide klassifikatsiooni väljatöötamisel. Suur panus on Raimol ka Eesti aastamuldade populariseerimisel ajakirjades "Eesti Loodus" ja "Agraarteadus". Praeguseks ulatub Raimo publitseeritud artiklite ja teadustööde nimestik 460-ni, millest viimase nelja aasta jooksul on trükis ilmunud koos kaasautoritega 50 artiklit.

Soovime Raimole tugevat tervist ja vahedat sulge tema kogutud suure andmebaasi edasisel lahtimõtestamisel ning tulemuste publitseerimisel.

Kolleegide nimel,
Enn Leedu ja Alar Astover

ARVO TÕNISSOO – 80

Aprilli lõpupäevadel pühitsesid oma 80-ndat sünnipäeva Arvo ja Anu Tõnissoo. Koos nendega jõuavad sellise verstapostini tervelt kolmandik 1964. aastal EPA Agronoomiateaduskonna lõpetanud õpetatud agronoome, kes vastavalt ajastu nõuetele, on andnud oma panuse põllumajanduse hüveks.

Arvo Tõnissoo on pärit Mulgimaa südamest. Pärast Halliste 7-klassilise kooli lõpetamist astus ta Kehtna Kolhooside Esimeeste Ettevalmistamise Põllumajanduskeskkooli, kus omandas nooremagronoomi kutse. Praktilise põllumehe kogemused said alguse Penuja sovhoosis põllundusbrigadirina töötades. Järgnesid õpinguaastad Eesti Põllumajanduse Akadeemias ja aastatel 1968–1971 aspirantuuris. Pärast akadeemia lõpetamist töötas Arvo Halliste sovhoosis osakonna juhataja ja peaagronoomina. Huvist teadutöö vastu siirdus Arvo aspirantuuri ja hiljem tööle EPA maaviljeluse kateedrisse assistendina. 1975. a kaitses ta professor E. Halleri juhendamisel valminud kandidaadikraadi väitekirja teemal "Kevadise mullaharimise aja ja viisi mõju odrasaagile erinevatel külviaegadel". Arvo Tõnissoo on olnud üliõpilaste diplomitööde juhendaja, oponendiks mitmetele dissertantidele ja juhtinud ka EPA Agronoomiateaduskonna Riikliku Eksamikomisjoni tööd. Aastatel 1973–1977 töötas ta Tori näidissovhoosi peaagronoomi ametikohtal.

1977. aastal asus perekond Tõnissoo elama Sakku, kus Arvost sai EMMTUI Saku katsejaama juhataja, seoses instituudi struktuuri muutumisega, hiljem ka tera- ja kaunviljakasvatuse osakonna juhtivtöötaja. Samas jätkus teadustöö külvieelse mullaharimise, füüsikaliste meetoditega seemnete töötlemise (laser jt) ja teraviljasortidele sobiva agrotehnika uurimise alal. Töötulemusi on kajastatud artklitena põllumajanduslikes ajakirjades, teadustööde kogumikes ja arvukates konverentside materjalides.

Alates 1994. a töötas Arvo Tõnissoo endise Riigi Seemne ja Sordikatse Inspektsiooni süsteemis, kus tegeles teravilja sordivõrdluskatsete korraldamisega. Oma töös ja õpingutes on Arvo Tõnissoo alati olnud väga täpne ja kohusetundlik, nii enese kui alluvate suhtes nõudlik.

Ühiskondlikus korras juhendas ta rida aastaid Saku Keskkoolis noorte liiklusinspektorite tööd ja tegeles ka Harju koondvõistkonna võistlusteks ettevalmistusega. Tema juhendamisel tuli võistkond alati Eesti meistriks.

Koos abikaasa Anuga on juubilar kasvatanud ja koolitanud kõrgema haridusega insenerideks kolm poega ja rajanud kauni aiaga suvekodu, kus veeta mõni ilus suvepäev laste, lastelaste ja sõpradega.

Jätkuvat õnne, vastupidavat tervist ja palju aastaid!

Erika Vesik

ALEKSANDER LEMBER – 65

Tänavu 10. jaanuaril tähistas oma 65. juubelit loomakasvatuse õppejõud ja teadlane pm-dr Aleksander Lember.

Kui ta 1985. aastal oma teadlaskarjääri toonases Eesti Põllumajanduse Akadeemias (EPA) alustas, siis siinkirjutaja alles laulis lasteaia vanemas rühmas igatsevalt "*Oh, kooliaeg, oh kooliaeg,* …". Kuigi oleme erineva põlvkonna mehed, siis tema töödele ja tegemistele tagasi vaadates leian nii mõndagi sarnast oma elukäigule. Igatahes on tal olnud võimalus töötada ja teadmisi koguda mitmete nimekate õppejõudude käe all. Seeläbi jätta ka omalt poolt märkimisväärne jälg akadeemilisse ellu. Järgnevalt teen peaasjalikult oma mälestuste ja kolleegide meenutuste varal põgusa tagasivaate juubilari mitmekülgsele tegevusele ülikoolis ja väljaspool seda.

Enne 35 aasta pikkuseks kujunenud teadlaskarjäärile eelnes praktiline töö põllumajanduses. Pärast EPA zooinseneri teaduskonna lõpetamist 1978. aastal suunati ta tööle Vao sovhoosi veiste suurfarmi zootehnikuks. Ühtlasi oli tal võimalus teenida leiba sama majandi peazootehniku ning Sootaga sovhoosi seakasvatuse vanemzootehnikuna. Ent saatusel oli varuks teine plaan. Keeruline öelda, kas see, et ta sõbra ja kursusekaaslase Jaan Loite õhutusel 1985. aasta kevadel professor Ülo Olli kabineti sattus – oli juhus või mitte? Mine sa võtta kinni – mõnede arvates juhuseid pole olemas. Igatahes oli tal veel suhteliselt värskelt meeles kui vaevaliselt saadi toona kätte professor Ü. Olli käest mahuka söötmisõpetuse eksamihinne. Temal õnnestus see juba teisel korral! Aga saatusel oli temaga omad plaanid ning hiljem eneselegi üllatuseks sai temast igas mõttes professor Ü. Olli töö jätkaja. Nagu juubilar ise on meenutanud, siis aspirantuuriaastad juhendaja käe all olid üsna pingelised ja "midagi kandikul ette ei kantud". Tema esimesed viljad teaduspõllul valmisid 1989. aastal, kui kaitses kandidaadiväitekirja teemal "Sööda kokkuhoid emiste reproduktsioonitsükli jooksul". Loogilise jätkuna järgnes töö assistendi ja hiljem vanemõpetajana EPA põllumajandusloomade söötmise kateedris.

