## CONTENTS

### MECHANIZATION IN AGRICULTURE

**Grinding Characteristics and Heat of Combustion of Sprouted Wheat**  
M.Sc. Waleed H. Hassoon, PhD, Prof. M.Sc. Dariusz Dzi .......................................................... 117

**Soil and Water Resources as Important Objects and Prerequisites for the Design of Agricultural Machines and the Formation of Professional Competencies of an Agricultural Engineer**  
Candidate of Technical Sciences, Associate Professor Viktor Pryshliak, Dr. in Agriculture, Prof., Corresponding Member of the National Academy of Agrarian Sciences of Ukraine Vasyl Kurylo ................................................................. 120

### CONSERVING OF THE RESOURCES

**Soil Moisture and Soil Density Variation During Plant Growing Season by Implementation of Mineral and Organic Fertilization**  
Prof. Dr Eng. Błaśzkiewicz Z., Dr Eng. Sztukowski P. .............................................................. 126

**Changes in Soil Properties Due to Application of Digestate**  

**Assisted Phytostabilization of a Heavy Metals Contaminated Soil Using Mineral Amendments and L. Perenne**  
Assoc. Prof. Dr. Maja Radziemska, Dr. Agnieszka Beż .......................................................... 132

**Biobased Adsorbent Prepared by Pyrolysis of a Renewable Agriculture Waste**  
Assoc. Prof. Dr. Eng. Uzunov I., Assoc. Prof. Dr. Vassileva P., Assoc. Prof. Dr. Eng. Uzunova S. 135

**Monitoring of Natural Waters Using Sorption Cartridges**  

**Nature-Based Solutions for Soil and Water Quality Protection – Experiences from the Nordic-Baltic Region**  
Dr. silv. Libiете Z., Mg. chem. Bārdule A., Dr. sc. ing. Lagzdinš A., Mg. sc. ing. Grinberga L., Dr. silv. Lazdiņā A., Mg. silv. Lupikis A., Dr. silv. Lazdiņa D. ........................................ 142

**The Influence of Bioorganic Preparations on Plant Productivity and Soil Quality**  
Dr. Brazienė Z., Dr. Paltanavičius V., Dr. Aleknavičienė A. ...................................................... 146

**Evaluation of Garden Pea Cultivars to Salt Stress Tolerance**  
Assoc. Prof. Grozeva S. PhD, Assoc. Prof. Kalapchieva S. PhD, Assoc. Prof. Tringovska I. PhD. ................................................................. 150

**Irrigation Regime for Long-fruit Cucumbers Grown Under Greenhouse Conditions**  
Assoc. Prof. PhD R. Kireva, Prof. PhD M. Mihov ........................................................................ 153
Abstract: Pre-harvest sprouting is the premature germination of cereal seeds so that the embryo starts growing while still on the head in the field. Grain germination before the harvest is a serious problem in many wheat-growing areas of the world. The grain and flour quality parameters impacted by pre-harvest sprouting are strongly related with climatic variables and soil water condition. This process especially occurs when wet conditions delay harvest. Sprouted seed is usually inadequate for flour productions. Products made of sprouted flour are generally unacceptable to producers and consumers. Moreover, it is also often inadequate as feed because microbiological contamination. However, it seems that such kind of waste grain can be utilized for energetic purposes. The aim of the present work was to study the grinding process of sprouted wheat. The heat of combustion of sprouted grain and sound grains was also determined. Three-day germinated kernels of three wheat varieties were used for investigation. After germination the wheat kernels were dried at 40°C by using an air dryer to obtain the same moisture as that of the grain before sprouting (14.0% w.b.). The sound kernels were used as a control sample. The sprouted and the sound samples of grain were ground by using the knife mill MG-200. The results showed that the spraying of wheat had a significant influence on the grinding process, both on the particle size distribution and grinding energy requirements. The spraying caused a decrease in the average particle size and value of specific grinding energy in all cultivars. The values of specific grinding energy ranged average from 21.6 kJ·kg⁻¹ to 23.6 for kJ·kg⁻¹ fore sprouted and sound kernels, respectively. The heat of combustion of sprouted grain was only slightly lower value of this parameter obtained for sound grain and ranged from 15.9 to 16.5 MJ/kg.

Keywords: WHEAT, SPROUTING, GRINDING, HEAT OF COMBUSTION, WASTE WHEAT.

1. Introduction

Wheat grain is a major global commodity. The Food and Agriculture Organization of United Nations (FAO) reported that the world wheat production in 2014 reached 729.5 million tons (FAO, 2015). In food applications, wheat is mostly ground into flour and used, among others, for bread, pasta and biscuits. Pre-harvest sprouting (PHS) is defined as the premature germination of wheat kernels in the spike under unfavorable environmental conditions (Groos et al 2002). PHS phenomenon is a well-known and worldwide problem, occurring once or twice every 10 years in some of the major wheat-producing areas throughout the world. In some regions of the world PHS might occur, at least locally, every year (Meredith & Pomeranz, 1985; Wahl & O’Rourke, 1994). The direct annual losses caused by PHS were estimated to reach up to 1 billion dollars a year (Wahl & O’Rourke, 1994).

The biochemical changes occurred during sprouting of wheat results in the production of several hydrolytic enzymes in the kernel, which decreases the technological quality of wheat and causes problems during processing of the flour into cereal-based products and less suitable for products for human consumption (Olaerts & Courtin, 2018). These changes adversely affect the baking quality of wheat (Lorenz and Valvano, 1981). On the other hand, some conditions (warm and humid) and nutritious media promote the growth of pathogenic microorganisms (Waje et al., 2009). In recent years, producing energy from biomass has increased, owing to depleting fossil energy supplies and climate change caused by carbon emissions. In the field of biomass-based bioenergy, mechanical size reduction plays a crucial part in supplying feedstock to bioenergy production (Sokhansanj et al., 2006; Hess et al., 2009). Report by SWD (Commission Staff Working Document, 2014) pointed out that the biomass is the biggest source of renewable energy in the EU and is expected to make a significant contribution to the 20% EU renewable energy target by 2020. In addition size reduction is an important energy intensive unit operation essential for bioenergy conversion process and densification to reduce transportation costs. Biomass size reduction process changes the particle size and shape, increases bulk density, improves flow-properties, increases porosity, and generates new surface area (Drzymala, 1993). The aim of the work was to study the grinding characteristic and heat of combustion of sprouted wheat in terms of using such a raw material for energetic purposes.

2. Materials and methods

The investigations were carried out on three wheat verities: Bamberka, Mulan and Ostroga. The initial moisture of grain was determined and the process of grain germination was performed in constricted conditions using climatic chamber (ICH 256 Memmert) according to described procedure (Gawlik-Dziki, et al., 2016). After three days of germination grain was dried at 40°C up to the moisture content 14% (w.b.). The samples (50 g) were milled used knife mill MG-200. The changes in the power consumption of the electric current during the grinding process were recorded using laboratory equipment including a grinding machine, transducer of power and a special data acquisition card connected to a PC computer and operated with special computer software. The detailed description of the laboratory mill has been provided by (Dziki et al 1997). The specific grinding energy (Er) was determined as the ratio of the grinding energy to the mass of the material taken for grinding. The sieving analysis was used to determine the particle size distribution of the pulverized material, by using a laboratory screen (Thyr 2, SASKIA, Germany), and separated into fractions using sieves of sizes, 0.800, 0.700, 0.600, 0.500, 0.400, 0.300, 0.200 and 0.100 mm. On the basis of the particle size distribution, the average particle size (d50) was calculated (Velu et al. 2006). The grinding ability index (Ei) was calculated as a ratio of the grinding energy to the surface area of the pulverized material. The surface area of the pulverized material and average particle size was evaluated.
according to the procedure described by Jha and Sharma (2010). The Sokolowski’s grinding index ($K_s$) was calculated on the basis of the size reduction theory described by Sokolowski (1996). Details of the procedure used in determining these indices can be found in Dziki (2011).

The heat of combustion of sound and sprouted wheat was conducted using the calorimeter pursuant (KL-10) to the applicable standard PN-EN ISO 9831:2005 according the methods described by Żabiński et al. (2012).

All tests were performed in four replicates. The results were statistically analyzed in the Statistica 10. One-way analysis of variance (ANOVA) was made with significance level. The homogenous groups were determined by Tukey’s test.

### 3. Results and discussion

The sieve analysis of ground material showed that amount of coarse particles (above 0.8 mm) for sound wheat varieties were always higher than for sprouted wheat. On the other hand, the reverse relation was found taking into account the mass fraction of fine particles. Ground sprouted grain was characterized by higher amount of small particles, especially below 0.2 mm (Table 1). The particle size of materials determines its specific surface area and influences its combustion rate (Wenjie et al., 2018).

**Table 1. Particle size distribution (%) of the ground wheat samples.**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>&gt;0.8</th>
<th>0.8-0.6</th>
<th>0.6-0.4</th>
<th>0.4-0.2</th>
<th>0.2-0.1</th>
<th>&lt;0.1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bamberka</td>
<td>84.32±2.86</td>
<td>6.21±0.34</td>
<td>7.63±0.61</td>
<td>9.33±0.33</td>
<td>11.23±0.63</td>
<td>1.86±0.13</td>
</tr>
<tr>
<td>Mulan</td>
<td>62.61±5.1</td>
<td>8.26±0.66</td>
<td>7.16±0.37</td>
<td>9.43±0.38</td>
<td>11.63±0.47</td>
<td>6.97±0.05</td>
</tr>
<tr>
<td>Ostroga</td>
<td>65.12±2.86</td>
<td>8.53±0.49</td>
<td>7.44±0.28</td>
<td>9.57±0.19</td>
<td>9.52±0.35</td>
<td>1.94±0.05</td>
</tr>
<tr>
<td>Bamberka</td>
<td>62.30±6.66</td>
<td>6.16±0.38</td>
<td>7.35±0.55</td>
<td>9.56±0.39</td>
<td>12.75±0.54</td>
<td>1.94±0.09</td>
</tr>
<tr>
<td>Mulan</td>
<td>59.11±2.31</td>
<td>8.54±0.34</td>
<td>7.83±0.30</td>
<td>10.22±0.37</td>
<td>12.83±0.60</td>
<td>1.37±0.08</td>
</tr>
<tr>
<td>Ostroga</td>
<td>62.42±2.73</td>
<td>8.71±0.52</td>
<td>7.93±0.45</td>
<td>8.21±0.62</td>
<td>11.12±0.26</td>
<td>1.64±0.11</td>
</tr>
</tbody>
</table>

Fig 1. presents the results of average particle size of ground wheat. The lowest value of this parameter was always found for sprouted wheat and was on average 0.73 mm. Whereas the highest values of this parameter were found for all sound wheat varieties (average 0.76 mm).

**Fig 1. Average particle size ($d_{50}$) of ground wheat.**

The specific grinding energy is one of the most frequently determined parameters characterizing the grinding process. The results showed that sprouting caused a decrease in specific grinding energy. These tendency was found for all tested wheat varieties. The average value of specific grinding energy ranged from 26.18 kJ/kg for sprouted wheat to 297 kJ/kg for sound wheat. This difference can be caused due to that biochemical changes during grain germination and weakness of grain structure.

**Fig 2. Specific grinding energy (Er) of sound and sprouted wheat.**

The results of grinding ability index of the sound wheat and sprouted wheat were shown in Fig. 3. The obtained data clearly revealed, that the grinding ability index was significantly higher for sound wheat and lower values of this index were always obtained for sprouted wheat. The values of this index ranged from 3.91 to 5.06 m$^2$kg$^{-1}$. Fig. 4. shows the results of Sokolowski’s grinding index. The values of this parameters changed ranged from 48.43 kJkg$^{-1}$mm$^{-1}$ to 60.09 kJkg$^{-1}$mm$^{-1}$. The lowest values of this index were always obtained for sprouted wheat.

The grinding ability index and Sokolowski’s grinding index are the very important indices for the evaluation the grinding energy requirements because this indices take into account the size of particles after grinding (Hassoon and Dziki 2017).

**Fig 3. Grinding ability index ($E_r$) of sound and sprouted wheat.**

**Fig 4. Sokolowski’s grinding index ($K_s$) for sound and sprouted grain.**

The data in Fig. 5 revealed that there is no significant influence on heat of combustion of sprouted grain and sound grains. The same tendency was found for all wheat varieties. The values of this parameter were ranged from 15.9 to 16.5 MJ/kg. Similar values the
heat of combustion for wheat grain were found by others authors (Zabiński et al., 2012).

Fig 5. Heat of combustion of sound and sprouted wheat.

4. Conclusion

The study showed that sprouted grain required less energy for size reduction in comparison with sound grain. Moreover sprouting caused a decrease in the average particle size, especially the mass fraction of coarse particles decreased and the mass fraction of fine particles increased. The heat of combustion of sprouted grain had a similar value that heat of combustion of sound grain. In summary, sprouted grain can be useful material for energetic purposes.

5. References

SOIL AND WATER RESOURCES AS IMPORTANT OBJECTS AND PREREQUISITES FOR THE DESIGN OF AGRICULTURAL MACHINES AND THE FORMATION OF PROFESSIONAL COMPETENCIES OF AN AGRICULTURAL ENGINEER

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Summary. The scientific, technical and pedagogical bases of studying issues of soil and water protection by future specialists in agro-engineering in higher education institutions are presented. Some concepts and categories that are used in the educational process for students to study agricultural land reclamation machinery and equipment are analyzed. Depending on the purpose, tasks, techniques of technological processes, the types of land reclamation measures are distinguished. The example of calculation of working bodies of earth-moving reclamation machines is given. According to the developed innovative studying technologies, students first study and analyze the state of agricultural production, identify the disadvantages of technological processes, the level of technical support, and then, using mathematical apparatus, methods of engineering calculations design and construct a reclamation machine. The methodological features of calculating the power balance of the earth-moving reclamation machine, which includes the power required to: isolate the material to be processed, taking into account its deformation, are theoretically described; the movement of the material being treated, that is, providing it with kinetic energy; lifting of the processed material; overcoming the friction resistance of the treated material against the surface of the working body and guide surfaces; overcoming the full resistance of the movement of the machine, taking into account the slope of the surface of the movement to the horizon; overcoming the propulsion of the propulsion; acceleration of the machine to the calculated speed of movement (overcoming the forces of inertia); drive conveyors and accessories. The developed procedure of laboratory and practical work includes the study of the methods and features of the calculation of balance capacity components of reclamation machines, taking into account such indicators as the type of soil, its density, thickness of layer, productivity, kinematics of the working body, the required lifting height, etc. The lecturer must draw up a general report on the theoretical and practical part of the laboratory and practical work in accordance with his task and protect it from the faculty of the department. The developed pedagogical technology of cross training emphasizes that soil and water resources are important objects and prerequisites for the development of agricultural machines and the formation of design competencies of agricultural engineers.

KEYWORDS: AGROENGINEERING, TECHNOLOGICAL PROCESS, TECHNOLOGY TRAINING, METHODOLOGY, SOIL, WATER RESOURCES, DESIGN, AGRICULTURAL MACHINERY, POWER, SOIL PROTECTION.

1. Introduction

Ukraine’s land and water resources are diverse. Features of their effective use in agro-industrial production, conservation and multiplication are studied by future specialists in agro-engineering during the whole period of studying: lectures, laboratory-practical classes, educational and industrial practices, course and diploma design. Land reclamation is the science of ways and methods of improving land in order to increase their fertility and create the optimal regime for the growth and development of agricultural plants [1]. One of the main reasons for the lack of development of the reclamation complex in Ukraine is the lack of highly qualified agricultural engineers. In this regard, it is necessary to carry out special pedagogical and technical research aimed at developing methodological support of the educational process, improving its quality, development of professional competencies [2] of agricultural engineers. Developed pedagogical technology should provide for the throughput of the educational process in the study of soil and water resources, their protection and conservation [3, 4].

2. Prerequisites and means for solving the problem

Modern pedagogical technologies for the preparation of future agro-engineers involve studying the problematic issues of soil and water protection. As stated in [4], students study these topical issues systematically and consistently throughout the study period. At lectures, students receive information about the general theoretical features of the use of soil and water resources in agro-industrial production, and in practical and laboratory classes they investigate the mechanical and technological properties of soils, the interaction with them of working bodies of agricultural machines.