Rada oli nüüdseks lõplikult sisse tallatud. Pärast aspirantuuri tuli püstitada uusi sihte – ees ootas doktoritöö. Koostöö professor Ü. Olliga jätkus, ent 1990-ndate esimesel pooles töötas A. Lember juba teises osakonnas seakasvatuse dotsendina. 3. mail 1996. aastal tuli Eesti Põllumajandusülikooli põllumajandus- ja majandusteaduste doktorinõukogus kaitsmisele tema põllumajandusdoktori väitekiri teemal "Emiste jõudlusnäitajate sõltuvus ratsiooni metaboliseeruva energia ja proteiini kogusest". Omaaegsed mäletavad, et dissertandi vastas oli kõva kahurvägi eesotsas akadeemik Elmar-Ants Valdmanni ja emeriitprofessor Elmar Rätsepaga. Väitekiri sai edukalt kaitstud ning selle mahukusele viitab asjaolu, et tulemused publitseeriti ligemale kümnekonnas artiklis.

Kui allakirjutanu 2000-ndate alguses Loomakasvatusinstituuti õppima asus, hõljus veel mõisamaja kohal professor Ü. Olli aura. Juba üsna varakult hoiatasid vanemate kursuste tudengid, et ega professor A. Lemberiga kergemalt ei lähe kui tema akadeemilise isaga. Ilmselt kohtusime temaga koridori peal juba esimese kursuse sügisel. Pealegi oli toona instituudis kombeks kõik suuremad sündmused (rebaste ristimised, jõulupeod jne) ühtse perena pidada ja kõik tundsid kõiki. Õppejõudude teretamine üliõpilaste poolt oli elementaarne. Ühtlasi asus tema kabinet mõisamaja teise korrusel peamise õppeklassi vastas, seega teadsime esmakursuslastena üsna varakult, kus tuleb vaikselt olla, kuna professor töötab. Esimese kursuse kevadel oli meil temaga õppeaine "Teadustööde vormistamine". Saime üsna hästi tunda tema punktuaalsust ja ranget hoiakut, et üliõpilase kirjatöö akadeemias peab olema ladusa sõnastuse ja korrektse vormistusega. Aga see tuli ainult kasuks, kuna siis olid paljud eksamid ja arvestused kirjalikud ning õppejõud eeldasid kirjutajalt sisutihedaid ja korrektse käekirjaga vastuseid. Ja nüüd, kui mina esmakursuslastele sama ainet õpetan, teen seda omaaegse loomakasvatusinstituudi traditsioone järgides – asjakohase nõudlikkuse ja täpsusega nagu mu eelkäijad. Hiljem kohtusime A. Lemberiga alles nelja-aastase stuudiumi viimasel kevadel aines "Seakasvatus". Kui ma nüüd taas oma matriklisse vaatan, siis pean kahetsusega nentima, et sinna märgitud eksamihinne vist väljendas tõika, et toona meeldisid mulle teised loomaliigid rohkem. Kuid kes seda enam täpselt mäletab.

Tänavu, mil möödub 30 aastat teadusajakirja Agraarteadus esimese numbri ilmumisest, on paslik kõnelda ka toonase professori hindamatust panusest ajakirja peatoimetajana. Sisuliselt tuli tal üle öö üle võtta professor Ü. Olli töö toimetuse juhtimisel. Kuigi ta oli kõrvalt näinud seda suurt pingutust ja vaeva, mida professor Ü. Oll laekunud käsikirjade toimetamisega nägi, tuli peatoimetaja amet ehk liialt vara. Samas juubilari enda sõnul tundis ta, et eks professor Ü. Oll tasapisi valmistas teda peatoimetaja ametiks ette, andes lugeda ja toimetada saabunud käsikirju. Ei saa märkimata jätta, et A. Lember oli ainukese(!) emakeelse põllumajandusteaduste ajakirja peatoimetaja 10 pikka aastat (1997–2006). Vastutus tema õlgadel oli ju keerulistel aegadel kui toimus ridamisi teaduspoliitilisi muudatusi, mis tõid paratamatult kaasa ajakirjale esitatud kaastööde märkimisväärse vähenemise.

Lisaks peatoimetaja kohustustele osales ta ka Akadeemilise Põllumajanduse Seltsi (APS) eestseisuse töös tulenevalt oma ametist. Seltsi üldkogus valis ta APS-i eestseisusesse 8.–9. aprillini 1998. a Tartus toimunud APSi III aastakonverentsil koos pm-dr Malle Järvani, pm-knd Ants Benderi, pm-dr Paul Lättemäe, professorite Rein Viiralti ja Jaan Praksi, emeriitprofessorite Harald Tiku ja Heino Mölleri ning filosoofiadoktor Matti Piirsaluga. Ühtlasi tuletasid kolleegid meelde, et 1997. aastal tunnustati teda APS-i üldkoosoleku otsusega seltsi aastapreemia vääriliseks.

Tema viljakasse karjäärikaukasse jäävad mitmed olulised kohustused – Eesti Põllumajandusülikooli põllumajandusteaduste ja majandusteaduse doktorinõukogu liikmelisus, Eesti Loomakasvatusinstituudi väikelooma- ja linnukasvatuse osakonna juhataja töö, mitmete dissertatsioonide juhendamine ja oponeerimine. Ajaloolise faktina tuleks rõhutada, et just tema alustas Loomakasvatusinstituudis, hiljem aga üle-ülikooli huvilistele koerakasvatust õpetama.

Tunnustust väärib ka mõningane kannapööre kümmekond aastat tagasi, kui ta sidus ennast Eesti Linnukasvatajate Seltsiga. Alguses seltsi sekretäri ametis, hiljem juba juhatuse esimehena. Nüüd teavadki paljud teda kui eesti vuti aretustöö eestvedajat ja propageerijat. Siinkirjutajalgi on temaga kahasse läbi viidud uurimistöö vuttide söötmise kohta, mille tulemused tänaseni laua serval kannatlikult publitseerimist ootavad.