In the project activity of students, during the implementation of course and diploma projects for the initial parameters during the design of soil-cultivation equipment take agrochemical, mechanical-technological and other characteristics of soil. Agrochemical properties of soils that students study are the content of humus, nitrogen, phosphorus, potassium, soil acidity. Physico-mechanical properties of soils, which are determined during laboratory work or used in the design activity, are the soil mass, angles of internal and external friction, particle size, maximum bearing capacity, modulus of elasticity, humidity, etc. [5]. The purpose of laboratory and practical work is to broaden and deepen the students’ knowledge of the basics of theory, calculation and design of agricultural machines, development of visual ideas on the basic theoretical provisions of the course on the interaction of working bodies of machines with soil, irrigation systems of land irrigation and more. The purpose of course work on agricultural machines is the technological development of the design of the machine or its components or the improvement of existing means of mechanization [6]. Future agricultural engineers should have a general understanding of erosion processes and prevent them from occurring. For example, soil erosion is the separation and movement of the upper most fertile soil layers from one place to another under the influence of water or wind. The process of water erosion consists of three steps: 1) separation of soil particles; 2) soil transfer – movement of soil particles from the site of erosion; 3) deposition of soil particles in a new place. Water erosion is appearing mostly when the effect of rain is exacerbated by the action of water flows: rain drops are separated by soil particles, and their flows are swept away [6].

Many scientific conferences have addressed the issue of soil and water protection. For example, at the II International Scientific Conference “Protection of Soils and Water Resources”, the report was presented – «The main components of studies and research of conserving soils and water in technologies of agroengineers training” [8]. This report partially discloses the scientific and methodological bases for soil and water exploration by future specialists in agroengineering in higher education institutions. Innovative pedagogical technology of development of project activity is developed in the form of a method of a consistent cross study of the material based on the objective relationship of disciplines and provides a qualitatively higher level of formation of professional competencies of agroengineers on the basis of preservation and even multiplication of natural resources. The report of [8] states that the current issues of soil science are devoted to many works by well-known scholars, for example, P. Zaika [9], M. Mangioglu [10], R. Meissner [11] and others. A particularly important scientific and production problem is the optimization of
the nutrient and water regimes of the soil on the slopes. A number of scientific works are devoted to the features of soil preparation for sowing crops on sloping lands, optimization and management of technological processes in these conditions [1, 7, 9, 12, 13].

The role of science in the educational process is growing significantly. Classical, practically oriented, as well as the most modern developments of scientists in the form of didactic materials are covered in textbooks, manuals, methodological developments and are used in the educational process of agricultural engineering. It is worth to mention that due to the considerable scientific contribution of scientists, agroengineering pedagogical science and educational practice have great achievements. Significant contribution to the development of the theory and methods of vocational education were done by I. Bendera [14], V. Duganets [15], V. Man`ko [16] and other.

These accents of scientific problems are prerequisites for solving urgent problems of soil and water conservation in pedagogical technologies for the formation of professional competencies of future agricultural engineers in higher educational institutions.

3. Results and discussion

Soil is the basic means of agricultural production. Samples are taken for soil analysis. From the conducted analyzes it is possible to obtain information on: the structure of the soil and the shape of its solids; soil type, density, humidity, crushing coefficients, etc. To a certain extent, this helps to find the optimal technology of tillage and restoration of soil and the necessary equipment for carrying out technological operations. Type, soil structure, its porosity play a decisive role in plant development and crop productivity. With the optimal soil condition, fertilizer efficiency is high. For experienced farmers, along with laboratory chemical analyzes, visual assessment of soil condition is of great importance. In the study of the soil, it is necessary to pay attention to many indicators, including even the plow sole, the depth of its occurrence, how the residual residues in the soil were placed evenly, whether a layer of residues was created at the bottom of the plow layer.

Students know that plowing is done with the purpose of deep loosening of the soil, earning organic and mineral fertilizers, crop residues and weeds, creating conditions for improvement of the water-air and nutritional regimes of the soil and qualitative carrying out of the following field works. Thus, deep plowing is carried out 21-25 days after the last harrowing or application of herbicides. To ensure good plowing and reduce energy costs, for example, it is advisable to use reversible plows under sugar beets. In the presence of a large number of plant residues, it is better to plow the PIA-3-35 tiered plows. This layer-by-layer cultivation ensures maximum development of roots per unit area of land. It is advisable to use reversible plows under sugar beets. In the presence of a large number of plant residues, it is better to plow the PIA-3-35 tiered plows. This layer-by-layer cultivation ensures maximum development of roots per unit area of land.

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The students are then introduced to the theoretical part of the work. Here are some steps for example.

An indicator of soil resistance to bending is the average soil hardness. Soil hardness is measured with hardness gauge. When inserting a hard tip into the soil, a diagram is drawn (Fig. 2).

There are several phases in the diagram. During the first phase (section OA), the deformation resistance increases in proportion to the depth of the tip into the ground. The second phase of AB is transitional. During this period, the cone-shaped growth from a strongly compacted soil (compacted core) is formed in front of the base of the tip. In the third phase (section of the BC), the soil is deformed by a conical outgrowth that spreads it, shifting to the sides and encountering constant resistance (ground "flowing"). The first phase is several times shorter than the third, but it is of great practical importance, since the deformation of the soil by agricultural machinery does not usually extend beyond the first section of the diagram. Only after passing the tip of the plow layer, the CD curve rises upward as a denser "plow sole" is encountered along its path.

After getting acquainted with the order of work, students perform it, draw up a report and protect [17, 18].

After studying the mechanical and technological properties of the soil, students make engineering, technological and energy calculations. As an example, we will partly consider the laboratory-practical work "Calculation of the working parameters of earth-moving reclamation machines", performed by students of specialty 208 "Agroengineering", during the study of machinery and equipment in agricultural land reclamation [1]. Purpose is to study the general methods of calculating the basic parameters of the working bodies of reclamation machines, the calculation of the balance of power; traction calculation; basics of dynamic calculation; determination of external forces and reactions acting on the machine in working order; static calculation; determination of
productivity of reclamation machines with working bodies of different types.

Consider the features of calculating the power balance of reclamation machines.

Power balance is calculated at maximum workload.

The drive power of any reclamation machine with a single-engine drive \( N' \) is determined by the formula, kW [1]:
\[
N' = \left( \frac{N_{accl} + N_{ad} + N_{k}}{\eta_{a}} + \frac{N_{in} + N_{int} + N_{accl}}{\eta_{a}} \right) \frac{N_{in} + N_{int}}{\eta_{a}^{2}}
\]
(1)
where \( N_k \) – the power required to separate the workpiece, taking into account its deformation; \( N_{accl} \) – the power required to accelerate the material to be treated, that is, to provide it with kinetic energy; \( N_{ad} \) – the power required to lift the workpiece; \( N_{in} \) – the power required to overcome the friction resistance of the workpiece material against the surface of the working body and guide surfaces; \( N_{int} \) – traction power; \( N_{accl} \) – the power required to overcome the propulsion; \( N_{ad} \) – power required to accelerate the machine to the estimated speed; \( N_{in} \) – the power required to drive the transporting organs that move the processed material beyond the transport of it directly by the main working body; \( N_{int} \) – total power to drive additional devices that ensure the functioning of the working body; \( \eta_{a} \) – the efficiency of the working body; \( \eta_{in} \) – efficiency mechanisms of drive of the working body; \( \eta_{ad} \) – efficiency transport body; \( \eta_{ad} \) – efficiency additional devices; \( \eta_{int} \) – total power to drive the active working body; \( \eta_{int} \) – total power to move the machine.

Taking into account the oscillatory nature of the torque and the active forces of the engine \( N_k \) for preliminary calculation take with the factor of reserve of power \( k_{res} = 1,2 : 1,4 \) by the formula, kW [1]:
\[
N_k = k_{res} N',
\]
(2)

According to formulas (1) and (2) the engine power of any reclamation machine with a single-motor drive can be calculated taking into account the peculiarities of its operations, the material being processed, the number and type of working and transporting bodies.

Formula (1) in its entirety is used to calculate the balance of power of machines with one-motor drive and active working bodies having the above transporting and auxiliary devices.

For machines with passive working bodies in which the bulk of the power is used to overcome traction resistance, \( N_{in} = 0 \) and for machines with passive working bodies in which the bulk of the power is used to overcome traction resistance, \( N_{in} \).

If the working body is combined, that is, consists of several simultaneously working active or active and passive working bodies, then the corresponding capacity is calculated for each of the working bodies and summed up.

For machines with multi-motor electric or diesel-electric drives, the required power of the individual engines is also determined by formulas (1) and (2), and after selecting the engines, the total installed power of the machine \( N_{in} \) is summed up:
\[
N_{in} = k_{res} \sum N_i,
\]
where \( N_i \) – engine power required to drive individual mechanisms, kW.

Consider common ways to determine the components of the balance of power on the example of the most common excavation machines.

The approximate capacity for digging the soil \( N_d \) (kW) (see formula (1)) determine, based on the known formula V.P. Goryachkin and the works of N.G. Dombrusky for the total tangential component of the soil response to the working body, kW:
\[
\sum R_l = 10^3 k' \sum b_l \delta_l = 10^3 k' \sum S_l,
\]
(4)
where \( k' \) – specific digging resistance, MPa; \( b_l \) – layer width (m); \( \delta_l \) – thickness (m) of layer; \( S_l \) – the area of the sliced layer (m²).

Refined calculation \( 2 \Delta R_d \) can be carried out by methods known from the theory of soil cutting according to the formulas A.N. Zelenina, D.I. Fedorova, Yu.A. Vetrowa and others.

By multiplying both parts of formula (4) by the length of the path of the digging organ, \( I = \Sigma l_i \), where \( I \) – the length of individual sections of the path, and dividing by the time of digging \( t \), we get:
\[
\sum R_l I = k \sum b_l \delta_l I \frac{10^3}{10^6 t}.
\]
(5)
The left side of the formula is a unit of time, that is, power \( N_d \) (kW), and the right – the product of specific resistance to digging \( k \) for volumetric performance \( I \) (m³/h):
\[
N_d = k \frac{I I}{3600},
\]
where \( v \) – speed of the working body, m/s.

Formulas (6) give sufficient accuracy for technical calculations (10...15%).

Specific resistance to digging \( k \) depends on many factors and is not a soil constant. If \( k \) is not defined for the respective working bodies, it is possible to temporarily use the values obtained for the excavators (Table 1). When working with soil collapse, the average values \( k \) reduced by 25 ... 40%.

Much of the reclamation machines with active working bodies are digging the soil with shavings of smaller thickness, which increase the crushing of the soil, the relative area of propagation of deformation and the volume of deformed soil in relation to the volume of shavings. Therefore, resistance to digging \( k \) (MPa) increases sharply under the hyperbolic law:

\[
\begin{array}{|c|c|c|c|c|}
\hline
\text{Group of soils} & 1 & 2 & 3 & 4 \\
\hline
\text{Number of strokes, } C_{st} & 1...4 & 5...8 & 9...15 & 16...34 \\
\text{Specific resistance to digging, } k, \text{ MPa} & 0,012...0,065 & 0,058...0,13 & 0,12...0,2 & 0,18...0,3 \\
\hline
\end{array}
\]

\[
k = (0,11..0,12) \frac{C_{st}}{\delta^e},
\]
(7)
where \( C_{st} \) – the index (number of strokes) of the densimeter characterizing the properties and condition of the soil; \( \delta \) – the thickness of the sliced layer (cm); \( e \) – an indicator of the degree depending on the type of soil for minerals \( e = 0,4 \), for marsh peatlands \( e = 0,33 \).

According to the experimental data, the specific soil resistance to digging [1]:
\[
k = k_l \left( \frac{\delta_l}{\delta} \right)^{c_e} k_k k_k k_k k_k,
\]
(8)
where \( k_l \) – the overall coefficient of resistance to the shavings thickness \( \delta_l \) equal to 1 cm; \( \delta \) – the actual thickness of the layer (cm), \( k_k \) – coefficient depending on cutting angle \( \psi \); \( k_k \) – a factor that depends on the width of the grip \( b \); \( k_k \) – coefficient depending on the angle of capture \( \alpha \); \( k_k \) – coefficient that depends on the number of strokes of the solid meter \( C_{st} \).

Power required to accelerate the soil \( N_{accl} \) (kW), is defined as the increase in kinetic energy that characterizes the second-hand operation of soil acceleration by the formula [1]:
\[
N_{accl} = \frac{mv^2}{2} - \frac{mv_{init}^2}{2} = \frac{\Pi \rho v_s^2}{2} \cdot 3,6 \cdot 10^6,
\]
(9)
where \( m \) – mass of the accelerated soil per hour, kg/h; \( v_s \) – soil
speed, depending on the type and kinematics of the working body; \(v\) — finite velocity of soil particles; \(v = v_i\); \(v_{\text{init}}\) — the initial velocity of the soil particles \(v_{\text{init}} = 0\), m/s; \(\Pi_t\) — technical productivity, m\(^3\)/h; \(\rho\) — density of soil, kg/m\(^3\).

The power required to lift the soil \(N_t\) (kW), determined on the basis of lifting the volume of soil moved in one second, according to the formula [1]:

\[
N_t = \frac{\Pi_t \gamma_{\text{w}} h_t}{3.6 \cdot 10^6}, \tag{10}
\]

where \(h_t\) — required lifting height, m. Determined for each type of working body based on the construction profile.

Power required to overcome soil friction resistance against the surface of the working body, or the guide housing \(N_{fr\text{s}}\) (kW), found as a second operation on the friction surface length by the formula [1]:

\[
N_{fr\text{s}} = \frac{\Pi_{fr\text{slip}} l_k f_i}{3.6 \cdot 10^6}, \tag{11}
\]

where \(l_k\) — the length of the projection of the friction surface onto the displacement plane, m (determined based on kinematics and type of working body); \(f_i\) — coefficient of soil friction against the corresponding friction surface.

The power required to overcome the full resistance of the machine \(N_{\text{res}}\) kW:

\[
N_{\text{res}} = \frac{F' v_w}{3.6 \cdot 10^6}, \tag{12}
\]

where \(F'\) — total traction resistance, kN; \(v_w\) — operating speed of the machine, m/h.

Power consumed by the propulsion \(N_p\) (kW), calculated by the formula [1]:

\[
N_p = F' (v_p - v_{\text{act}}) 3.6^{-1} \cdot 10^{-3} = F' v_p k_p 3.6^{-1} \cdot 10^{-3}, \tag{13}
\]

where \(v_p\) — estimated working speed of the machine, m/h; \(v_{\text{act}}\) — actual operating speed of the machine, m/h; \(k_p\) — slip factor, %,

\[
k_p = 100 \frac{(v_p - v_{\text{act}})}{v_p}. \tag{14}
\]

On mineral moist soils in normal operation of the caterpillar propulsion acceptable value \(k_p = 8...10\%\), on a crawler bog \(k_p \leq 15\%\), wheel drive \(k_p = 20...25\%\).

Power required to accelerate the machine (overcoming inertia forces) \(N_{\text{acctp}}\) (kW), are given by the formula [1]:

\[
N_{\text{acctp}} = F' v_w (v_p - v_{\text{act}}) 3.6^{-1} \cdot 10^{-3} = \alpha \gamma_{\text{w}} v_w (g l_{\text{acc}} 12.76)^{-1} \cdot 10^{-9}, \tag{15}
\]

where \(F'\) — resistance from overcoming inertia forces during acceleration, N; \(v_p\) — operating speed, m/h; \(v_{\text{act}}\) — actual speed of the machine, m/h; \(k_p\) — slip factor; \(\gamma_{\text{w}}\) — working body density, kg/m\(^3\); \(l_{\text{acc}}\) — acceleration time, sec.

Power \(N_{\text{un}}\) and \(N_{\text{ed}}\) required for the drive of the transporting organs and additional devices are determined by known formulas depending on the type of these organs.

For indicative calculations [1]:

\[
N_{\text{un}} = x_0 10^{-3} (N_{\text{unw}} + N_{\text{inh}} + N_{\text{1}}), \tag{16}
\]

where \(x_0\) = 5...7.

Specific power \(N_{\text{spe}}\) per unit of output (kW/unit) is calculated by the formulas [1]:

\[
N_{\text{spe}} = \frac{N_{\text{eng}}}{\Pi t} \quad \text{or} \quad N_{\text{spe}} = \frac{N_{\text{inh}}}{\Pi t}, \tag{17}
\]

where \(\Pi\) — hourly performance in units of measurement of hourly performance.

The procedure for performing this laboratory-practical work is given in [1]. To do this, it is first necessary to read and summarize the basic theoretical provisions and definitions. To get acquainted in detail and to study the methodology and features of calculating the power balance of reclamation machines.