Kuigi juubilar on võtnud kindlaks nõuks tõmmata joon alla akadeemilisele karjäärile, siis loodetavasti linnukasvatusalane aretustöö ja valdkonna populariseerimine jätkub veel aastaid. Ühtlasi loodan, et tal oleks mahti pikkadel talveõhtutel panna kirja mälestusi endistest aegadest – kuldsetest kaheksakümnendatest ja pöörastest üheksakümnendatest. Ja kuuldavasti on tal need lauasahtlis olemas.

Soovin nii APS-i eestseisuse kui söötmisteaduse õppetooli kolleegide nimel juubilari veel kord õnnitleda ning tänada märkimisväärse panuse eest loomakasvatusteadusesse.

Tervist ja jaksu!

Marko Kass

MATI KOPPEL – 60

Ümmarguse verstapostini jõudis jaanuaris Akadeemilise Põllumajanduse Seltsi liige (1990. a-st), endine Eesti Taimekasvatuse Instituudi pikaaegne direktor, filosoofiadoktor Mati Koppel. Sündinud on ta 25. jaanuaril 1960 Tartu linnas. Isa ja ema töötasid kolhoosis. Seega elades Tartu rajoonis Jõusa külas ei olnud maatöö talle võõras. Ta õppis Lähte Keskkoolis, mille lõpetas 1978. a ja siirdus koheselt õppima Tartu Riiklikku Ülikooli bioloogia-geograafia teaduskonda bioloogia erialale, mille lõpetas 1984. aastal bioloogi-botaanikuna. Peale ülikooli lõpetamist asus ta tööle Jõgeva Sordiaretusjaama nooremteadurina kuni 1993. aastani, kus ta hakkas tegelema kartuli resistentsusaretusega. Töötades kõrvuti staažika fütopatoloogi Jaan Sarvega, valmis tal ka tema juhendamisel 1992. aastal doktoritöö "Kartulisortide märgmädanikukindlus hinnatuna erinevate nakatumismeetoditega". Peale doktoritöö kaitsmist määrati ta 1993. a vanemteaduriks ja alates 1995. a resistentsuse ja biokeemia laboratooriumi juhatajaks, kellena töötas kuni 1999. a-ni. Alates 22.03.1999 kuni 19.04.2019 töötas Mati Koppel Jõgeva Sordiaretuse Instituudi direktorina, mis 2013. aastast nimetati ümber Eesti Taimekasvatuse Instituudiks (ETKI) kui toimus ühinemine Eesti Maaviljeluse Instituudiga. 20 aastat ETKI-t juhtida ei olnud mitte alati kerge, aga ta sai sellega suurepäraselt hakkama. Tegeleda tuli teadustöö rahastamise, taristu kaasajastamise, teadlasjärelkasvu ja väga paljude teiste küsimustega, mis alati ei olnudki tema ülesannete hulka kuuluvad. Samal ajal tegeles aga aktiivselt ise teadustööga. Südamelähedaseks on talle jäänud mitmete põllukultuuride haiguskindluse uurimine. Erilist rõhku pani ta tihedatele sidemetele Eesti põllumeestega. Aastaid on kestnud koostöö paljude põllumeestega, kes on tunnustavalt öelnud, et M. Koppel näeb pikemat perspektiivi, mitte kõik ei suuda selliselt mõelda. Samuti on neile meeldinud, et kõik probleemid on tema eestvedamisel alati üles tõstatatud, üritatud leida võimalusi nende uurimiseks ja katsete tegemiseks. Lisaks koostööle põllumeestega on tal olnud arvukaid koostöösidemed ülikoolide ja välisriikide uurimisasutustega. Nagu ta ise on öelnud, et kõrgetasemeline teadustöö on eelduseks sellele, et suudaksime anda põllumeestele tasemel nõuandeid ja soovitusi. Juba enne direktoriks saamist osales ta põhjamaade sordiaretuse alastel doktorantide kursustel. Esimesel korral õpilasena, hiljem mitmeid aastaid õpetajana. Ta on stažeerinud ka Üleliidulise Taimekaitse Instituudis ja Svalöf ABs (Rootsi). Osalenud mitmete kodumaiste ja välismaiste seminaride ja konverentside orgkomiteedes. M. Koppel on juhtinud või olnud osaleja 19 teadusprojektis. Olnud mitme magistri- ja doktoritöö juhendaja või kaasjuhendaja. Ka on olnud ta kaasautoriks üheksale sordile (4 kartuli- ja 3 suvinisusorti). Ta on avaldanud 162 teaduslikku ja populaarteaduslikku artiklit, mida on tsiteeritud 372 korda.

Ta on kuulunud ja on seda ka praegu väga mitmetes teadus- ja administratiivorganisatsioonides. Oma eduka töö eest on M. Koppelit autasustatud Valgetähe IV klassi teenetemärgi, Põllumajandusministeeriumi sinise teenetemärgi ja Jõgevamaa hõberistiga.

Direktori- ja teadustöö kõrval on tal jätkunud püsivust kaasa lüüa kõikvõimalikel spordiüritustel. Osalemisi on olnud nii palju, et seda ei mahutaks see kirjatükk ära. Küll on need olnud kodumaised jooksuüritused ja suusamaratonid kui ka piiritagused suusamaratonid Poolast kuni Ameerikani, kaasategijaks ikka abikaasa Reine. Nagu Mati isegi on öelnud, et talle meeldivad eriti maastikul kulgevad 10–15 km jooksud ja talvised suusamaratonid. Võistlustel osalemise motoks on ta võtnud oma hea sõbra Karl Oissari sõnad: "*Olla finišis parema enesetunde ja positiivsemate emotsioonidega kui stardis*". M. Koppel on ka fanaatiline "reisisell", kes töötab põhjalikult enne reisi läbi kogu marsruudi, et saada sellest tõelist naudingut ja ikka koos abikaasaga.

Mati on olnud väga hea isa oma viiele lapsele ja vanaisa kahele lapselapsele.