Students also do laboratory work to determine the moisture content of soils and other agricultural materials [19]. Here they learn that the humidity of various agricultural materials is determined in order to: characterize the working conditions of agricultural machines (humidity of air, soil, fertilizers, seeds, etc.); control the technological process performed by the machine (humidity of the coolant in the dryer, soil moisture in layers before and after the passage of the working body of the machine, the dynamics of humidity of agricultural material, etc.); to characterize the conditions of agricultural plant development. Humidity can be determined directly or indirectly. Direct measurements of soil moisture, seeds and some agricultural materials are carried out using special electrical appliances. This method is convenient because it does not take much time. However, often depending on the internal structure of the material and its condition, errors can occur, so such measurements should be resorted to only when high accuracy is not required.

Future agricultural engineers are also exploring agricultural irrigation machines. For example, they study the sprinklers, the algorithm for their calculation. Thus, the flow rate of the working fluid with one nozzle centrifugal type (Fig. 3) is determined by the formula:

\[
Q = \sqrt{\frac{\alpha}{1 + \frac{\alpha^2}{1 - \alpha^2}}} f_s \sqrt{2gH}; \tag{18}
\]

where \(A = \frac{R r_i}{r_0^3}\) — design characteristics of the nozzle.

**Fig. 3. The scheme of the centrifugal nozzle. [1]**

The dependence of the coefficient \(\alpha\) from \(A\) determined according to the schedule (Fig. 4). Spray torch angle [1]:

\[
tg \theta = \frac{2A \alpha}{1 + \sqrt{1 - \alpha^2}}. \tag{19}
\]

The flow rate of the spray nozzle with conical deflector is determined by the formula [1]:

\[
Q = \mu f_s \sqrt{2gH}. \tag{19}
\]

Cost ratio \(\mu\) depends on the contour of the inlet edges. For sharp edges \(\mu = 0.7 \ldots 0.8\), for the rounded ones \(\mu = 0.9\) The angle of the torch is equal to the angle of the cone \(2\theta\).
5. References


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SOIL MOISTURE AND SOIL DENSITY VARIATION DURING PLANT GROWING SEASON BY IMPLEMENTATION OF MINERAL AND ORGANIC FERTILIZATION

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Abstract: Soil water retention and soil compaction are very important factors in the plant production and environment protection. The field investigations of the variation of soil moisture and soil density of Luvisol loamy sand in arable layer and in hard pen during sugar beet growing season in conventional tillage with implementation of mineral and organic fertilization were realised. In the growing season the soil moisture extremely fluctuates in the range from 4 to 18%. At the same time, it causes fluctuations of soil density, which totally decreases in time. Starting from June one can observe that the natural changes of the soil moisture cause contrary changes of soil density. Mostly, the soil moisture and soil density variation during growing season are similar in ruts and at the field besides the ruts. Generally, the organic fertilization increases the soil retention to about 4% in arable layer and profitable enhance the loosened action of water.

Keywords: SOIL, MOISTURE, DENSITY, SUGAR BEET, GROWING SEASON, MINERAL AND MANURE FERTILISATION

1. Introduction
Crop production needs, among other, the optimal soil compaction and water content for obtaining satisfactory results [1, 2, 3]. These factors are as well very important in environment protection [4]. Now, we observe small and irregularly rainfalls and harmful soil compaction caused by passage of tractors and machines what implicate the above problems of special significance. These problems are important in all soil cultivation systems, also, in the conventional system realised to this day at giant farmlands [5].

Soil moisture expressed as a quotient of water mass and dry soil mass, in % (w.b.) is one of the most important indicators of water retention. Soil moisture changes during plant growing season under the influence of numerous factors, including soil-climate conditions, plants, soil compaction, organic matter, depth, etc. [1, 2, 5, 6]. Soil moisture variations result in change of water availability for plants in time. Variation of water content at depth determine morphology and architecture of plant root system and in consequences plant growth [7, 8, 9, 10]. Some researchers indicate that water can compress and loose soil and these processes depend on the water content and on many other factors [6]. Soil density is one of important factors determining crop yield. It is changed especially by soil tillage and by wheels passage of tractors and machines [1, 2, 11]. This higher soil dense can favour to retention of rainfall water. What more, soil moisture changes can influence the soil density what depends on numerous factors, among others, organic matters content and numerous other local factors [6]. The researches prove that the subsoil is also compacted what determines water content and other processes important for plant growth, depending on the factors presented above [12].

Above analyse results with the conclusion that the problem of moisture and soil density changes in time is very complicated and unknown. This implicates investigations conducted under different conditions to achieve the knowledge to make practical use of them.

The aim of this paper is the determination of:
- soil moisture and density variation in arable layer and in hard pen during sugar beet growing season in conditions of mineral and manure fertilisation,
- and the effect of soil moisture on soil density by implementation mineral and manure fertilisation.

The investigations in ruts made by tractor during seeds sowing and at the field places without these ruts were realised.

2. Materials and methods
The experiment was carried out in the Central Poland Region, on soil Luvisol loamy sand (sand 2-0.063: 75%, silt 0.063-0.002: 20%, clay <0.002: 5%) [13]. The place of the experiment and the range of factors under analysis were characteristic for agriculture in that region. The average density of soil solids was 2.63 g∙cm⁻³. The content of organic matter in the soil in the arable layer before fertilisation ranged from 1.5 to 1.7%. The investigations were realised in a conventional cultivation system at the arable fields. In autumn the ploughing at the 24 cm depth with harrowing was performed. In spring the sugar beet seeds of cultivar Sonja were sowed. The distance between rows amounted to 45 cm, the distance between seeds in rows 24 cm and the depth of sowing 4 cm. This operation using drill Unicorn 3 (6 rows) combined with Zetor 7411 tractor (with 34 kN weight) was realised. The experiment was performed at the two fields. At the first field the typical mineral fertilisation of P K in 35% in autumn was realised. In spring the N P K fertilizer was applied two times. At the second field the manure in dose by weight 40 Mg/ha in autumn was distributed.

The soil moisture and soil density were measured in both of these fields 7 times during vegetation periods from April to October. Four divided plots of the two fields were randomly ordered and were the repetition of the experiment. The soil probes were taken from ruts (in rut) and from fields places without ruts (w. rut) using 100 cm³ cylinders. In the ruts from the layer at the depth: 15-20 (layer I), 20-24 (layer II) and from hard pen from 30-35 cm (h.p.). At the places of the fields without the ruts (w.rut) from the depths: 5-10 (layer I), 18-22 (layer II) and from hard pen 30-34 cm (h.p.). The soil density and water content were measured with the gravimetric (weight-dryer) method. The soil density was expressed as g/cm³ and the soil weight water content was expressed in % (w.b.). These parameters characterise soil only for the moments when the probes were taken. The monthly precipitation and air temperatures in the year of investigations are presented in the Table 1.

The regression equations, determination rates and correlation coefficients in this paper using professional statistic program STATISTICA 12 were determined.

3. Results and Discussion
Figure 1 shows the soil moisture variation in arable layer and in hard pen during sugar beet growing season at the field with mineral fertilisation and at the field with manure fertilisation. These results indicate that the soil moisture extremely fluctuated under natural factors during growing season. The soil moisture changes in the field with mineral fertilisation in the range from 5 to about 17% and in the field with manure fertilisation from 5 to about 22%. Generally, the variation of the soil moisture during vegetation period run across similarly in the arable layer and in the hard pen. Nevertheless, one observed the higher soil moisture to about 4-5% in the arable layer in the field with manure fertilisation. This prove that the introduced organic material is profitable for the higher water retention.

Table 1 Monthly precipitation and air temperatures in the year of investigations

<table>
<thead>
<tr>
<th>Month</th>
<th>Precipitation, in cm</th>
<th>Temperature, in Celsius degree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>48.8</td>
<td>1.7</td>
</tr>
<tr>
<td>Feb</td>
<td>30.3</td>
<td>4.1</td>
</tr>
<tr>
<td>Mar</td>
<td>45.4</td>
<td>3.0</td>
</tr>
<tr>
<td>Apr</td>
<td>40.5</td>
<td>4.5</td>
</tr>
<tr>
<td>May</td>
<td>28.2</td>
<td>16.5</td>
</tr>
<tr>
<td>Jun</td>
<td>52.8</td>
<td>17.3</td>
</tr>
<tr>
<td>Jul</td>
<td>43.5</td>
<td>17.6</td>
</tr>
<tr>
<td>Aug</td>
<td>103.8</td>
<td>16.9</td>
</tr>
<tr>
<td>Sep</td>
<td>92.8</td>
<td>15.9</td>
</tr>
<tr>
<td>Oct</td>
<td>32.3</td>
<td>8.0</td>
</tr>
<tr>
<td>Nov</td>
<td>27.8</td>
<td>2.6</td>
</tr>
<tr>
<td>Dec</td>
<td>67.2</td>
<td>1.3</td>
</tr>
</tbody>
</table>

The regression equations, determination rates and correlation coefficients in this paper using professional statistic program STATISTICA 12 were determined.
The soil density variation in the arable layer and in hard pen during growing season at the field with mineral fertilisation is presented at the Figure 2. At these Figures we observe that the soil density fluctuated at the time, but, generally, on medianly it decreases during growing season. The density fluctuations amounted on average to about 0.1 g·cm⁻³. The similar soil density changes occur in the arable layer and in hard pen, as well, at the fields with both kinds of fertilisation.

Generally, the soil moisture and soil density variation during growing season are similar in ruts and at the field besides the ruts.

Generally, from the analyse of the Figures 1, 2 and 3 results from that when the soil moisture is low then the soil density is high, and when the soil moisture is high then the soil density is low. This dependence occurs in growing season from June and take place in the arable layer and in hard pen, as well, at the fields with both kinds of the fertilisations. The soil density changes amounted on average to about 0.1 g·cm⁻³ under influence of natural changes of the soil moisture amounted on average to about 10%. We can assume that it is caused by known mechanism of soil shrinkage under influence of soil drying and soil loosening under influence of soil wetting [6].

At the Figure 4 the two dependencies of the soil density on the soil moisture: first for the mineral fertilisation and second for the manure fertilisation – they are presented and analysed. Each of these dependences was determined as a result of investigations conducted with these soil parameters from layers: I, II and deep drying the soil compact.

5. Generally, the organic fertilization increases soil moisture to about 4 % in arable layer.

At the same Figure 4 we see that the soil density linear decreases when the soil moisture increases at the field with manure fertilisation. The correlation between soil moisture and soil density is fairly high. Correlation coefficient for this dependence amount to $r = -0.36$. This proves that the higher soil moisture weakens influence at the lowering of the soil density when is used along with the mineral fertilisation. The determination rate for the regression equation for the above dependence amounted to $R^2 = 0.14$. This shows that the soil moisture only in 14% cause the soil density decrease.

The soil density lowering is especially showing in ruts where the soil is more dense.


CHANGES IN SOIL PROPERTIES DUE TO APPLICATION OF DIGESTATE

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Abstract: The EU is currently addressing the problem of depletion of phosphate, which is a source of phosphorus. Due to the usage of modern digestate treatment enabling macroelements recycling, the digestate can be a suitable substitute for anorganic fertilizers. This experiment is focused on improving the soil properties due to digestate application in sugar beet growing region. Applicated digestate comes from a biogas plant of agricultural cooperative Velešovice. The obtained results show better physical properties (soil structure, stability of soil aggregates) and differences in pH values, Cox (%) and nutrient content between variants.

Keywords: DIGESTATE, SOIL PROPERTIES, SOIL pH, NUTRIENTS, Cox

1. Introduction

Digestate is either solid or liquid product of anaerobic digestion coming from organic wastes. The thermophilic anaerobic digestion eliminates pathogenic bacteria, therefore the amounts of fecal coliforms and enterococcus fulfilled the requirements of EU for hygienic indicators [1], [2]. The quality of a digestate is determined by the digestion process used and the composition of ingestates. Digastate has higher available phosphorus (P) and potassium (K) concentration than that of composts [3], [4] therefore it is more suitable for supplement of these missing macronutrients in soils [2]. The solid fraction is composed of a large amount of residual fibres and phosphorous, whereas the liquid fraction contains a large part of N and K [5]. Due to these reasons, the use of digestate as fertilizer or soil improver during the past decades has generated a lot of interest [4], [6], [8].

2. Materials and methods

This experiment is focused on improving the soil properties due to digestate application in sugar beet growing region during 2017-2019 (spring). Three experimental variants were prepared: Variant 1 - control, no digestate; Variant 2 - with every second year digestate application (2017), Variant 3 - with annual digestate application (2017). The digestate application was always carried out in the spring. Applicated digestate comes from a biogas plant of agricultural cooperative Velešovice. Digestate was produced from maize silage. The chemical composition of digestate was dry matter 8.07 %, ash 1.83 %, pH 7.92, Ca 0.109 %, K 0.480 %, Mg 0.07 %, P 0.089 %, N tot. 0.65 %, S 25.6 %. Cultivated crops were maize (for silage) and winter cereals (wheat, rye). Soil samples were collected from depths 0-0.15 m and 0.15-0.30 m during spring growing season and during the autumn period. In this experiment were monitored physical properties – reduced bulk density, soil structure (dry aggregation) and total carbon content (Cox - organic, carbon), chemical properties (Mehlich III) - pH and nutrient content (NPK).

3. Results and discussion

3.1. Physical properties

Tabs. 1, 2 show results of observation of physical soil properties during autumn 2017-2018. The reduced bulk density (RBD) in average values ranged from 1.24 to 1.32 g.cm⁻³. Total porosity (%) decreased with increasing RBD. The highest average bulk density and subsequently lowest total porosity (%) was measured in control variant (Variant 1). RBD increased in Variants 2 and 3 with digestate application. Similar conclusions were published by [8]. A soil structure coefficient was calculated by a relation between agronomically valuable (0.25-10.00 mm) and less valuable structural elements (>10.00 and <0.25 mm). Application of digestate into soil leads to better soil structure. The highest soil structure was measured in all seasons in soil samples with annual digestate application (Variant 3) (Table 3). The same results were published in studies from ZD Budíšov [9].

Table 1: Physical properties of soil (Velešovice 2017)

<table>
<thead>
<tr>
<th>Variant</th>
<th>Soil depth</th>
<th>Reduced bulk density (g.cm⁻³)</th>
<th>Total porosity (%)</th>
<th>Minimal contents</th>
<th>Max. capillary capacity</th>
<th>Micron capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0–0.1</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>1</td>
<td>0.81</td>
<td>0.98</td>
<td>97.87</td>
<td>22.10</td>
<td>0.37</td>
<td>27.62</td>
</tr>
<tr>
<td>2</td>
<td>0.93</td>
<td>1.24</td>
<td>90.13</td>
<td>20.17</td>
<td>0.37</td>
<td>26.76</td>
</tr>
<tr>
<td>3</td>
<td>1.02</td>
<td>1.26</td>
<td>92.75</td>
<td>15.90</td>
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<td>92.63</td>
<td>18.20</td>
<td>0.32</td>
<td>17.77</td>
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</table>

Table 3: Soil structure coefficient (Velešovice 2017-2018)

<table>
<thead>
<tr>
<th>Variant</th>
<th>Soil depth</th>
<th>Soil structure coefficient</th>
<th>spring 2017</th>
<th>autumn 2017</th>
<th>spring 2018</th>
<th>autumn 2018</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0–0.1</td>
<td>0.0-0.15</td>
<td>0.0-1.05</td>
<td>0.0-0.3</td>
<td>0.0-0.3</td>
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<tr>
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</table>

3.2. Chemical properties

The pH of the digestate is generally slightly-alkaline and depends on digesting process, mainly by the degradation of volatile fatty acids (VFAs) and the production of ammonia (NH3) during the process [4], [10]. The alkaline pH of digestate is an effective tool for the problem of soil acidification [2]. During 2018, the pH increased in particular in depth 0.15–0.30 m in all variants. During the spring 2019, there was a noticeable decrease in pH in all variants. The noticeable decrease of pH values from alkaline (7.7-7.3) to neutral (6.6-7.2) and the differences between pH values during all seasons were observed in Variant 3 with annual digestate.

MECHANIZATION IN AGRICULTURE & CONSERVING OF THE RESOURCES 4-2019
129
application (20 t/ha) (Fig 1). This decrease of soil pH could be caused by various acid compounds (e.g. gallic acid) in digestate. The polycondensation, connection to organic and inorganic colloids and transformation of these acids can have an effect also on the soil chemical properties and finally the decrease of soil pH [2], [11,12].

The digestate application does not cause any significant changes in the total-N. Similar conclusions were also reached by the [13]. The highest percentage of total N was measured in Variant 3 in depth 0-0.15 m. However, there is evidently a linear decrease in depth 0.15-0.30 m during 2017-2019. This could be caused by microbial activity or consumption of nitrogen by plants.