Jäägu lõpetuseks ETKI asedirektori Pille Ardeli iseloomustus tema kohta: "*Mati Koppel on alati koostööks aldis nii teadurite kui põllumeestega ja ta ei põlga ära ühtegi koostööettepanekut. Pigem jääb asi meie oma aja ja töötajate vähesuse taha. M. Koppel tahab alati ise kaasa lüüa igas praktilises töös ja olla kõigega kursis, samas annab ta võimaluse meil oma töös iseseisvalt teha ja olla selle juures loominguline"*.

Praegu töötab M. Koppel Eesti Maaülikooli Põllumajandus- ja keskkonnainstituudis taimetervise õppetooli vanemteadurina. Jätkugu juubilaril veel kauaks energiat teaduspõllul tegutsemiseks ja kordaminekuid kõigis ettevõtmistes.

Aide Tsahkna

VIRVE KARIS – *in memoriam*

08.03.1929–†06.06.2020

Igavikuteele on lahkunud teenekas põllumajandusloomade söötmise eriteadlane Virve Karis. Ta sündis 08.03.1929 Tatumaal Laiuse-Tähtvere vallas teenistujate perekonnas. Kooliteed alustas Virve Lilastvere algkoolis, kuid perekonna elukoha vahetuse tõttu lõpetas 1942. aastal Võrumaal asuva Loosi algkooli. Sõja-aastad jätsid jälje nii perekonna kannatustele kui Virve haridusteele. Perekond otsustas punase terrori eest põgeneda Saksamaale, kuid sellel ajal kehtiv Ida ja Lääne vaheline piir osutus ületamatuks ja perekond otsustas Eestisse tagasi pöörduda. Õnneks kõik see ei saanud Virve haridusteele takistuseks. 1946. aasta sügisel astus Virve Väimela Põllumajandustehnikumi ja selle eduka lõpetamise järel 1949. aastal Tartu Riikliku Ülikooli põllumajandusteaduskonda. Alates 1951-st aastast, mil loodi Eesti Põllumajanduse Akadeemia, jätkas Virve õpinguid agronoomia teaduskonnas. Selle lõpetamise järel suunati ta 1954. aastal tööle Märjamaa rajooni Sipa masina-traktorijaama. Noore õpetatud agronoomi karjäär masina-traktorijaamas jäi siiski lühikeseks. Kuna abikaasa oli vastu võetud Eesti Põllumajanduse Akadeemia aspirantuuri anti ka Virvele luba Tartusse naasta. Alates 1955-st aastast sai ja jäi Teaduste Akadeemia alluvuses olev Loomakasvatuse ja Veterinaaria Teaduliku Uurimise Instituut ja kõik selle asutuse järeltulijad Virve Karile asutuseks, millega ta jäi seotus viiekümneks aastaks. Alustades laborandina jõudis ta karjääriredelil vanemteaduri ja söötmise sektori juhatajani. 1967. aastal kaitses Virve teaduste kandidaadi kraadi sellel ajal väga aktuaalsel teemal "Hübriidkaalika ja poolsuhkrupeedi efektiivsus piima tootmisel".

Nõutud põllumajandusloomade söötmise eriteadlasena kutsuti Virve Karis 1972. aastal ENSV Varumisministeeriumi alluvuses oleva ja Eesti Põllumajanduse Akadeemia söötmise kateedri juures tegutseva Vabariikliku Jõusööda Kesklaboratooriumi juhatajaks. See polnud siiski asutus, mis tegeles vaid söötade analüüsi, tulemuste interpreteerimise ja söötmise soovituste andmisega, see oli ka noorteadlaste kasvulava. Hästi varustatud laboratoorium ja piisavad rahalised võimalused lubasid kaasata hulgaliselt noori, kes põhitöö kõrvalt läbisid söötmise kateedri juures oleva aspirantuuri ja kellest paljud kaitsesid hiljem teaduskraadid. Nii sai Virve Karisest mitme noore kaasjuhendaja, kes oma laialdaste teadmistega teadusse pürgijatele akadeemilisi teadmisi jagas. Kõik tema käe all kasvanud noored meenutavad austusega Virve teadmiste jagamise oskust. Pöördudes Virve poole mõne teoreetilise küsimusega tõi ta sulle esmalt mitu viidetega tähistatud raamatut ja alles siis, kui olid need ise läbi uurinud, kontrollis diskussiooni käigus probleemist aru saamist. Kuigi aspirantidele oli teaduslikuks juhendajaks prof Ü. Oll, saavad paljud nendest pidada Virvet oma akadeemiliseks emaks.

Laboratooriumi juhataja kohustustega kaasas käiv bürokraatia ja aruandlus Virve Karist ei rahuldanud, samuti soov sügavuti edasi tegelda söötmisalase teadusega viis ta peagi tagasi Loomakasvatuse ja Veterinaaria Teadusliku Uurimise Instituuti. Uurimisteemade ring, millega ta instituudis tegeles oli lai. Nii uuris ta mittevalguliste lämmastikühendite söötmise võimalusi lüpsilehmadele proteiinidefitsiidi leevendamiseks, söötmisvõtete abil piima rasvasisalduse suurendamise võimalusi, rapsiõli söötmise mõju lehmade ainevahetusele ja või kvaliteedile jne. Virve oli aktiivselt seotud Piistaojal toimunud eesti mustakirju tõugu lehmade maksimaalse piimajõudlusvõime selgitamiseks sobilike ratsioonide ja söötmisviisi väljaselgitamisega. Viimaseks suuremaks tööks jäi Virvele osalemine töögrupis, kus töötati välja Eestis kasutusel olev metaboliseeruval proteiinil põhinev söötade hindamise süsteem. Virve Karise sulest on ilmunud üle 100 teadustöö ja artikli.

Virve Karis oli suur loodusesõber. Piusa jõe kaldale, maalilisse ürgorgu rajatud suvekodus veetis ta oma suved, tihti metsaradadel rännates, marju ja seeni korjates, loodust imetledes ja iseolemist nautides. Kõike seda, ürgse looduse keskel olemist, pakkus Virve ka oma sõpradele ja kolleegidele, kes selle küllalt kauge ja eksootilise reisi ette võtsid.

Kõikidele kolleegidele jääb alatiseks meelde eelkõige Virve inimlikkus, sõbralikkus ja abivalmidus. Oma mured ja raskused elas Virve läbi endas, toomata neid kolleegide ette. Virvel oli põhjust uhkust tunda oma poja pere ja lastelaste üle, jäädes ka seejuures alati tagasihoidlikuks oma emotsioonide väljendamisel töökollektiivis. Täname sind kallis Virve ühiste tegusate aastate eest meie seltsis. Helge mälestus sinust elab meis edasi.

Kolleegide ja õpilaste nimel
Olav Kärt.

KOIDU KELT – *in memoriam*

15.01.1932–†18.04.2020

18.aprillil 2020 lahkus meie hulgast Koidu Kelt, bioloog-taimefüsioloog, Polli aiandusuuringute keskuse keemialabori pikaaegne eestvedaja ja teadur, uurimisasutuse raudvara puuviljade ja marjade keemilise koostise määramisel ja toitainete sisalduse uurimisel.

Koidu Kelt (endise nimega Sõgel) sündis 15. jaanuaril 1932. aastal Kabala vallas Järvamaal.

Ta oli kolmelapselise pere noorim laps. Koidu meenutas lapsepõlvest, ta õppis õe kõrvalt varakult lugema ja ootas pikisilmi kooliaega. 1939. aastal astus ta Kabala algkooli, mille lõpetas kiitusega. Seejärel õppis ta Viljandi tütarlaste gümnaasiumis, mille lõpetas 1949. aastal ning õppis veel ühe aasta Viljandi gümnaasiumis. Peale gümnaasiumi lõpetamist 1950. aastal astus ta Tartu riiklikku ülikooli matemaatika- ja loodusteaduskonna bioloogia osakonda, mille lõpetas 1955. a bioloog-taimefüsioloogina. Lõputöö teema oli: "Lämmastikusisalduse uurimine sootaimedes". Talle meeldisid laboratoorsed uuringud, töötamine valges kitlis. Peale Ülikooli lõpetamist suunati Koidu Kelt Vana-Võidu loomakasvatustehnikumi keemia õpetajaks, kus ta töötas kaks aastat 1955–1957. Peatselt kutsuti teda Polli puuviljandusteaduse keemialaborisse tööle, kus ta sihikindlalt töötas teaduri ja vanemteadurina aastatel 1957–2005. Bioloogia-kandidaadi väitekirja kaitses Koidu Kelt 1968. a teemal: "Õunapuu erinevate pookekomponentide biokeemilisi ja anatoomilis-füsioloogilisi uurimisi Eesti NSV-s."

Töö Polli aiandusuuringute keskuses oli väga mahukas ja mitmekesine. Ta tegeles aastaid Polli teadusasutuse tutvustamisega, eksponaatide valimise, üles panemise ning näitustega Tallinnas, Viljandis ja ka Pollis igal sügisel. Polli keemialaboris analüüsis ta Polli aedades kasvavaid sorte, seemikuid ja ka rahvaselektsiooni aeda kogutud materjali vilju, selgitamaks neist parimaid. Kokku on ta analüüsinud üle 1200 sordi vilju, usaldusväärsete andmete saamiseks iga sorti veel mitmeid aastaid, määrates olulisemad puuviljades ja marjades sisalduvad toitained. Lisaks uuris Koidu Kelt mõnede õuna-, pirni-, ploomi- maasika- ja musta sõstra toitainete akumulatsiooni ja lokalisatsiooni ning ilmastiku mõju sellele.

Koidu Kelt on palju esinenud ettekannetega loengutel puuviljade ja marjade toitainete sisaldusest ja nende kasulikkusest inimeste tervisele. Ta on avaldanud üle 50 erialaartikli.

Koidu Kelt on raamatu "Puuviljad, marjad, tervis" (1997) üks autoreid.

Koidu Kelt oli Karksi-Nuia muinsuskaitse seltsi ja haridus- ja kultuuriseltsi ning Kitzbergi loodukaitse seltsi liige ja on osalenud arvukatel kokkutulekutel ja ekskursioonidel. Koidu toimetas Polli seinalehte "Inimene ja Loodus" kuhu ta põimis mälestused looduradadelt.

Koidu Kelt on harrastanud sporti, kuuludes Viljandi linna võrkpalli koondisesse, oli gümnaasiumi ajal maakonna meister. Hiljem harrastas ta lauatennist, milles omistati III järk. Suur huvi oli tal ka rahvatantsu vastu. Koidu tantsis TRÜ rahvakunstiansamblis ja teaduskonna segarühmas, hiljem Polli naisrühmas, Karksi naisrühmas "Kärtu" ja Nuia eakate rühmas "Kadri". Koidu juhendas ka Polli naisrühma "Ubin". Lisaks pakkus talle huvi võimlemine ja isetegevuslik näitlemine.

Inimesena oli Koidu väga abivalmis, sõbralik, usaldusväärne kaaslane ja hea diplomaat keerukate olukordade lahendamisel.

Koidul oli seltsiliseks alati karvane kass ja hulk raamatuid. Koidu Kelti aktiivset tegevust on tunnustatud mitmete aukirjade ja diplomitega.

Mälestame head kolleegi, õpetajat ja kohaliku kultuurielu edendajat.

EMÜ PKI Polli aiandusuuringute keskus

AGROKEEMIK-SPORDIFANAATIK, EMERIITPROFESSOR PAUL KULDKEPP – *in memoriam*

10.08.1934–†03.02.2020

3. veebruaril 2020. a läks manalateele armastatud õppejõud, emeriitprofessor, kahekordne EPMÜ teenetemedali omanik, kauaaegne APS-i aktiivne tegevliige, 1994. aastast APS-i teadustöö aastapreemia omanik ja 2009. a auliige Paul Kuldkepp.