Fig. 1 The changes of soil pH during seasons

Fig. 2 The content of Cox (%) in soil samples

The Cox content (%) was higher in the spring season in Variants 2, 3 with digestate application compared to the control variant (Fig. 2). Higher Cox in the spring season may be due to higher biological activity in the soil and/or digestate application. For Variant 3 with annual digestate application, there is no significant depletion of Cox in depth 0–0.15 m during 2017-2018. From this point of view, annual digestate application could be useful to keep the stable percentage of Cox in topsoil.

Fig. 4 The content of P (mg/kg) in soil samples

The phosphorus content decreased with increasing depth in all variants (Fig. 4). The greatest changes in P content were determined in spring samples. The highest P content was in Variant 2 in depth 0–0.15 m probably due to the first application of digestate in spring 2017. Significant changes in phosphorus content were determined in Variant 3 with annual digestate application in both depths. The phosphorus, very important element for plants decreased in autumn soil samples in Variant 3 probably due to the increasing biological activity and its consumption during microbial processes.

Fig. 5 The content of K (mg/kg) in soil samples

Distribution of potassium noticeable decreased in Variant 3 with annual digestate application during 2017-2018 (Fig. 5). However, in the digestate is supposed higher content of K. Thus, the potassium which comes from digestate is may be more available for plants e. g. [3], [4].

4. Conclusion

Annual application of digestate into the soil leads to better soil structure and higher RBD. The decreasing content potassium in variants with digestate show better availability of K for plants. However, the greatest changes were determined in P content, Cox
content and pH values. The application of digestate in the spring markedly affected the P content in the soil. On the contrary, the total nitrogen content was in similar values in all variants. Soil pH values changed from alkaline to neutral in spring 2019 due to various acid compounds in digestate.

Acknowledgements
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5. References


ASSISTED PHYTOSTABILIZATION OF A HEAVY METALS CONTAMINATED SOIL USING MINERAL AMENDMENTS AND L. PERENNE

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Abstract: Pressures exerted on the soil ecosystem due to its exposure to Zn evoke a real and aggravating effect on the quality of life. Greenhouse pot experiments were conducted to study the effects of mineral amendments (zeolite and bentonite) on selected physico-chemical properties of soil, L. perenne growth, Zn accumulation in plant and soil. The contents of Zn in the plants and soil were determined using the method of spectrophotometry. Zn contents in the tested parts of L. perenne differed significantly in the case of applying amendments to the soil, as well as increasing concentrations of Zn. The greatest average above-ground biomass was observed when zeolite were amended into the soil. Bentonite also caused significant increases in Zn concentrations in the roots. Bentonite and zeolite were shown to be the most effective and decreased the average Zn contents in soil.

Keywords: PHYTOSTABILIZATION, SOIL CONTAMINATION, MINERAL AMENDMENTS, LOLIUM PERENNE

1. Introduction

As a result of ongoing urbanization, excessive exploitation of the environment and the constantly increasing human populations, the level of contamination of individual components of the natural environment has also been increasing. A particularly important problem is contamination with heavy metals, which may derive from a very wide spectrum of anthropogenic activity (González-Acvedo et al. 2018).

The process of phytoremediation may proceed via: phytoextraction, phytostabilization, phytodegradation, or phytovolatalization (Odoh et al. 2019). Phytoextraction process makes use of the potential of plants (hyperaccumulators) to absorb high quantities of heavy metals (HMs) (Salam et al. 2019). After the completed growing period, plants are extracted and removed, and the remediation process may be multiply repeated until expected results are achieved. This method, however, bears the risk of HMs transfer to other matrices of the natural environment (air, water) and of their inclusion into the food chain (Wang, et al. 2019). In turn, the main principle of the phytostabilization technique is to enhance the development of the plant cover to reduce the availability of heavy metals, to minimize the erosion and leaching of metals, and also to improve soil quality (Zhan et al. 2018). The process of phytostabilization results in the precipitation or immobilization of inorganic contaminants in the soil, on the surface of roots or in root tissues (Radziemska, et al. 2016). The third mentioned process – phytodegradation – is based on the capability of selected plant species for the uptake of contaminants from the polluted sites and then on their conversion by enzymatic complexes of the metabolic cycle (Park et al. 2011). Owing to degrading enzymes, this process may also proceed in the rhizosphere of plants. Finally, the phytovolatalization makes use of plants capability for the uptake of contaminants from the soil, their accumulation, and finally their release in the modified form to the atmosphere (Gong et al. 2018).

In connection with the above, studies were assumed whose aim was to determine the influence of zeolite and bentonite applied to soil contaminated with Zn on the effectiveness of the process of aided phytostabilization by determining mobility and redistribution of Zn on L. perenne and the concentration of Zn in soil.

2. Materials and Methods

2.1. Plant Growth Experiment

The greenhouse experiment was carried out in 5.0 kg polyethylene pots containing soil contaminated with Zn, amended with zeolite and bentonite, and vegetated with L. perenne plants. Simulated soil contamination with Zn was introduced in the following doses (mg/kg of soil): 0 (control), 200, 400, and 600, with the soil also fertilized with a macro- and micronutrient fertilizer mixture containing N-26%, P2O5-12%, K2O-26%, B-0.013%, Cu-0.025%, Fe-0.05%, Mn-0.25%, and Mo-0.20%. The soil, obtained from the surface layer of a non-contaminated site in an agricultural area, was air-dried and sieved through a 2 mm mesh screen. Physico-chemical properties of the soils included: pH 5.03; hydrolytic acidity (mmol/kg) 33.24; sum of exchangeable bases Ca2+, Mg2+, K+, Na+ (mmol/kg) 62.10; cation exchange capacity (mmol/kg) 93.20; base saturation (%) 64.20, total N (g/kg) 1.13, organic carbon (g/kg) 7.12, N-NH4+ (mg/kg) 22.11, N-NO3- (mg/kg) 11.12, extractable P (mg/kg) 33.20, extractable K (mg/kg) 7.62, extractable Mg (mg/kg) 33.12, and Zn (mg/kg) 24.12. Amendments (zeolite, bentonite) was mixed in with the soil in the amount of 3.0% (each). Soils without Zn and amendments (0.0%) were designated as the control. The soil samples were thoroughly mixed and were allowed to stabilize under natural conditions for two weeks before using as a growth experiment. The plants were watered every other day to 60% of the maximum water holding capacity of the soil by adding deionized water. At the end of the experiment (approx. 45 days after seed sowing), plants were harvested, weighed and separated into above-ground parts and roots.

2.2. Plant and soil analysis

Plant material was carefully washed with deionized and further ultrapure water to remove soil particles, and then air-dried at room temperature. Before analysis, the plants were powdered using an analytical mill (Retsch type ZM300, Hann, Germany) and kept at ambient temperature prior to the chemical analyses. A representative subsample was mineralized in nitric acid (HNO3 p.a.) with a concentration of 1.40 g/cm and 30% H2O2 using a microwave oven (Milestone Start D, Italy). After filtration, the digestion products were adjusted to 100 mL volume with deionized water. Extracts were analyzed for total copper concentrations were determined by Atomic Absorption Spectrometry method using an iCE-3000 spectrophotometer (Thermo Scientific, USA). Copper in soil was analyzed using U.S. EPA method 3051.

2.3. Statistical analysis

Experiments were performed in triplicates and the values presented as the means ± standard deviation. The data were analysed using Statistica software (version 10.0, San Diego, CA, USA). Significant differences (p<0.05) between the mean values of different treatments were compared and evaluated using Duncan's multiple range test.
3. Results and Discussion

Areas contaminated with heavy metals generally represent a low level of plant cover growth, and deprived of vegetation. The effects of zeolite and bentonite on the biomass production of *L. perenne* grown in a Zn contaminated soils are shown in Fig. 1. In our study, the biomass of plants in the control series (without the addition of amendments to Zn-contaminated soil) decreased by 68% in the treatment with the highest Zn dose (600 mg/kg soil). Vijayarengan and Mahalakshmi (2013), in turn, showed that Zn toxicity decreased the length of the roots and shoot, as well as the area of the leaves in *S. lycopersicum*. In the carried out study, *L. perenne* did not show any visible symptoms of Zn toxicity or nutrient deficiency when grown on the contaminated soil with amendments. The greatest average aboveground biomass was observed in cases of amending soil with zeolite (33%) as compared to not applying any of these substances to the soil. Bentonite also had a positive, though lesser, influence. The application of inorganic amendments to soil alleviates the toxic effect of heavy metals on soils and, at same time, influences crop yield (Friesl et al. 2003). In another experiment conducted by Radziemska et al. (2016), mineral-amendments added to soil contaminated with heavy metals caused an increase in *L. perenne*. Moreover, Wyszkowski and Radziemska (2010, 2013) confirm that zeolite increased the average yield of plants (oat, spring barley, and maize) grown on soil polluted with Cr(VI). There are some reports indicating that rice seed biomass increases in bentonite-treated soil (Sun et al. 2014).

![Fig. 1. Effect of zinc and various mineral amendments on the aboveground biomass of *L. perenne*, in grams fresh mass per pot. Error bars are ± standard error (n=3). Bars indicated by the different letter are significantly different (P<0.05) according to Duncan test.](image)

Soil Zn concentrations have been presented in Fig. 3. In this study, the application of zeolite and bentonite led to a significant decrease in total Zn concentrations in soil as compared to the control pots. This suggests that soils treated with the application of mineral-based amendments exhibit a greater ability to desorb Zn from the soil in comparison to soil without amendments. In the control series (without amendments), the differences in the Zn contents of soil were positively correlated with increasing doses of this heavy metal. The application of bentonite and zeolite led to a significant decrease in Zn concentrations in soil as compared to the control pots. These results were similar to another experiment conducted by Radziemska and Mazur (2016), the addition of zeolite to soil contaminated with heavy metals caused a significant decrease of Zn in the soil. The remediation of Pb-polluted garden soil by zeolite limited the availability of Pb in the soil as well as enhancing the validity of phytoremediation (Shi et al. 2009).

![Fig. 2. Zinc concentration (mg/kg, dry weight basis) in the above-ground part (a) and roots (b) of *L. perenne* at the end of the trial. Error bars are ± standard error (n=3). Bars marked with different letters differ significantly for the same Cu exposure (P<0.05) according to the Duncan test.](image)

![Fig. 3. Zinc concentrations in soil with the different soil treatments (mean±SD, n=3). Values in columns marked with the same letter do not differ significantly (Duncan test, P>0.05).](image)
4. Conclusion

In the conducted experiment, the use of mineral-based amendments such as zeolite and bentonite gave promising results in the process of aiding the phytostabilization of soils contaminated with Zn. The biomass of tested plants depended on the dose of a Zn contaminant and amendments incorporated into the soil. The greatest average above-ground biomass of L. perenne was observed in cases of amending soil with zeolite. In this experiment, Zn accumulated predominantly in the roots of the tested plant. Zn accumulated in the roots, thereby reducing its toxicity to the aerial parts of the plant. Bentonite caused significant increases of Zn concentrations in the roots and turned out to be the most effective when it came to reducing total Zn content in the soil.

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5. References


BIOBASED ADSORBENT PREPARED BY PYROLYSIS OF A RENEWABLE AGRICULTURE WASTE

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Abstract: The study deals with preparation of carbon/SiO₂ based natural composite material by slow pyrolysis of rice husks at 480°C. The phase composition, microstructure and morphology of the solid pyrolysis residue were investigated by XRD, FTIR spectrometry, thermal analysis, H₂-porosimetry, B.E.T. specific surface area and SEM-EDS. The sorption capacity of the pyrolyzed rice husks (PRH) upon adsorption of oil and oil products spills was determined. The obtained results revealed that PRH possess high sorption ability toward gasoline, diesel, motor oil, light and heavy crude oil, in the range of 3.7 to 9.2 kg.kg⁻¹. The adsorbent is characterized with hydrophobicity and bu-effect 90% more 10 days. PRH were investigated also as material for deep adsorption removal of thiophene from model fuel under batch mode. It was found that adsorption of 92% of the aromatic sulfur compound from the model fuel was achieved.

KEYWORDS: RICE HUSKS, PYROLYSIS, OIL SPILLS, ADSORPTION, THIOPHENE, DESULFURIZATION

1. Introduction

Rice is one of the main agricultural crops in many regions of the world. Its harvesting and processing lead to the accumulation of rice husks waste in amount of millions of tons, which represents 20% of the total weight of the raw material. For Bulgaria only, this quantity, according to the MAF Annual Agricultural Reports in recent years, amounts to an average of about 12,100 tons per year [1].

High ash content and low calorific and nutrient values make this large scale renewable waste virtually unusable as fodder or energy source. The low bulk density of the husks, ~ 110 kg.m⁻³ and high resistance, create problems concerning with their storage and manage which directly impact on environmental. Using the waste from rice husks by the processing to the value added products, with applicability in different areas of technic is a challenge that is still searching for sustainable decision.

Rice husks contain an average of about 35 m. % cellulose, 24 m.% hemicellulose, 19 m.% lignin and more than 20 m.% ash [2,3]. In the ash residue the amount of amorphous SiO₂ is about 99 mass.%. In principle, the composition of the husks depends on the applied agro-technical activities as well as on the soil and climate characteristics of the region. Therefore, from a chemical point of view, the rice husks can be regarded as a natural, large scale and renewable natural source of pure carbon and amorphous SiO₂. This could be used as a base for the production of various carbon-silicon containing compounds using thermochemical processes for the waste treatment [4]. Subjected to a pyrolysis process, the waste biomass as a result of thermal destruction of the ligno-cellulose matrix dramatically changes its phase composition as well as the structural/morphological characteristics [5]. The solid pyrolysis residue obtained possesses some specific characteristics that make it, directly or after activation, suitable adsorbent for many compounds from different media [2,7-9].

Have arisen in recent years as a result of incidents large spills of oil and oil products related to the their yield and transport, had led to huge environmental disasters and economic losses for areas where this has happened. Demand of fast and efficient methods for their limiting and eradicating is very important. A great number of studies in the field, during last decades are subjected to the creation of suitable adsorbents which have to combine the triad: high adsorption capacity- accessibility and not expensive production cost [10,11].

Another global problem, directly impacts on environmental and human health is reduction the sulfur content in transportation fuels. Considering the emergency of the problem in 2003, the European Parliament adopted Directive 2003/17 of the European Commission, which limits the sulfur content in diesel fuels to 10 ppm [12]. This led to an intensive search of methods different than the traditional process of HDS, so called “non-HDS” based methods. Among these alternative methods for the purification of fuels, particular attention is paid to the methods of adsorptive desulfurization (ADS), which are based on the selective adsorption of the organic sulfur compounds from the fuel onto different solid adsorbents [13]. The process is carried out under soft conditions, such as moderate temperature and atmospheric pressure. The separation of the adsorbed organic sulfur compounds and their post utilization provides real ecological solution for regulation of a part of the refinery wastes.

The present work exhibits results, deal with the preparation of solid pyrolysis residue from rice husks, its characterization and testing as an adsorbent for treatment of spills of oil and petroleum products as well as adsorptive desulphurization of model fuel, containing the organic sulfur compound thiophene.

2. Experimental

2.1. Materials

Rice husks (RH) were obtained in the processing of rice from Pazardjik region, Bulgaria, harvest 2008. Rice husks were initially washed several times with water to remove any mechanical impurities and dried at 110°C. The dried husks were activated by slow pyrolysis at 480°C, in a fixed bed stainless steel reactor under vacuum of 1.33 Pa. The temperature of the furnace was increased linearly from ambient temperature up to 480°C with a heating rate of 4°. min⁻¹ and temperature retention for 3 hours.

2.2. Sample characterization

The ratio carbonaceous material/ash in the solid pyrolysis residue was determined by thermal analysis (TG/DTA) provided on a SETARAM Labsys Evo apparatus, at a heating rate of 10° min⁻¹ in oxygen, in an open corundum crucible. The phase composition of pyrolyzed rice husks (PRH) was determined by a Philips ADP 15 diffractometer using Cu Kα radiation. The infrared spectra were recorded on a Nicolet-320 FTIR spectrometer in a tablet of KBr. The porosity of the material has been determined by mercury porosimetry on a MICROMERITICS Auto-Pore 9200 apparatus. The morphology of the surface of the raw rice husks and that of the pyrolyzed ones was observed by scanning electron microscopy (SEM) using JEOL JSM 6390 microscope in secondary electron image mode (SEI), applying the appropriate magnification. The specific surface area was assessed by B.E.T. nitrogen adsorption measured in a static volumetric device Area Meter, Strehlein. The bulk density of the investigated sample was determined by the
MECHANIZATION IN AGRICULTURE & CONSERVING OF THE RESOURCES 4-2019

2.3. Methodology for determining the sorption capacity toward crude oil and petroleum products

Blank test: Stainless steel grid, with about 100–150 apertures per square centimeter and mass \( M_1 \) is immersed into the crude oil or oil product for 10 min. The grid is drained from excess of the liquid for 10 min and then weighed \( M_2 \). The difference between \( (M_2 - M_1) \) is the mass of oil/oil product retained by the empty grid.