Paul sündis 10. augustil 1934. a Viljandimaal Kabala vallas Jaan ja Liisa Kuldkepi peres teise lapsena. Rahulikku lapsepõlve jätkus tal vaid Teise maailmasõja alguseni, kui 1941. a augustis mõrvati Pauli isa kohalike abipolitseinike poolt. Sealt edasi kulus Paulil kasuisa juures tehtavate raskete talutööde tegemisele kogu vaba aeg. Alghariduse sai Paul tänu kasuisale Kabala Mittetäielikus Keskkoolis. Spordipisik nakatas teda juba Kabala kooli päevil ja tema elu suureks unistuseks oli minna Tallinnasse kehakultuuri õppima. Venna õnnetu surm lõi plaanid sassi ja Paulil tuli minna Olustveresse põllumajandust õppima, sest kasuisa lootis temast teha haritud talutööde jätkaja. Olustveres sai ta spordiga tõsisemalt tegelema hakata. Paul lõpetas Olustvere Põllumajandustehnikumi 1954. a kiitusega ning kuulus selle 5% lõpetajate hulka, kes võisid kohe õpinguid jätkata Eesti Põllumajanduse Akadeemias. Pärast EPA Agronoomiateaduskonna *cum laude* lõpetamist 1959. a asus ta tööle Sootaga sovhoosis esmalt brigadirina, edasi osakonna juhatajana (olles samal ajal kohakaasluse korras Lähte keskkooli tootmisõpetuse õpetajaks ning maadlustreeneriks). 1961. a määrati Paul Nõgiaru sovhoosi direktoriks, kus ta töötas 1964. a-ni professor Osvald Halliku poolt aspirantuuri kutsumiseni. Aastatel 1964–1967 õppis ta EPA statsionaarses aspirantuuris agrokeemia erialal ja 1969. a on ta põllumajanduskandidaat.

Paul Kuldkepi kandidaadi väitekiri käsitles tolmjate lubiväetiste kasutamise võimalusi karbonaatsel moreenil väljakujunenud muldadel. Hiljem on ta uurinud Kagu-Eesti kuppelmaastiku muldade viljakuse tõstmise võimalusi, kompleksväetiste kasutamist, taimede kasvuaegset saagikuse diagnoosimist, orgaaniliste väetiste mõju mullaviljakusele pikaajalistes põldkatsetes ning põlevkivi poolkoksist valmistatud kompostide kasutamist põllumajanduses ja aianduses.

Paul Kuldkepp töötas EPA-s (EPMÜ-s, EMÜ-s) õppejõuna aastatel 1966–2003 assistendist kuni professorini. Nelja aastakümne jooksul jagas ta ligi 4000 tudengile agrokeemia-alaseid teadmisi. Hiljem töötas ta kuni 2008. aastani lepinguliste tööde vanemteadurina sest üle 65 aastastel ei lubatud sel ajal enam õppetööd teha. Viljaka õppe- ja teadustöö tulemusena on ta kirjutanud ligi 190 teaduspublikatsiooni, olnud mitmete raamatute kaasautoriks, kirjutanud üle 30 õppevahendi, juhendanud 100 üliõpilase diplomi-, magistri- ja doktoritöö valmimist ning aidanud mitmeid doktoridissertatsioone vormistada. Ta on pidanud rohkesti loenguid tegevpõllumeestele erialastel koolitustel.

Kuigi Paul pidas esmatähtsaks tööalaseid kohustusi, on tema spordisaavutused kadestamisväärsed – ligi paarikümne erineva spordiala võistlustelt on ta koju toonud üle 440 auhinnalise koha. Rahvusvahelistel võistlustel kaitses ta maadluse meeskondades Eestit 16 aasta jooksul 52 korral spordiühingute Kalev ja Jõud koosseisus. Tartut ja EPA-t on ta palju kordi esindanud kõige kõrgemal tasemel. Maadlusmatil tuli tal rinda pista mitme olümpiavõitja, maailma-, Euroopa ja NSV Liidu meistriga, millest mitmel korral tuli välja võitjana. Oma viimase ametliku maadlusmatši pidas ta 48 aastasena. Pauli spordisaavutusi kokku lugedes on ta aumeistersportlane Kreeka-Rooma maadluses, meistersportlane vabamaadluses, meistersportlase kandidaat VTK mitmevõistluses, I spordijärk jalgrattaspordis, murdmaa suusatamises ja motokrossis. Paul on saanud Tartu suusamaratonist osavõtja hõbe- ja kuldmärgi ning korduvalt võttis ta osa Tartu rattarallist. Pidevalt koos noortega, oli Paul suureks autoriteediks-eeskujuks, innustajaks ja toetajaks mitmele põlvkonnale sportlastele. Lisaks võistlusspordile on ta olnud kogu elu ka spordiorganisaatoriks. Ta oli ühiskondlikult aktiivne, kuuludes Tartu Linna Maadlussektsiooni, Eesti Maadlusveteranide Ühenduse ja Eesti Spordiajaloo Seltsi juhatusse, oli spordiorganisaatoriks koolides ja EPA-s. Paul Kuldkepp kuulus suurte traditsioonide nagu Georg Hackenschmidti ja Jaan Jaago mälestusvõistluste algatamise initsiatiivgruppi.

Oma sportliku entusiasmi tõi ta kaasa agronoomiateaduskonna tegevustesse, õppetöösse ja teadmiste-oskuste kontrolli. Aastatel 1972–1981 oli Paul EPA agronoomiateaduskonna dekaaniks, tema algatas mitmeid tudengielu rikastavaid ettevõtmisi nagu Eerika Mängud, tudengite suusamaratonid, Noorte Põllumeeste Klubi ja väga populaarseks saanud Vabariiklikud Agronoomide Kutsealavõistlused.

Ta oli üheks esimeseks EPA õppejõuks-teadlaseks, kes hakkas arendama rahvusvahelist koostööd, rajades 1989. a IOSDV (International Organische-Stickstoff Dauerversuche) püsikatse, mis on elujõus tänaseni. Kahel korral, aastatel 1995 ja 2005 organiseeris ta IOSDV rahvusvahelise suvekonverentsi Tartus koos mitmepäevase Eestimaa muldi tutvustava ekskursiooniga, sealjuures 1995. a suvekonverentsiks ilmus ka artiklite kogumik. 1995. aastast on ta professor, 1999. ja 2001. a tunnustati tema tööd EPMÜ teenetemedaliga ja 2001. aastast sai temast emeriitprofessor.