On clean grid was placed preweighed sample of 1.00 g PRH. The grid with sorbent \( (M_3) \) is immersed into the petroleum product for 10 min, then allowed 10 min to drain the excess liquid and was weighed \( M_4 \). The difference between \( (M_4 - M_3) \) is the weight of oil (oil product) retained by the grid and the sorbent. The difference \( (M_2 - M_3) \) is the mass of oil absorbed. The sorption capacity \( C_{ads} \) of the material was calculated in dimensions g \( g^{-1} \) by Equation (1):

\[
C_{ads} = \frac{(M_3 - M_1) - (M_4 - M_3)}{M_3 - M_1}
\]

Commercial oil products with different densities were used as test-pollutants in the investigation: gasoline (BDS 17374-95); diesel (BDS 8884-89); motor oil (BDS 9785-89); light crude oil (origin Georgia) and heavy crude oil (origin Bulgaria).

2.4. Adsorbed sulfur by PRH at equilibrium conditions

The influence of the initial content of sulfur on the adsorption capability of the pyrolyzed rice husks was studied on four model blends of thiophene/dodecane containing 0.032; 0.063; 0.126 and 0.252 wt.% of thiophene. The concentrations correspond to a total sulfur level of 120; 240; 480 and 960 ppmw. Thiophene and dodecane, pure grade of Sigma Aldrich were used.

A volume of 30.00 ml of the above mentioned blends was placed in an Erlenmeyer flask and thereto 1.000 g of the adsorbent was added. The mixtures were agitated by shaking for 24 h to attain the equilibrium state. The mixtures were filtered and the residual sulfur concentration in the model fuel, \( S_{res} \) was determined in dimensions ppmw-S.

The change s in the rice husk structure leads to an increase in the B.E.T. specific surface area of the solid pyrolysis residue, Table 1. As can be seen, the PRH’s are characterized by high porosity, of about more than 50% and total pore volume of 1.0 cm\(^3\) g\(^{-1}\). The pores by the nature are predominantly meso- and macropores, according to the IUPAC classification [15].

### Table 1. Characteristics of the pyrolyzed rice husks

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total pore volume, cm(^3) g(^{-1})</td>
<td>1.05</td>
</tr>
<tr>
<td>Porosity, %</td>
<td>57.1</td>
</tr>
<tr>
<td>Total pore surface, m(^2) g(^{-1})</td>
<td>5.9</td>
</tr>
<tr>
<td>Average pore diameter, ( \mu ) m</td>
<td>0.72</td>
</tr>
<tr>
<td>Bulk density, g cm(^{-3})</td>
<td>0.54</td>
</tr>
<tr>
<td>B.E.T. specific surface area, m(^2) g(^{-1})</td>
<td>253</td>
</tr>
<tr>
<td>Mass yield, wt. %</td>
<td>38.0</td>
</tr>
<tr>
<td>Ash ratio / carbonaceous phase</td>
<td>1.1</td>
</tr>
<tr>
<td>Average fractional composition, (0.8-1.2 mm), %</td>
<td>30.0</td>
</tr>
<tr>
<td>pH</td>
<td>7.5</td>
</tr>
</tbody>
</table>

The results from FTIR analysis show that the biogenic silica, comprised in the rice husks in two forms- \( \alpha \)-cristobalite and tridymite, Fig.1(a). The basic absorption band at 1099 cm\(^{-1}\) is a triplet with weakly expressed shoulders. It is typical of the spectrum of the tridymite. The singlet band lying at 800 cm\(^{-1}\), the ones at 560 cm\(^{-1}\) and 466 cm\(^{-1}\) are due to the presence of cristobalite. The broad band around 3437 cm\(^{-1}\) is attributable to the existence of surface hydroxyl groups. The peak at 1693 cm\(^{-1}\) is due to hydrogen bonded C=O stretch modes. The peaks at 2854 and 2924 cm\(^{-1}\) are assigned to the C-H surface groups. The C=O and C-H groups are hydrophobic by their nature. The double peak around 1370 cm\(^{-1}\) is due to C-O stretching vibrations of the hydrophilic carboxylate groups. The band with a maximum at 1099 cm\(^{-1}\) could be assigned to vibrations of the C-OH bond as well as to the stretching mode of the siloxane groups [16,17]. As can be seen, on the material surface exist both, hydrophobic and hydrophilic functional groups which render PRH suitable for adsorption from different liquid media.
The X-ray diffraction shown in Fig. 1(b) revealed that phase composition of the PRH is a mixture of amorphous silica and carbon. The possible bonding of the silicon with the monosaccharides in rice husks has been discussed by Patel et al. [18]. The sharp halo observed at 20 22° corresponds to the presence of amorphous SiO₂ [19]. The halo at 20 44° is typical for carbonized cellulose and reflects the initial formation of (002) and (100/101) planes related to the graphite structure [20].

A typical structure with granular formations located linearly on the outer epidermis, as well as the fibrous structure of the inner epidermis can be seen in Figure 2(a). As a result of the pyrolysis the lamellar inner epidermis structure remains undestroyed. The evacuation of the volatile compounds creates an interior structure of RH, characterized by a lot of sheets-like pores of different size with rough surface and irregularities, Fig.2 (b).

3.2 Sorption capacity of PRH toward oil and oil product

The obtained data show that the amount of PRH’s used strongly depends on kind of spillage, Fig. 3a. The dependence between petroleum products density and the sorption ability of the PRH is presented on Fig. 3b. As can be seen, there is almost upward linear correlation between the petroleum products density and the sorption capacity of the PRH. The adsorbent obtained by carbonization of rice husks displays higher efficiency at the adsorption of various petroleum products compared to similar adsorbents proposed [21,22]. The achieved predominant mesoporous structure provides a good retention of the petroleum product into the pores of the sorbent. In our opinion, the other important characteristic related to the good sorption capacity is the SiO₂/C ratio. In the used PRH the value is equal to 1.1, which thresholds two or three times the level (0.34-0.50), which has reported for the such products [23].

Fig. 1. FTIR (a) and XRD (b) of pyrolyzed RH

Fig. 2. SEM micrographs of: (a) inner and external surface of raw RH; (b) inner surface of pyrolyzed RH

3.3 Adsorption of thiophene from model fuels. Influence of the initial sulfur concentration and amount of adsorbent on the adsorption kinetics

Fig. 3. Specific consumption of the adsorbent (a) and sorption ability of PRH toward different oil products spillages (b)

Fig. 4. Dependence between initial sulfur content and adsorption capacity of PRH

The kinetics relationships under batch mode of adsorption are presented in Figure 5. It may be concluded from the type of the experimental curve that the adsorption of thiophene from the model fuel proceeds as a two-stage process. As can be seen, the first stage occurs with high rate, while the velocity decreases during the second stage. It was calculated that the rate of adsorption is about 8.0 ppmw-S/g.h for the first 10 hours. In the second stage the rate decreases to 2.5 ppmw-S/g.h, Fig.5(a). The measured adsorption capacity is 2.47 mg-S /g-A, and the achieved degree of sulfur removal is 92 %.
The influence of the adsorbent mass/fuel volume ratio, in g·A/ml upon the kinetics of adsorption is demonstrated on Fig.5(b). It is seen that the greater the ratio, the faster the limit concentration of 10 ppm will be reached. The concentration of 10 ppm is reached after 16 h for an adsorbent/fuel ratio of 1:15; for a ratio of 1:10 - after 10 h, and at a ratio of 1:30 - for 24 h. In practice, an optimum balance between fuel volume and amount of adsorbent should be sought, based on the price of the adsorbent and the duration of the process.

![Fig. 5. Kinetics of thiophene adsorption](image)

**4. Conclusions**

Rice husks, one of the large scale, renewable agriculture waste were processed by pyrolysis and sold pyrolysis residue was tested as material for oil spillages reduction and adsorptive desulfurization of fuels. The obtained results revealed:

- Thermal treatment of RH leads to tailored of their surface chemistry, structural and morphological characteristics. The adsorption capacity of the PRH strongly depends on the mentioned properties.
- Thermal treatment of rice husks leads to production of a material with high sorption ability toward wide range of feasible spillages, including petrol, diesel fuel, motor oil, light and heavy crude oils.
- Pyrolyzed rice husks without any pretreatment are an adsorbent with good potential for the adsorptive desulfurization of fuels at different adsorbent/fuel ratios. Under the optimum conditions a removal of 92% of the sulfur from the fuel was achieved.
- The adsorption of thiophene is influenced by the initial sulfur level. Higher adsorption capacity is observed at high initial concentrations of sulfur in the fuel.
- The investigation showed that rice husks are suitable to produce of value added materials, encompassing technological and scientific aspects as well as economic and environmental issues.

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MONITORING OF NATURAL WATERS USING SORPTION CARTRIDGES

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Abstract: In the present work a mobile complex for monitoring natural waters for the detection of toxic substances has been proposed. The conditions for the detection and quantification of doubly charged cations of copper, nickel, cobalt and zinc on fibrous and cross-linked cation exchangers and polyampholytes, as well as fluoride, nitrate and nitrite ions on anion exchangers, and sodium oleate and sodium dodecyl sulfate on activated carbons, shungite and silicas were selected. The concentration of ions in the eluate was determined by ion-selective electrodes. An approbation of the proposed method for the detection and quantification of the ions was carried out on model aqueous mixtures containing various metal cations, anionic surfactants, inorganic and organic compounds. The mobile complex can be used to monitor the state of water objects without taking liquid samples to the laboratory and the concentration of toxic compounds, as well as to assess the effectiveness of the purification measures employed.

KEYWORDS: MONITORING OF NATURAL WATER, SORPTION CARTRIDGE, POLLUTANTS, HEAVY METAL CATIONS, TOXIC ANIONS, ANIONIC SURFACTANTS.

1. Introduction

The presence of microelements and pollutants in natural waters is determined by external conditions, human activity and can significantly change in the event of emergency situations of technogenic and natural origin. At present, the monitoring of natural waters comprises the determination of a number of characteristics, including the ionic composition of natural waters. Anionic surfactants are considered to be the most aggressive substances with respect to living organisms [1, 2]. They can cause eutrophication of reservoirs or form a film on the surface; therefore there is a need for constant monitoring of the content of these compounds. The existing methods for monitoring the state of natural waters require the use of expensive equipment [3-5], which is a 4-contact platinum sensor.

The purpose of the work was the development of a mobile complex for the on-site monitoring of natural waters for the detection of toxic substances with the possibility of their quantification.

2. Preconditions and means for resolving the problem

The assessment of a total mineralization and accelerated quality control of natural water was carried out by the value of the electrical conductivity of aqueous solution on the conductometric liquid analyzer of modification HI 2314 with electrode HI 76300, which is a 4-contact platinum sensor.

The present work studies the individual and joint sorption from aqueous solutions of the most common toxic inorganic ions: doubly charged cations of copper, nickel, cadmium, zinc and fluoride-, nitrate-, nitrite ions, and also some anionic surface-active substances (anionic surfactants) - sodium oleate and sodium dodecyl sulfate.

The basic sorption characteristics of toxic substances on polar and non-polar materials are determined under static and dynamic conditions.

The aminophosphonic polyampholyte is more selective with respect to heavy metal ions than the purolite iminodicarboxylic ion exchanger Purolite. It does not absorb the divalent cations of calcium and magnesium, which are present in water in sufficient amount [6]. Therefore, the determination of the possibility of detecting heavy metal cations was performed on a column filled with amino phosphonic polyampholyte in the sodium form. At various rates, aqueous solutions of individual ions of Cu²⁺, Ni²⁺, Cd²⁺, Zn²⁺ and their binary mixtures were passed through the column with a ratio of concentrations in the range from 10⁻⁴ to 10⁻³ mol/dm³. The study of the detection of fluoride, nitrate and nitrite ions in the presence of chloride and sulfate ions was done on ion exchange resins AB-17 and Purolite. Sorbents are monofunctional highly basic polymerization anion exchangers. Solutions of each of the detected ions and their mixtures with a different total concentration of 0.1 mol/dm³ were passed through a column filled with an ion exchanger, and output ion exchange curves were obtained.

After certain periods of time, the filtrate was sampled at the column outlet, and the concentration of the detected cations and anions in them was determined by a potentiometric method using ion-selective electrodes of the Elite and Volta brands.

The conditioning and transfer of ion exchangers into the working form was carried out according to the standard procedure, by sequential treatment with the solutions of sodium hydroxide, hydrochloric acid and distilled water. In this way, polyampholytes were obtained in the Na⁺ form, and anion exchangers in the OH⁻ form.

To assess the accuracy of the results obtained, independent standard methods for the detection of toxic ions were used. Determination of the concentration of cations in an aqueous solution was performed by the method of stripping voltammetry on a voltammetric analyzer AKV-07MK. The concentration of anions in a multicomponent aqueous solution was determined by the method of capillary electrophoresis “KAPEL-104T”.

The sorption of sodium oleate and sodium dodecyl sulfate was studied on activated carbons of the UBF (Russian) and SV-50 brands, enterosorbent “Polysorb”, shungite and flint, as well as carboxyl, aminocarboxylic ion exchangers, and a weakly basic anion exchanger Purolite.

Adsorption isotherms of anionic surfactants were obtained by varying concentrations; for this purpose, a weighed amount of the sorbent was placed in flasks, filled with sodium oleate solutions with concentrations from 0.05 to 0.30 mg/dm³. Sorption was performed under conditions of 24 hours at a temperature of 20°C, after which the solutions were filtered and the concentration of anionic surfactants in the filtrate was determined.

The concentration of anionic surfactants was carried out under dynamic conditions by passing the solution through a filter and subsequent elution with Na₂SO₄ solution. To prepare the sorption layer, a weighed amount of SV-50 coal was mixed with the fiber FIBAN AK-22-1, poured with a small amount of water, stirred until an external homogeneous mass was obtained, and placed in a column. The concentration of anionic surfactants was determined by a potentiometric method using anionic surfactant-selective and silver chloride electrodes.

To assess the correctness of the results obtained, standard methods for identifying anionic surfactants were used. Concentration of the substances was determined by extraction-photometric method using chloroform and methylene blue on photoelectric colorimeter KFK-3 and by fluorimetric method on liquid analyzer Fluorat-02.
3. Results and discussion

Electrical conductivity is a complex function of individual components of an aqueous solution, and it characterizes the total value of the ionic composition of water.

Using the results previously obtained and the literature data, the conditions for the detection and quantification of doubly charged cations of copper, nickel, cadmium and zinc on polyampholytes, carboxyl cationites and sulfocationites were selected. It was established that aminophosphonic macroporous polyampholyte of the Purolite brand in sodium form is the most effective sorbent. The method for detecting and isolating toxic cations from multicomponent solutions was realized on concentrating cartridges with a diameter of 2 cm and an absorbing layer height of up to 11 cm.

An example of the sorption of cations from 200 cm$^3$ of the solution with a total concentration of cations of $2 \times 10^{-5}$ mol/dm$^3$ and a flow rate of 0.12 cm$^3$/s is shown in Fig. 1.

During the sorption of the mixtures of cations of equal concentration on ion-exchange resin, clear separation zones are observed. In Figure 1 (a), the upper zone is colored blue, indicating the presence of copper cations. In Figure 1 (b), the upper zone is colored green, indicating the presence of nickel cations. The lower zones of the ionite are colored pink as a result of adding dithizone to cadmium cations. Between the upper and lower zones, a fairly clear-cut color transition is observed. When adding sulfarsazen to zinc (II) cations, the zones of the ionite are colored orange. The studied cations are detected in chromatographic zones when their content in the resin is higher than 0.01 mmol/g. This makes it possible to detect toxic cations in water at the concentration below the admissible limit values.

For the quantification of metal cations, the elution with a solution of hydrochloric acid was carried out, as well as the potentiometric determination of the concentration. An example of the output desorption curves for heavy metal cations is shown in Fig. 2.

The results obtained using the sorption cartridge were compared with the results of determining the concentration of cations in water by the method of stripping voltammetry, and the convergence was established above 85%.

The sorption of fluoride, nitrate and nitrite ions on strongly and weakly basic anionites from multicomponent solutions was studied. It was found that because of a high affinity to anionites, large size of the molecule and high admissible concentration limit in water, the sulfate ion interfered with the sorption of other ions. For this reason, the sulfates were first removed from the aqueous solution by the precipitation method. The separation of nitrate and nitrite ions was done in the presence of chloride ions.