Paul on üles kasvatanud agronoomiharidusega tütre ja kolm poega. 2008. aastast elas ta koos abikaasa Maiega Võrtsjärve-äärses Nõmmeotsa talus, kus nad tegid oma kätega suuri ümberkorraldusi – tiik, saun, kaev, garaaž, spordiväljak, metsarada jms. Alati olid seal teretulnud tema endised õpilased, sõbrad ja kolleegid. Igal sügisel võõrustas Paul seal IOSDV uurimisgruppi.

Paul Kuldkepp puhkab oma viimses puhkepaigas Suure-Jaani kalmistul. Olgu muld Sulle kerge, suurepärane õpetaja, juhendaja, kolleeg, mõttekaaslane ja sõber.

Eesti Mullateaduse Seltsi ja EMÜ mullateaduse õppetooli nimel
Pauli esimene diplomand Enn Leedu ja Alar Astover

25 AASTAT LOOMAKASVATUSTEADLASE, PÕLLUMAJANDUSDOKTOR PROF KARL-ROBERT KURMI LAHKUMISEST

Karl-Robert Kurm (15.02. 1926–26.05.1995) lõpetas TRÜ põllumajandusteaduskonna õpetatud agronoomina 1949. aastal ja töötas ka sealses loomakasvatuse kateedris. Eesti Põllumajanduse Akadeemia loomisel tuli ta tööle EPA põllumajandusloomade söötmise kateedrisse, siis sai temast põllumajandusloomade aretuse kateedri vanemõpetaja, dotsent, professor. 1979. aastast, kui veisekasvatuse õppeaine viidi eriloomakasvatuse kateedri vastutusalasse, töötas prof K.-R. Kurm eriloomakasvatuse kateedris.

K.-R. Kurm oli EPA kaugõppeteaduskonna esimene dekaan (1955–1960). Aastatel 1961–1965 ja 1971–1974 oli ta Zootehnikateaduskonna dekaan. 1974. aastal omistati talle Eesti NSV teenelise teadlase nimetus.

K.-R. Kurm õpetas peamiselt veisekasvatust ning piima- ja veiseliha tootmise tehnoloogiat. Ta on avaldanud töid veiste aretuse, noorveiste kasvu ja arengu ning piima ja veiseliha tootmise tehnoloogia alal.

Kandidaadidissertatsiooni kaitses ta EPA Teaduslikus Nõukogus 1955. aastal teemal "Veiste paaritusaegse vanuse mõju järglaste omadustele ja selle tähtsus paaridevalikul". Doktoridissertatsiooni kaitses K.-R. Kurm Eesti NSV Teaduste Akadeemia 1970. aasta otsusega Keemia, Geoloogia ja Bioloogiateaduste Osakonna juurde loodud Põllumajandusteaduste Nõukogu ees 1971. aastal teemal "Veisetõugude täiustamise metoodikast Eesti NSV-s". Ta oli esimene loomakasvatusalase dissertatsiooni kaitsja selles nõukogus Eestis.

K.-R. Kurm on kõrgkooliõpiku "Veisekasvatus" (1970, 1981) autor ja mitme loomakasvatusalase õpiku ja käsiraamatu autor.

Ühe teemana uuris K.-R. Kurm eesti punast tõugu veiste lihajõudluse suurendamise võimalusi lihatõugu pullidega (aberdiini anguse, herefordi) ristamise teel. Uuringud näitasid, et niisugune ristamine ei suurenda järglaste massi-iivet, küll aga parandab tunduvalt liha kvaliteeti.

Juba 1960-ndatel aastatel rääkis ta loengus, et lehm peab olema suur; kaaluma 1000 kg ja sellised lehmad annavad kunagi 10 000 kg piima aastas. Ei tea, kust selline optimism, sest tol ajal oli Eestis lehma piimatoodang kõikides majandikategooriates keskmiselt 2639 kg.

1970-ndatel aastatel pidid üliõpilased veisekasvatuse praktikal olles kronometreerima lehmade lüpsikiirust sh udaraveerandikes, ja tühilüpsi. Praktikajuhendajana nägin, kuidas Kamara sovhoosis praktikal olevad üliõpilased-praktikandid istusid elutoas laua taga ja n.ö lakke vaadates täitsid prof Kurmi poolt etteantud tabeleid lüpsikiiruste kohta... Õnneks ei teadnud (?) selliseid andmete kogumisi mitmed teisedki õppejõud, kes kasutasid andmete kogumisel üliõpilaste n.ö abi.

Tegus, aktiivne ja hea suhtleja, samas nõudlik, kindlameelne ja soliidne – sellisena me teda mäletame.

Paljude asjaolude kokkulangemisel ja üliõpilaste tagasiside tõttu pidi prof K.-R. Kurm loobuma tööst õppejõuna 1992. aastal. Kolme aasta pärast lahkus ta igaveseks.

Matusepäeval, 1995. aastal maikuus astus enamus Zootehnikateaduskonna õppejõududest lennukile, et sõita TEMPUS projekti raames Walesi Ülikooli Suurbritannias, ja prof K.-R. Kurmi matustel osaleda ei saanud.

Olen tänulik prof K.-R. Kurmile, kes teaduskonna dekaanina tegi mulle 1973. aastal ettepaneku astuda sihtaspirantuuri Moskva Veterinaaria Akadeemiasse (1974), mille ka vastu võtsin.

Anne Lüpsik,
endine üliõpilane ja hilisem kolleeg.
Aprill 2020

LOIT REINTAM – 90

12. novembril aga ka 5. detsembril 2019. a toimunud mullapäeval tähistas EMÜ mullateaduse õppetool koos Eesti Mullateaduse Seltsiga mullateadlase bioloogiadoktori, ETA akadeemik Loit Reintami 90. sünniaastapäeva.