The sorption was carried out on the most effective highly basic anionite Purolite in OH form. Fig. 3 shows the obtained output sorption curves of anions.

![Fig. 1. Aminophosphonic ionite Purolite after sorption of a mixture of cadmium and nickel cations (a) and a mixture of cadmium and copper cations (b).](image)

![Fig. 2. Output desorption curves of Zn$^{2+}$ (1), Ni$^{2+}$ (2) and Cu$^{2+}$ (3) ions from the concentrating cartridge of 8 cm in height under similar initial concentrations of cations and the elution rate of 0.12 cm$^3$/s.](image)

![Fig. 3. Output sorption curves: chloride ions (1), nitrite ions (2) and nitrate ions (3) on anionite Purolite in OH form. Transmission rate is 0.015 cm/s.](image)

The saturation of the ionite with chloride, nitrate, and nitrite ions occurs in different volumes of solutions. On the Purolite ion exchange resin, the chloride ion emerges first with a transmission time of 20 s, the nitrite ion emerges second with a transmission time of 120 s, and the nitrate ion emerges the third with a transmission time of 240 s. To quantify the anions, the elution with a solution of sodium hydroxide was carried out, and the potentiometric determination of the concentration of ions in the eluate was performed. The results obtained with the use of a sorption cartridge were compared with the results of determining the concentration of anions in water by a laboratory method of capillary electrophoresis, and the convergence was established above 80%.

The sorption of anionic surfactants (sodium oleate and sodium dodecyl sulfate) was studied on non-polar sorbents: activated carbons of various porosities, shungite, as well as on polar adsorbents: flint, “Polysorb” and various ion-exchange resins. The isotherms were obtained, and the equilibrium characteristics of the adsorption of anionic surfactants were calculated. The values of the maximum adsorption ($A_{max}$), the constant of the sorption-desorption equilibrium (K) and the Henry constant ($K_H$), which has the meaning of the coefficient of distribution of anionic surfactants between the adsorbent and the aqueous solution, are given in Table 1.
On the basis of the research conducted and the data in Table 1, the most effective sorbent was selected, an activated carbon SV-50, which has a developed network of mesopores.

For the concentration of anionic surfactants, a sorption layer consisting of activated carbon and anion-exchange fiber was developed and placed in a sorption cartridge. Sodium sulphate solution meeting the conditions of potentiometric determination was used as the eluent. The results obtained with the use of a sorption cartridge were compared with the results of extraction-photometric and fluorimetric methods for determination of the concentration of anionic surfactants, and the convergence was established above 85%. Table 2 presents the results of the detection of anionic surfactants in aqueous solutions by extraction-photometric (1), fluorimetric (2) and sorption-potentiometric (3) methods.

Table 2: The results of determining the concentration of sodium dodecyl sulfate in the control samples

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Introduced, mg/dm³</th>
<th>Found, mg/dm³</th>
<th>Δ_f</th>
<th>Found, mg/dm³</th>
<th>Δ_f</th>
<th>Found, mg/dm³</th>
<th>Δ_f</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1,44</td>
<td>1,452</td>
<td>0,83</td>
<td>1,447</td>
<td>0,7</td>
<td>1,584</td>
<td>10</td>
</tr>
<tr>
<td>2</td>
<td>2,88</td>
<td>3,05</td>
<td>5,9</td>
<td>2,97</td>
<td>3,13</td>
<td>3,151</td>
<td>9,4</td>
</tr>
<tr>
<td>3</td>
<td>14,4</td>
<td>14,11</td>
<td>2,01</td>
<td>14,05</td>
<td>2,43</td>
<td>14,68</td>
<td>1,94</td>
</tr>
</tbody>
</table>

The assessment of the stability and approbation of the proposed method for the detection and quantification of ions was carried out on model aqueous mixtures imitating natural water and containing various metal cations, anionic surfactants, inorganic and organic compounds. The results of the approbation exemplified by copper (II) cations, nitrate ions and sodium dodecyl sulfate are shown in Table 3.

Table 3: Results of determination of the content of toxic substances in model solutions

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cu⁺</td>
<td>10⁻³</td>
<td>10⁻³</td>
<td>1</td>
<td>2</td>
<td>10⁻³</td>
<td>1</td>
<td>10⁻³</td>
</tr>
<tr>
<td>NO₃⁻</td>
<td>10⁻³</td>
<td>10⁻³</td>
<td>1</td>
<td>2</td>
<td>9·10⁻⁴</td>
<td>1</td>
<td>9·10⁻⁴</td>
</tr>
<tr>
<td>Sodium dodecyl sulfate</td>
<td>3,3</td>
<td>3,3</td>
<td>0,2</td>
<td>0,2</td>
<td>6</td>
<td>6</td>
<td>3,3</td>
</tr>
<tr>
<td>Introduceed, mg/dm³</td>
<td>3,4</td>
<td>3,3</td>
<td>0,22</td>
<td>0,21</td>
<td>6</td>
<td>6</td>
<td>3,4</td>
</tr>
</tbody>
</table>

In all the samples, the content of toxic substances is determined with a permissible error. The smallest error was obtained when analyzing sample 2, in which the presence of copper ions and anionic surfactants was minimal, and sample 6, in which, on the contrary, the concentration of the components was high. The results obtained testify to the stability of this method for detection of pollutants and its high reliability.

The assessment of the influence of various substances on analytical signals of the methods in determining the toxic substances was carried out using multidimensional analysis of the dispersions (Analysis of Variance, ANOVA) and the coefficients calculated using the multiple linear regression (MLR) method. After excluding insignificant components from the regression and checking its adequacy, the values of the influence of components in the regression (p < 0.2) were obtained, and the multiple regression coefficients ($\beta$) were calculated for the procedure of detecting each component. MLR models were obtained for predicting the analytical signal of the method depending on the composition of the mixture. In general, the regression coefficients in the models for the substances are higher than for the related components. However, when determining copper ions, it is necessary to take into account the possible presence of ammonia, and when detecting nitrate ions, the presence of sulfate ions is necessary to reduce the determination error.

It has been established that the coefficient of variation for the developed methods for detecting substances is within the allowable range of values, which indicates a high degree of proximity of independent results of the individual tests obtained under specific conditions.

4. Conclusions

A mobile complex for the on-site monitoring of natural waters in order to detect toxic substances with the possibility of their quantification has been proposed. The developed methods for determining the concentrations of cations, anions and anionic surfactants are rather stable, and have high metrological characteristics. The discrepancy between the results obtained by the studied methods and the comparison method is insignificant. The main advantage of the mobile complex is its ability to detect toxic substances under field conditions.

The mobile complex can be used to monitor the state of water objects without taking liquid samples to the laboratory, as well as the concentration of toxic compounds, and to assess the effectiveness of the purification measures employed.

References

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NATURE-BASED SOLUTIONS FOR SOIL AND WATER QUALITY PROTECTION – EXPERIENCES FROM THE NORDIC-BALTIC REGION

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Abstract: World ecosystems are confronted with multiple challenges related to the global change drivers, namely, population growth, climate change, land use change, urbanization, invasive species, and interactions between these. Intensified land management practices implemented with the primary aim to increase the land productivity, may have severe adverse effects on soil and water quality. In the Nordic-Baltic region, both agriculture and forestry have high economic importance and long traditions, and currently intensive management is applied in both these sectors. Even though regulations and framework for soil and water protection exists, the management practices have to be extended beyond simple compliance with the regulations in order to secure holistic approach to the land management. Therefore, several collaboration projects with Nordic-Baltic partnership in forestry and agriculture sectors have been implemented during recent years to test nature-based solutions for soil and water protection.

Keywords: NATURE-BASED SOLUTIONS, INTENSIVE LAND MANAGEMENT, AGRICULTURE, FORESTRY, SOIL AND WATER QUALITY

1. Introduction

Healthy soils and clean water are the preconditions of human welfare as they support healthy ecosystems, which, in turn, provide people with a broad set of ecosystem services. Unfortunately, in the conditions of growing global pressures, the quality of soils and water is deteriorating in many parts of the world including Europe.

Three main ecological functions of soils can be defined, namely, 1) production of biomass ensuring food, fodder, renewable energy and raw materials; 2) filtering, buffering and transformation capacity between the atmosphere, groundwater and plant cover influencing the water cycle and gas exchange and protecting the environment (groundwater and food chain); 3) biological habitat and gene reserve with a large variety of organisms. In addition, soils have several functions linked to technical, industrial, and socio-economic uses, serving as: 1) physical basis for technical, industrial and socio-economic structures; 2) source of mineral raw materials, geogenic energy, and water; 3) geogenic and cultural heritage, an essential part of the landscape [1].

The risk of soil degradation arises from spatial and/or temporal competition in the use of the above-mentioned soil functions or their misuse. The risks to soil quality are mainly related to different types of land use, and agriculture and forestry play a key role in this aspect.

The main pressures related to Europe’s waters are water pollution, water abstractions, droughts, and floods. Densely populated river basins, corresponding to 11% of the total area of Europe are hotspots for water stress conditions, especially in southern Europe. According to European Environment Agency [9], agriculture is the main pressure on renewable water resources, while population growth and urbanization, including tourism, and water abstraction for hydropower and cooling as well have a significant impact on water resources, hydromorphology and natural hydrological regimes of waterbodies. Water quality is affected by both point and diffuse sources, diffuse pollution from agricultural activities, nowadays requiring high levels of fertilizers and manure, is among the principal sources of pollution. In this regard urban settlements, forestry, atmospheric deposition, and rural dwellings may be important sources as well. Leaching of nutrients to waterbodies causes eutrophication that, by increasing the ecosystem productivity, alters light and habitat conditions with detrimental effects on aquatic organisms, while excessive sediment runoff destroys fish spawning grounds and aquatic habitats.

Legally binding instruments and recommendations are used to prevent the mentioned threats on a world level, regional level (EU), and country and/or county level. The UN Convention to Combat Desertification (1994; international agreement linking environment and development to sustainable land management), the UN Watercourses convention (1997; pertaining to the uses and conservation of all waters that cross international boundaries) and the Revised World Soil Charter (2015; the overarching goal is to increase the area under sustainable soil management and the area of soils rehabilitated or restored) are some of the examples of global level documents pertaining to use and conservation of soil and water resources.

Soil and water protection is one of the priorities of the European Commission, thus the need to protect soil and water is stated in several binding European level documents, for instance, the Water Framework Directive (2000) aiming to achieve “good status” for all waters by integrated river basin management, the Nitrates Directive (1991) aiming to protect water quality across Europe by preventing nitrates from agricultural sources polluting ground and surface waters and by promoting the use of good farming practices, the Thematic Strategy of Soil Protection (2006) aiming to protect and promote sustainable use of soil, based on the following guiding principles: (1) preventing further soil degradation and preserving its functions; (2) restoring degraded soils to a level of functionality consistent at least with current and intended use, thus also considering the cost implications of the restoration of soil. Several of these documents highlight the need to implement nature-based solutions or “green/blue infrastructure” elements instead of traditional “grey infrastructure”.

Soil and water quality is recognized as important also in regional agreements and national legislation. The European Union Strategy for the Baltic Sea Region is the first macro-regional Strategy in Europe and one of the three key challenges of the Strategy is saving the Baltic Sea. Objective of the Sustainable Development Strategy of Latvia until 2030 related to natural capital is to be an EU leader in conservation, enhancement, and sustainable use of natural capital including soil fertility and clean water. The National Development Plan 2014–2020 (NDP2020) is hierarchically the highest national-level medium-term planning document in Latvia, one of the strategic objectives is “Sustainable Management of Natural and Cultural Capital”. The main aim of Latvian Environmental Policy Guidelines 2014-2020 is to provide citizens with the opportunity to live in a clean and orderly environment implementing sustainable development actions, preserving environmental quality and biodiversity, ensuring sustainable use of natural resources, and public participation in decision-making and environmental awareness. All mentioned environmental policy documents and a number of specific regulations are adopted in Latvia to maintain and improve the quality of the environment including soil and water emphasizing that healthy soil and clean water are among the most important environmental assets in Latvia. Moreover, a number of policy support projects are implemented to indirectly contribute to the improvement of water and soil quality. For instance, one of the initiatives to mitigate eutrophication problem in the Baltic Sea is...
Interreg Estonia-Latvia programme project “Integrated Nitrogen Management System for the Gulf of Riga (GURINIMAS)” implemented to promote close cooperation between Estonian and Latvian authorities and research institutions for the reduction of the nitrogen load into the Gulf of Riga by developing an integrated nitrogen management system. Information about the project and its results are found under: https://www.envir.ee/en/news-goals-activities/protection-marine-environment/est-lat-project-gurinimas.

2. Practical solutions for soil and water protection - examples from Nordic-Baltic cooperation projects

This section presents selected results of several collaboration projects implemented during the recent years in Northern Europe with Nordic-Baltic partnership focusing specifically on the use and efficiency of nature-based solutions to mitigate the effect of land management on soil and water quality in forestry, agriculture, and peatland management.

2.1. NUTRINFLOW

Interreg Central Baltic Programme project CB295 “Practical actions for holistic drainage management for reduced nutrient inflow to Baltic Sea (NUTRINFLOW)” was implemented from 2015 to 2019 in Finland, Latvia and Sweden to test, demonstrate and increase the recognition of innovative and holistic water management measures in agricultural areas contributing to reduced nutrient losses in the immediate watershed and into the Baltic Sea. According to the Fifth Baltic Sea Pollution Load Compilation (PLC-5) agriculture contributed from approximately 70% to over 90% of the anthropogenic diffuse riverine nitrogen load and 60-80% of the corresponding phosphorus load, therefore, there is a need to implement more effective water protection measures including in-field and edge-of-field practices to reduce diffuse nutrient losses from agriculture.

Since 2015, the Rural Support Service of the Republic of Latvia as a state administration institution offers financial support for reconstruction and renovation of drainage systems. In waterbodies considered as being at risk not to meet water quality objectives, financial support for reconstruction and renovation of drainage systems is available only if edge-of-field practices are implemented. In Latvia, edge-of-field practices are mainly implemented in the agricultural landscape are so-called “environmentally friendly drainage systems”. These are: sedimentation ponds, two-stage ditches, bottom dams, meandering, controlled drainage, and constructed wetlands (CWs).

Two existing pilot-scale constructed wetlands situated at the Mezaciruli Farm (56º 34' 22" N, 23º 29' 46" E), Zalenieki county, Jelgava region, Latvia were monitored under the NUTRINFLOW project. The study site is located within the Nitrate Vulnerable Zones designated according to the criteria of the EU Nitrates Directive (EC, 1991), since intensity of agricultural production throughout the Zemgale region is high. The subsurface flow CWs is available only if edge-of-field practices are implemented in Latvia, and therefore, the corresponding phosphorus load, therefore, there is a need to implement more effective water protection measures including in-field and edge-of-field practices to reduce diffuse nutrient losses from agriculture.

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The efficiency of both constructed wetlands to retain nutrients and total suspended solids (TSS) was determined by comparing respective concentrations at the inlet and outlet. Water samples were collected twice a month at the inlet and outlet of both constructed wetlands using a manual grab sampling approach. In order to detect the seasonal impact monthly mean nutrient and TSS retention values were compared. The statistical analysis was used to examine a significance level for dependence of air temperature, precipitation for both CWs and discharge at the outlet of the surface flow CW.

This study showed that surface and subsurface flow CWs have a potential to reduce nitrogen and phosphorus concentrations in drainage water and storm water. The concentrations of TN and TP were reduced in the subsurface flow CW on average by 53% and 46%, respectively, while the surface flow CW reduced the concentrations of TN and TP on average by 19% and 46%, respectively [4].

The project activities included implementation and monitoring of several water management related practices in agricultural areas in Latvia and Finland. Information about the project and its results are found under: http://nutrinflow.eu/.

2.2. WAMBAF

Interreg Baltic Sea Region Programme project “Water management in Baltic forests (WAMBAF)” was implemented from 2016 to 2019 in Sweden, Finland, Latvia, Lithuania and Poland aiming at tackling problems concerning forestry activities in relation to water quality.

Forests cover 48% of the Baltic Sea catchment. Most forests are managed for timber and energy production and have high economic value. Rivers and streams transport nutrients and hazardous substances (e.g. methyl mercury) from forests to the regional and coastal waters causing eutrophication, pollution, and decrease in biodiversity. HELCOM has estimated that the natural background load from forests comprise approx. 19% of the total nitrogen and 16% of the total phosphorus load to the Baltic Sea.