Loit sündis Tallinnas koolija kirjamehe ning talupidaja Juliuse ning Hermine peres esimese lapsena. Lapsepõlveaastad möödusid tal Tallinnas ja isakodus Mälivere talus Harjumaal Kernu vallas. Pärast Tallinna Nõmme Gümnaasiumi lõpetamist 1949. a astus ta TRÜ põllumajandusteaduskonda. 1951. a jätkusid õpingud vastloodud EPA agronoomiateaduskonnas, mille ta lõpetas 1954. a kiitusega. Aastatel 1954–1957 oli Loit EPA aspirant mullateaduse erialal. Aspirantuuri jooksul valmis L. Reintami ettevõtmisel Kagu-Eesti mullastiku kaart, kus olid välja toodud peale muldade omaduste ka nende pindalad, seosed reljeefi ja lähtekivimiga ning kergesti omastatava fosfori sisaldus sealsetes põllumuldades. Selle mahuka tööga tegi ta algust Eesti jaotamisel agromullastikulisteks mikrorajoonideks. 1960. a kaitses Loit kandidaadi kraadi muldade geneesi ja geograafia alal ning 1973. a doktorikraadi Novosibirskis NSVL TA Siberi osakonnas muldade geneesi ja klassifikatsiooni alal. Üle 50 aasta Loidi elust möödus aktiivse, sisutiheda ning viljaka teadusliku, pedagoogilise, administratiivse ja ühiskondliku tegevusega. 1977. a omistati talle professori kutse. Aastatel 1953–1999 oli ta Eesti Põllumajanduse Akadeemia ning selle järeltulija EPMÜ agronoomiateaduskonna mullateaduse ja agrokeemia kateedris tööl laborandist kuni professorikateedrijuhatajani. Loit oli aastatel 1958–1993 ka TRÜ-s õppejõud ja aastatel 1986–1992 Juhtimise Kõrgemas Koolis mullateaduse professoriks. Ta on õpetanud üldist agronoomilist ja metsamullateadust, muldade kaardistamist ja hindamist, erimullateadust, ökoloogiat, loodus- ja keskkonnakaitset. Loidi initsiatiivil avati 1965. a agronoomiateaduskonna koosseisus mullateaduse eriharu spetsiaalselt RPI Eesti Põllumajandusprojektile spetsialistide ettevalmistamiseks.

Aastatel 1963–1966 oli Loit agronoomiateaduskonna dekaaniks, 1965–1992 mullateaduse ja agrokeemia kateedri juhatajaks. Reorganiseerimise perioodil oli ta 1992–1994 ökoloogia ja agrokeemia õppetooli juhatajaks. Ta juhendas üliõpilasi, aspirante, ja doktorante lisaks Eestile ka Moskvast, Peterburist, Harkovist, Wageningenist ja mujalt. Õppejõu staaži tuli tal kokku 100 semestrit.

Loidi peamised uurimisvaldkonnad olid Eesti ja Euraasia mitme piirkonna (Kaug-Ida, Lääne- ja Ida-Siberi, Kesk-Vene kõrgustiku) muldade genees, ökoloogia, geograafia, klassifikatsioon ja kaardistamine, mineraalne, keemiline ja granulomeetriline koostis, huumus ja selle koostis, taim-muld süsteemide talitlused, mullateaduse ajalugu ning kõige selle õpetamine. Mullauurimise eesmärgil viibis ja töötas ta enam kui 30 riigis.

Loit Reintami organisaatoritööd on võimatu üle hinnata – aastatel 1963–1966 oli ta agronoomiateaduskonna dekaaniks, 1964. a III üleliidulise mullateadlaste kongressi peakorraldajaks Tartus, lisaks mitmete konverentside korraldamine, kraadiõppuritega püsiuurimisalade võrgu rajamine, uue Eesti muldade klassifikatsiooni väljatöötamine, mullamuuseumi rajamine, 50 aasta jooksul õppevahendina kasutusel olnud originaalse mullateaduse õpiku väljaandmise toimetamine, perioodiliste mullateaduse alaste teadustööde kogumike publitseerimine ja mullateaduse kateedri uue maja ehituse organiseerimine Eerikale.

Loit oli osalejaks-esinejaks-organiseerijaks ligi 350 teaduskonverentsil lisaks Eestile ja endisele NSV Liidule ka paljudes teistes riikides üle maailma. Teadlasena esindas Loit biopedoloogilise taim-muld süsteemide geneesi ja ökoloogia uurimissuunaga koolkonda. Trükis jõudis ta ilmutada ca 600 kirjatööd ja toimetada ligi 50 kogumikku, teaduse populariseerimise esinemisi oli tal üle 2000 ja oponendi-eksperdi hinnanguid andis ca 700 doktori- ja kandidaadiväitekirjale.

Loit oli perioođiti arvukate nõukogude, organisatsioonide ja ekspertkomisjonide liikmeks ja esimeheks (Eesti Teadusfondi nõukogu, EV haridus- ja teadusministeeriumi teadukompetentsi nõukogu, Rahvusvahelise Mullateadlaste Liidu nõukogu, Euroopa Mullakaitse Seltsi nõukogu), oli Ülemaailmse Mullateadlaste Seltsi asepresidendiks, mitmete doktoritööde kaitsmise nõukogude liige ja esimees, rahvusvaheliselt tunnustatud teadusajakirjade toimetuskolleegiumi liige, Maailma mullaressursside ja klassifikatsiooni komitee liige.

Loit Reintami on autasustatud NSVL Rahvamajandussaavutuste Näituse medali, V.V. Dokutšajevi, K.E. v Baeri, ETA ja EMÜ medaliga, Valgetähe III klassi teenetemärgi, ATK Kuldse Viljapea, Accademia dei Georgofili juubelimedaliga, E. Kumari nimelise loodushoiu preemia ja paljude ministeeriumide aukirjadega. 1989. a valiti Loit Reintam Eesti teeneliseks teadlaseks, 1990. a ETA akadeemikuks mullateaduse erialal, 2000. a Vene Teaduste Akadeemia V.V. Dokutšajevi nim Mullaseltsi auliikmeks ja 2005. a Gruusia Riikliku Põllumajandusülikooli audoktoriks.

1997. a sai Loit Reintamist EPMÜ (praeguse EMÜ) emeriitprofessor. Pärast emeriteerumist suutis Loit kogu muu tegevuse kõrvalt ideaalses korras hoida oma isakodu ja olla aktiivne tegevliige Kernu valla Maakomisjonis.

17. jaanuaril 2010. a lakkas tuksumast viljaka teadlase ja organisaatori Loit Reintami süda, ta puhkab Tallinnas Pärnamäe kalmistul.

Eesti Mullateaduse Seltsi ja EMÜ mullateaduse õppetooli nimel,
Enn Leedu