Maintenance of forest ditch networks, management of riparian forests, and the distribution of beaver dams are main drivers in the forests of the Baltic Sea Region, which affect the export of nutrients and methyl mercury, and affect biodiversity in riparian ecosystems.
Therefore, the project activities were grouped around these three topics, and the project results were compiled in three Tool Boxes.

Tool Box - Riparian forests consists of: wet area maps - help to plan maintenance of ditch networks; report for ditch network maintenance; film about forest buffers.

Table 3: Functions and proposed management measures of riparian buffers [8]

<table>
<thead>
<tr>
<th>Function</th>
<th>Proposed management</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protect aquatic and terrestrial habitats</td>
<td>Delineate the forest buffer so that important habitats are included and protected.</td>
</tr>
<tr>
<td>Supply aquatic organisms with food (e.g.</td>
<td>Promote broadleaved trees near surface water in conifer stands.</td>
</tr>
<tr>
<td>leaves, insects)</td>
<td>Provide shading</td>
</tr>
<tr>
<td>Supply large coarse woody debris (deadwood)</td>
<td>Leave trees of all ages in the forest buffer to ensure the continuous supply of</td>
</tr>
<tr>
<td>to watercourses</td>
<td>long-lived large woody debris to the streams (note: this does not include deposition</td>
</tr>
<tr>
<td>Protect the soil adjacent to surface waters</td>
<td>Try to create forest buffers resistant to wind felling.</td>
</tr>
<tr>
<td>Stabilize streambanks</td>
<td>Try to create forest buffers resistant to wind felling.</td>
</tr>
</tbody>
</table>

Tool Box – Forest drainage consists of: app for smartphones - helps to plan maintenance of ditch networks; report “Good practices for ditch network maintenance”; film about ditch cleaning.

Tool Box – Beaver consists of: beaver tool - classifies beaver dams as either positive or negative considering various impacts; beaver handbook - with information on beaver populations and management needs, country-specific legislation, good practices etc.; report “Good practices for management of beavers and beaver ponds in the Baltic Sea Region”; film about beavers in the Baltic Sea Region.

The demonstration areas have been established in 11 places around the Baltic Sea showing management in practice for forest buffers, ditch network maintenance, and beaver dams. In the demo areas, 19 training courses were carried out during 2018 with participants representing forest enterprises, forest owners, hunters, NGOs, authorities, scientists, and students.

All project material is available on the project website: https://www.skogsstyrelsen.se/en/wambaf/

2.3. LIFE REstore
EU LIFE program project “Sustainable and responsible management and re-use of degraded peatlands in Latvia (LIFE Restore)” was implemented in Latvia from 2015 to 2019 to establish a decision support system for responsible and sustainable degraded peatland re-use and management in Latvia.

Degraded peatlands are areas, where peat extraction has been discontinued or completed, but no after-use measures have been carried out, and there is no valid licence for the use of subterranean depths. Degraded peatlands create GHG emissions thus affecting the global climate; do not deliver potential economic benefits; do not ensure the restoration of biodiversity.

Peatlands degraded by peat extraction in Latvia were inventoried during the LIFE REstore project, and included in a publicly available database. Biophysical and economic assessment of degraded peatland ecosystem services has been carried out during the LIFE REstore project. Regulation, provisioning and cultural services of the project demo sites were evaluated in current situation and in perspective of five, 25 and 50 years.

Fig. 4: Comparison of GHG emission factors elaborated by the LIFE Restore and included in the IPCC guidelines

During the two-year period, the LIFE REstore project has carried out systematic measurements of greenhouse gas emissions in 41 differently managed peatlands in Latvia to identify the most efficient peatland management options from the point of view of climate change mitigation. Latvia is the first of the Baltic States, who has developed national GHG emission factors. The actual GHG emissions are on average twice as low as previously assumed [2, 5, 6, 7].
In five demo sites several after-use scenarios of degraded peatlands were tested, namely, renaturalization, planting of Sphagnum mosses, establishment of highbush blueberry plantations, afforestation, establishment of cranberry plantations.

3. Conclusions
Healthy soils and clean water are recognized as very important environmental assets on global, regional and national level serving as a basis for provision of variety of ecosystem services crucial for human welfare. They are jeopardised in many parts of the world, mostly due to increasing pressure on the ecosystems and climate change effects.

Intensification of agriculture and forestry to fulfil the needs of growing population and demand for renewable resources has adverse effects on soil and water quality worldwide, therefore, there is a need to introduce management practices that would mitigate and prevent the threats. Solutions of green and blue infrastructure are called for in this regard; and recently several approaches have been tested for agriculture, forestry and peatland management on national scale and in Nordic-Baltic cooperation projects.

The results of the NUTRINFLOW project demonstrated that surface and subsurface constructed wetlands have potential to reduce the leaching of nitrogen, phosphorus, and total suspended solids in storm water and drainage water from agricultural areas.

The results of the WAMBAF project demonstrated the need for decision support tools in forestry with regard to riparian forests, drainage system maintenance and beaver population management. Ecologically functional bufferzones, water protection structures in drainage system maintenance and guidance for removal or retention of beaver dams are needed to reduce the leaching of nutrients and mercury to the waterbodies. Several practically applicable tools for the above-mentioned purposes are developed within the WAMBAF project and are freely available.

The results of the LIFE Restore project demonstrated that the GHG emissions from nutrient-poor organic soils in Latvia are considerably smaller than it was reported earlier in the National GHG inventory according to the default IPCC emission factors. However, the area affected by peat extraction and still not transferred into other land uses is about twice larger than reported earlier. The project proved that afforestation of degraded peatlands has the largest climate change mitigation potential and in contrast to a common opinion forests on drained nutrient-poor soils are net sink of CO2 removals. The project also proved that cultivation of berries can contribute to the reduction of GHG emissions in the degraded peatlands. The GHG emission reduction potential of rewetting of the degraded peatlands was not confirmed by the project results.

4. Literature
5. Lazdiņš A., A. Butlers, A. Lupiķis. Contribution of LIFE REstore project to improvement of activity data for accounting greenhouse gas emissions due to management of wetlands.

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THE INFLUENCE OF BIOORGANIC PREPARATIONS ON PLANT PRODUCTIVITY
AND SOIL QUALITY

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Abstract: The global problem is that despite even the best efforts to eat a healthy balanced diet, most of our food sources no longer contain all necessary micronutrients, fulvic, humic and bio-active organic acids, minerals and other phytonutrients our bodies need to stay healthy because of soil degradation due to intensive industrial agriculture practices. Degraded soils cause poor nutrition value plants and poor nutrition value cause human physical and mental degeneration. One of the ways to solve the problem is humic and fulvic acid preparations. The field experiment was conducted in 2016-2017 at the Rumokai Experimental Station of the Lithuanian Research Centre for Agriculture and Forestry on a Bathihypogleyi-Calc(ar)ic Luvisol (LVk-gld-w) with predominant silt loam on clay loam. Mineral Ful and Ferbanat L were tested in the experiment. Mineral Ful is a high bioactive fulvic complex with 33 organic acids, and over 70 micronutrients that is free of chemicals. Mineral Ful produced water extraction method of leonardite. Ferbanat L contain humic and fulvic acids, vitamins, amino acids, enzymes, micro and macro elements and beneficial soil microorganism. The preparation obtained by the result of the transformations of organic waste by used of the worms. Test preparations had the influence on humus content in the soil. Mineral Ful and Ferbanat L increased sugar beets root yield from 1.33 to 7.11 t ha⁻¹. Cereal grain yield increased 2.6-1.0 %.

KEY WORDS: BIOLOGICAL PREPARATIONS, HUMUS, HUMIC ACID, SUGAR BEET, CEREAL CROPS

1. Introduction
Currently, farmers are widely using intensive field cultivation technologies. Abundant fertilisation, the use of pesticide and a failure to adhere to crop rotation causes a degradation of the soil. Negative changes of the soil biota and its biochemical processes take place as a result of a biological misbalance. This becomes a limiting factor for achieving the potential fertility of plants. However, the optimum fertilisation based on a scientific understanding can help improve the quality of the soil and ensure its sustainable use [9, 6]. Not only the necessary quantities of various microelements that can be supplied to plants but also the quantity of the water, nutrients and air in the soil, as well as its temperature and the microbiological activity, can be adjusted by partially replacing chemical fertilisers with organic ones [4, 6]. One of the ways to increase the activity of the soil and the productivity of plants is to use biological preparations and bioorganic fertilisers [15, 11]. Such preparations activate the natural morphophysiological processes of plants and supply them with complete nutrients [10]. However, it is necessary to consider not only the influence of such biological preparations on the plants’ fertility but also the fact that they improve the quality of the soil. Diseases spread less in healthy soil; therefore, fewer protective preparations are needed for the plants, and the environment becomes less polluted [13, 11]. Studies have shown that it is normally not possible to increase soil organic matter by more than 1 percent, but even an increase of this much can dramatically improve soil fertility [8]. During the formation of soil organic matter, nutrients such as nitrogen (N), phosphorus (P), and sulphur (S) are incorporated into the soil structure, allowing the soil to act as a reservoir of these and other nutrients. Various biologically active agents of a natural origin have been developed during recent years, i.e. biostimulators which allow a reduction in the use of fertilisers and other chemicals in agriculture [14, 5]. Usually, biostimulators are made of natural raw materials and they contain elements of mineral nutrition, biologically active compounds and the spores of beneficial microflora. There are plenty of biostimulators, the main component of which is humic substances. They are used both by inserting them into the soil and by spraying them on the plant leaves. Due to their physical, chemical and biological properties, the humic and fulvic acids activate and improve the vitality of the microflora and microfauna in the soil and stimulate its activity, as well as having a positive impact on germination, strengthening the growth of the root system (especially deeper down) and developing the plants’ immunity, thus improving the resistance to diseases and helping the plants absorb microelements.

2. Objects and methods
The field experiment was conducted in 2016-2017 at the Rumokai Experimental Station of the Lithuanian Research Centre for Agriculture and Forestry. A spring barley cultivar ‘Grace’ was grown, the seed rate was 4.0-4.5 million ha⁻¹. The sowing was carried out on 10-11 April. Preceding crop – sugar beets. Spring barley was harvested on 14-24 August. Spring barley was grown according to intensive technology, N100P60K60 fertilisers were applied before crop sowing. A sugar beet cultivar ‘Lavenda’ was grown. The pre-crop was winter wheat. The crop was sown on 15-20 April with a drill at a sowing density of 6–7 pelleted seeds per longitudinal meter with 45 cm interrow width. The sugar beet was grown in compliance with the recommendations of Institute of Agriculture [7]. Sugar beet was harvested on 10-14 October.

Soil was Bathihypogleyi-Calcaric Luvisol (LVk-gld-w) with predominant silt loam on clay loam. The top of the carbonate horizon and the gleyicity traces were determined at the 60 cm depth. The pH value in the arable soil layer ranged from 6.4 to 6.6. Soil pH was determined in 1 N KCl extraction using a potentiometric method. The content of plant-available P2O₅ at the 0-20 cm layer was 239.0-268.0 mg kg⁻¹ and the content of plant-available K₂O was 183.0-194.0 mg kg⁻¹. The content P₂O₅ and K₂O was determined using Egner-Riehm-Domingo (A-L) method.

Two preparations were used in our research: Mineral Ful and Ferbanat L. Mineral Ful is a high bioactive fulvic complex with 33 organic acids, and over 70 micronutrients that is free of chemicals. Mineral Ful produced water extraction method of leonardite. The organic biostimulator Ferbanat L. is made of a biologically clean natural raw material – vermicompost (a decomposed organic waste processed by earthworms) – using modern technologies which are based not on a chemical but on a physical effect. The use of vermicompost extracts improves the growth and development of plants [3, 1, 2]. Ferbanat L contains: 0.058 percent nitrogen, 0.05 percent phosphorus and 0.37 percent potassium, 38.36 percent organic carbon, 18.60 percent humic and 2.47 percent fulvic acids. It also contains microelements, biologically active agents of a natural origin, beneficial microflora and microorganisms such as: bacteria, fungi, yeast, algae, etc.

Meteorological conditions. The average day temperature of April in 2016 was +7.8°C, it is close to standard climate normal (SCN). The precipitation was 56.6 mm (SCN – 36 mm). Warm and humid weather after the sowing was favorable for the sugar beets and spring barley germination. The weather of May was warm. The precipitation of the month was close to SCN, although all precipitation (36.7 mm) occurred in the 2nd decade. June and July were warm with sufficient amount of precipitation. The temperature in August was close to SCN, the precipitation was 104.0 mm (SCN – 81 mm). The big amount of precipitation made it very difficult to
harvest barley. The weather of September was favorable for raising sugar beets; the average day temperature was close to SCN, without significant fluctuations, the amount of precipitation was close to SCN. The average day temperature of April in 2017 was +6.2 °C. The amount of precipitation was 65.7 mm. Although all precipitation occurred in the 1st and 2nd decades, therefore, the sowing of plants was delayed. Could and dry weather of May impeded the germination and development of plants. June and July were warm and dry. The weather of September was warm. The amount of precipitation was 119.7 mm (SCN – 72 mm).
The data of the research were evaluated using the dispersion analysis method (ANOVA) with the SELEKCIJA software package [12].

3. Results and discussion
Mineral Ful and Ferbanat L were tested in sugar beet crops. The number of sugar beet plants after germination were 99.36-109.94 thousand plants per hectare (Table 1). The Ferbanat L fertilizer was applied at a later stage of beet growth and therefore had no influence on germination. Mineral Ful increased number of plants 2.1 – 3.2 %. The density of the sugar beets before harvesting them varied from 90.00 to 105.83 thousand plants per hectare in the experiment with Ferbanat L. The plants were stronger and more resistant to unfavourable environmental conditions in the sections where the Ferbanat L fertiliser was used, 0.04 – 2.80% of the plants perished during their vegetation in these sections while 9.40% perished in the control sections.

Table 1. The effect of bioorganic preparations on sugar beet density

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Number of plants, 1000 ha⁻¹ after germination</th>
<th>Number of plants, 1000 ha⁻¹ before harvesting</th>
<th>Change in plant number during vegetation, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ferbanat L</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>99.36</td>
<td>90.00</td>
<td>-9.40</td>
</tr>
<tr>
<td>FL 3 lha⁻¹ BBCH 12-14+ FL 2 lha⁻¹ BBCH 18-20 + FL 2 lha⁻¹ BBCH 35</td>
<td>103.00</td>
<td>102.96</td>
<td>-0.04</td>
</tr>
<tr>
<td>FL 2 lha⁻¹ BBCH 12-14+ FL 2 lha⁻¹ BBCH 18-20 + FL 1 lha⁻¹ BBCH 35</td>
<td>100.58</td>
<td>97.78</td>
<td>-2.80</td>
</tr>
<tr>
<td>FL 1 lha⁻¹ BBCH 12-14+ FL 1 lha⁻¹ BBCH 18-20 + FL 1 lha⁻¹ BBCH 35</td>
<td>105.83</td>
<td>105.63</td>
<td>-0.20</td>
</tr>
<tr>
<td>LSD₀α</td>
<td>5.854</td>
<td>3.874</td>
<td></td>
</tr>
<tr>
<td>Mineral Ful</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>106.57</td>
<td>105.24</td>
<td>-1.25</td>
</tr>
<tr>
<td>MF 1 lha⁻¹ before sowing + MF 1 lha⁻¹ BBCH 14-16 + MF 1 lha⁻¹ BBCH 18-20</td>
<td>108.77</td>
<td>108.89</td>
<td>+0.11</td>
</tr>
<tr>
<td>MF 1.5 lha⁻¹ before sowing + MF 1 lha⁻¹ BBCH 14-16 + MF 1 lha⁻¹ BBCH 18-20</td>
<td>109.63</td>
<td>105.41</td>
<td>-3.85</td>
</tr>
<tr>
<td>MF 2 lha⁻¹ before sowing + MF 1 lha⁻¹ BBCH 14-16 + MF 1 lha⁻¹ BBCH 18-20</td>
<td>109.94</td>
<td>106.15</td>
<td>-3.44</td>
</tr>
<tr>
<td>LSD₀α</td>
<td>4.215</td>
<td>5.378</td>
<td></td>
</tr>
</tbody>
</table>

The harvest of the root crops varied from 83.41 to 101.26 t ha⁻¹ (Table 2.). The highest harvest was obtained when the sugar beets were fertilised with Ferbanat L three times during their vegetation using the maximum amount of fertiliser (3+2+2 lha⁻¹). The highest harvest with Mineral Ful was obtained when sugar beets were fertilised using the average rates of fertiliser (1.5+1.0+1.0 lha⁻¹).
The sugar content of the root crops varied from 18.00 to 18.57%. A trend of a reduction of the sugar content was observed when using the Ferbanat L fertiliser. However, these changes were small and insignificant. Mineral Ful increased sugar content 0.8-1.5%, however, however, this increase was not statistically significant. The highest amount of white sugar (15.52 t ha⁻¹) was obtained when the sugar beets were fertilised with Ferbanat L three times during their vegetation using the maximum amount of fertiliser. Ferbanat L increased the white sugar yield 1.6-4.0% and Mineral Ful – 5.2-9.7% compared to control sections.

Table 2. The effect of bioorganic preparations on sugar beet on sugar beet root yield and sugar content

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Root yield t ha⁻¹</th>
<th>Sugar content, %</th>
<th>White sugar yield t ha⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ferbanat L</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>97.11</td>
<td>18.22</td>
<td>14.92</td>
</tr>
<tr>
<td>FL 3 lha⁻¹ BBCH 12-14+ FL 2 lha⁻¹ BBCH 18-20 + FL 2 lha⁻¹ BBCH 35</td>
<td>101.26</td>
<td>18.00</td>
<td>15.52</td>
</tr>
<tr>
<td>FL 2 lha⁻¹ BBCH 12-14+ FL 2 lha⁻¹ BBCH 18-20 + FL 1 lha⁻¹ BBCH 35</td>
<td>98.44</td>
<td>18.07</td>
<td>15.16</td>
</tr>
<tr>
<td>FL 1 lha⁻¹ BBCH 12-14+ FL 1 lha⁻¹ BBCH 18-20 + FL 1 lha⁻¹ BBCH 35</td>
<td>100.49</td>
<td>18.18</td>
<td>15.51</td>
</tr>
<tr>
<td>LSD₀α</td>
<td>3.075</td>
<td>0.456</td>
<td>0.487</td>
</tr>
<tr>
<td>Mineral Ful</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>83.41</td>
<td>18.29</td>
<td>13.23</td>
</tr>
<tr>
<td>MF 1 lha⁻¹ before sowing + MF 1 lha⁻¹ BBCH 14-16 + MF 1 lha⁻¹ BBCH 18-20</td>
<td>87.41</td>
<td>18.49</td>
<td>13.92</td>
</tr>
<tr>
<td>MF 1.5 lha⁻¹ before sowing + MF 1 lha⁻¹ BBCH 14-16 + MF 1 lha⁻¹ BBCH 18-20</td>
<td>90.52</td>
<td>18.43</td>
<td>14.37</td>
</tr>
<tr>
<td>MF 2 lha⁻¹ before sowing + MF 1 lha⁻¹ BBCH 14-16 + MF 1 lha⁻¹ BBCH 18-20</td>
<td>89.33</td>
<td>18.57</td>
<td>14.51</td>
</tr>
<tr>
<td>LSD₀α</td>
<td>2.891</td>
<td>0.387</td>
<td>0.401</td>
</tr>
</tbody>
</table>

In spring barley crops was tested only Ferbanat L. The count of the productive stems varied from 802 to 875 number m⁻² in our investigation (Table 3). The most productive stems were produced in the sectors where the Ferbanat L fertiliser was sprayed three times during the vegetation of plants at 2 l ha⁻¹. When the crops were sprayed with 3 l ha⁻¹ Ferbanat L during the BBCH 12-14, 2 l ha⁻¹ during the the BBCH 23-29 and with the amount of Ferbanat L reduced to 1 l ha⁻¹ during the the BBCH 32-33, the barley had 5.8% less productive stems than in the control sections. This can be explained by the fact that larger quantities of fertiliser in the beginning of the vegetation intensified the tillering of the barley; however, they later lacked the nutrients needed for the
development of stems. Ferbanat L had no statistically significant effect on number of grains per ear. The Ferbanat L fertiliser had the tendency to increase the 1000 grain weight. The highest mass of 1000 grains were found in the sectors where the crops were sprayed with 3 l ha⁻¹ Ferbanat L during the stage of the flag leaf. The usage of nutrients on the flag leaf increased amount of humus and humic acid. In 2017 this indicator had no effect on soil quality. Mineral Ful in 2016 increased amount of humus and humic acids in the soil.

### Table 4. The effect of Ferbanat L on spring barley productivity indicators

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Number of productive stems per m²</th>
<th>Number of grains per ear</th>
<th>1000 grain weight g</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>851</td>
<td>20.6</td>
<td>49.33</td>
</tr>
<tr>
<td>FL 3 lha⁻¹ BBCH 12-14+ FL 2 lha⁻¹ BBCH 23-29 + FL 1 lha⁻¹ BBCH 32-33</td>
<td>802</td>
<td>21.1</td>
<td>51.01</td>
</tr>
<tr>
<td>FL 2 lha⁻¹ BBCH 12-14+ FL 2 lha⁻¹ BBCH 23-29 + FL 2 lha⁻¹ BBCH 32-33</td>
<td>875</td>
<td>20.5</td>
<td>50.50</td>
</tr>
<tr>
<td>FL 2 lha⁻¹ BBCH 12-14+ FL 2 lha⁻¹ BBCH 23-29 + FL 2 lha⁻¹ BBCH 339</td>
<td>873</td>
<td>20.7</td>
<td>50.07</td>
</tr>
<tr>
<td>LSD⁰⁰⁵</td>
<td>33.01</td>
<td>0.60</td>
<td>0.67</td>
</tr>
</tbody>
</table>

In our research, the yield of spring barley varied from 6.572 to 7.232 t ha⁻¹ (Table 4). The biggest yield of grains was obtained when the spring barley was additionally fertilised by the Ferbanat L fertiliser three times during its vegetation at 2 l ha⁻¹ (with the last fertilisation during the stage of the flag leaf BBCH 39). The amount of protein in the grains varied from 11.2 to 11.5%. A higher protein content was obtained in the sectors where the crops were sprayed with 3 l ha⁻¹ Ferbanat L during the stage of the flag leaf. The usage of nutrients on the flag leaf improves the quality of the grains, which is supported by the research conducted by other scientists. The weight of the dry measure increased by 0.5-2.1% after the use of the Ferbanat L fertiliser.

### Table 5. The effect of the biopreparations on quality of the soil

<table>
<thead>
<tr>
<th>Treatment</th>
<th>pH</th>
<th>Humus %</th>
<th>Humic acids %</th>
<th>Fulvic acids %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>6.8</td>
<td>2.21</td>
<td>0.28</td>
<td>0.14</td>
</tr>
<tr>
<td>Ferbanat L</td>
<td>6.7</td>
<td>2.25</td>
<td>0.26</td>
<td>0.16</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Treatment</th>
<th>pH</th>
<th>Humus %</th>
<th>Humic acids %</th>
<th>Fulvic acids %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>7.0</td>
<td>2.00</td>
<td>0.24</td>
<td>0.10</td>
</tr>
<tr>
<td>Mineral Ful</td>
<td>7.1</td>
<td>2.65</td>
<td>0.36</td>
<td>0.12</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Treatment</th>
<th>pH</th>
<th>Humus %</th>
<th>Humic acids %</th>
<th>Fulvic acids %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>6.4</td>
<td>1.89</td>
<td>0.21</td>
<td>0.10</td>
</tr>
<tr>
<td>Ferbanat L</td>
<td>6.5</td>
<td>1.92</td>
<td>0.23</td>
<td>0.09</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Treatment</th>
<th>pH</th>
<th>Humus %</th>
<th>Humic acids %</th>
<th>Fulvic acids %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>6.1</td>
<td>1.70</td>
<td>0.14</td>
<td>0.04</td>
</tr>
<tr>
<td>Mineral Ful</td>
<td>6.1</td>
<td>1.72</td>
<td>0.19</td>
<td>0.05</td>
</tr>
</tbody>
</table>

### 4. Conclusion

In our research, the organic biopreparations Ferbanat L and Mineral Ful increased sugar beets root yield from 1.33 to 7.11 t ha⁻¹. Mineral Ful improved quality of sugar beet root: sugar content increased 0.8-1.5%. The organic biostimulator Ferbanat L increased the spring barley grain yield 2.6-10.0 %. Mineral Ful increased the amount of humus and humic acids content in the soil.

5. Reference


EVALUATION OF GARDEN PEA CULTIVARS TO SALT STRESS TOLERANCE

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Abstract: Soil salinity is one of the main limiting factors for the plant growth and productivity. Response of three garden pea cultivars (Mira, Zornitsa and Ran 1) to salt stress in in vitro and in vivo conditions was studied. The in vitro stress was induced by adding of 0 (non-treated control), 50, 100 and 200 mM NaCl in culture medium. After two weeks the germination and seedling emergence rate were not significantly affected by 50 mM NaCl. In culture medium containing 200 mM NaCl only 13.3 - 43.3% of the seeds developed to the plants. The data indicated that increasing NaCl level the shoot and root lengths, and plant fresh weight were significantly reduced. In in vivo condition, such clear differences between the tested NaCl concentrations were not observed. Nevertheless, the applied salt stress more strongly affected the shoot fresh weight and root length than stem length. Among the three tested genotypes cultivar Zornitsa was the most tolerant one, proved in both in vitro and in vivo experiments.

Keywords: PISUM SATIVUM L., NaCl, SEEDLING EMERGENCE, IN VITRO AND IN VIVO CULTURE

1. Introduction

One of the most important abiotic factors limiting plant growth and development is water stress caused by drought or salinity. According to FAO (2008) over 6% of the of the world’s land is affected by salinity or more than 800 million hectares. Moreover, studies have been shown that increasing salinization in agricultural fields will reduce the land available for cultivation by 30% within the next 25 years (Wang et al., 2003). Therefore, the efforts to increase the tolerance of crop plants to salinity stress are extremely important for sustainable agriculture.

Physiological processes that occur in plants, such as seed germination and development, growth, flowering and fruit formation are negatively affected by high salt levels in soil which leads to reduced economic profitability and production quality. Salinity influenced photosynthetic activity by destruction of green pigments, reduction of leaf area, transpiration rate, activity of photosynthetic enzymes etc., which indirectly affected yield (Pandolfi et al., 2012; Miljus-Djukic et al., 2013).

Pea is the most adaptive species among leguminous crops and at the same time sensitive to salinity stress (Saxena et al., 1993, Francois and Maas 1994; Steppuhn et al. 2001). Some of the hypothesis explaining this is the effect of salinity on bacterial activity with respect to nitrogen fixation (Matere et al., 2007; Toker et al., 2007) On the other hand the plant response to the stress depends on the intensity and duration of exposure, stage of growth and genotype (Hernández et al., 2000; Duzdemir et al., 2009).

Various indicators as seed germination rate, Na+ and K+ concentrations in plant tissues, plant height, root length, leaf necrosis, plant productivity have been used to evaluate salinity tolerance of different pea genotypes (Toker et al., 2007). But the complex nature of salinity tolerance and lack of a single trait for assessment make the breeding of tolerant cultivars difficult and the rapid evaluation of a large number of genotypes to salt stress is time-consuming (Flowers et al., 2009). In vitro culture can be applied as an alternative approach for studying the effects of different abiotic stress factors like drought (Wang et al., 2003), heavy metals (Stanisavljevic et al., 2012) and for development of stress tolerant lines (Rai et al., 2011). Furthermore, in vitro conditions let to eliminate the impact of other potential stress factors as pathogens, temperature, humidity (Piwowarczyk et al., 2016) In vitro screening has been used as an effective method for rapid evaluation of a large number of genotypes to salt stress (Queiroz et al., 2007; Piwowarczyk et al., 2016). El Sayed and El Sayd, (2011) reported that resistant to salinity pea lines are obtained as result of callusogenesis. Miljus-Djukic et al., (2013) also successfully applied the in vitro culture to assess the salinity response of three pea species (Pisum arvense, P. sativum and P. fulvum).

The aim of this experimental work is to study the effect of salt stress of growth and development of three garden pea cultivars (Mira, Zornitsa and Ran 1) in in vitro and in vivo conditions.

2. Materials and Methods
2.1. Plant material

The experiment was carried out with three garden pea cultivars Mira, Zornitsa and Ran 1 from the collection of the Maritsa Vegetable Crops Research Institute in Plovdiv.

Ran 1 (old local cultivar). Early in maturity cultivar, vegetation period 49-50 days. Grains are round, green and comparatively large. Approximately weight per 1000 seeds is 212.8 g.

Zornitsa (Maritsa VCRI). Early to mid-early in maturity cultivar, vegetation period 52-54 days. Grains are round and green. Approximately weight per 1000 seeds is 173.3 g.

Mira (Maritsa VCRI). Late in maturity cultivar, vegetation period is 73-74 days. Grains are round and green. Approximately weight per 1000 seeds is 150.1 g.

2.2. In vitro treatment

Seeds of three pea cultivars were surface sterilized by soaked in 5% Calcium hypochlorite for one hour, rinsed three times in sterile distilled water and germinated on basal medium containing macron- and microsalts by Murashige and Skoog (1965), Vitamins B5 by Gamborg et al., (1968), 20 gL⁻¹ Sucrose and 7 gL⁻¹ Agar. Salinity stress was induced by adding of Sodium chloride (NaCl) in medium at concentration: 0 (control), 50, 100 and 200 mM. The culture vessels with seeds were incubated in growth chamber at 25°C ± 1°C temperature, a photosynthetic photon flux density (PPFD) of 200 µmol m⁻² s⁻¹ and 16/8 h photoperiod. The experiment was repeated two-times in three replications each, with 5 seeds per replication. Germination rate was determined after 7 days of seeds cultivation while seedling emergence was recorded after 14 days. The shoot and root length (mm) and shoot weight (g) of 14-days old seedling were also measured.

2.3. In vivo treatment

The experiment was carried out during the spring season of 2019 under glasshouse conditions. Five seeds per cultivar were sown in equal distance at 2 cm depth in pots contained 4 L mixture peat moss and perlite in the ratio 1:1 (v/v). Initially, pots were irrigated with tap water. After seeds germination, a modified Hoagland’s nutrient solution was used for irrigation. It contains 1 mM Ca(NO₃)₂; 1 mM KNO₃; 0.4 mM KH₂PO₄; 0.4 mM MgSO₄; 17.9 µM FeEDTA; 4.6 µM H₂BO₃; 0.9 µM MnCl₂; 0.08 µM ZnCl₂; 0.03 µM CuCl₂. Modification was made to induce salinity stress by supplementing the nutrient solution with 0 (control), 50, 100 and 200 mM NaCl. The treatments with the saline solutions started...
seven days after seeds germination. First treatment was made with ½ strengths solutions. During the vegetation period a total of five treatments with 500 mL saline solutions per pot were made. Between these treatments, 200 mL (50 and 100 mM NaCl) the reduction of shoot length ranged from 3.8% in cultiver Zornitsa to 34.4% in cultivar Ran 1 compared to non-treated control. Increasing the NaCl concentrations in a medium led to decrease of seedling growth between 68.8% in cultivar Zornitsa and over 80% in cultivars Mira and Ran 1. Regarding the root growth the tendency was similar. The root length was reduced with 7.0% in Ran 1, 14.6% in Mira and 43.3% in Zornitsa in the lowest concentration of NaCl (50 mM). The highest level of NaCl (200 mM) decreased the root length between 88.3% and 97.8% compared to the control treatment (0 mM NaCl). Increasing NaCl concentration in the media the weight of the plants significantly decreased from 16.5% at 50 mM NaCl to 89.5% in 200 mM NaCl. The results indicated that cultivar Zornitsa distinguished with the highest tolerance to applied salt stress, followed by cultivars Mira and Ran 1.

2.4. Statistical data

The results were presented as means ± standard deviation (SD). Duncan’s multiple range test was used (SPSS software) to compare means. The percentage of characteristics decrease compared to non-treated control (T-C0) was also calculated.

3. Results and Discussion

3.1. In vitro treatment

Data presented in Table 1 indicated that seed germination and emergency rate was not significantly affected by lower salt concentrations in a culture medium containing 200 mM NaCl. The highest decrease of seed germination (36.7% in Ran 1 to 60.0% in Zornitsa) was observed in culture medium containing 200 mM NaCl. Seeding emergency rate was significantly inhibited at the highest level of salt in three tested cultivars. In this concentration of NaCl (200 mM) in the medium, the percentage of seed that developed to plants was 43.3% in Zornitsa, 30.0% in Ran 1 and 13.3% in Mira, but with visible suppress of plant and root growth (Fig. 1). The results were consistent with those obtained by other authors (Pilowarzyk et al., 2016). Also it was established that grain legumes are more sensitive to salt at seedling development than weed germination stage (Kaya et al., 2008; Okcu et al., 2005).

Table 1: Seed germination and seedling development of three garden pea cultivars under salinity stress.

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>NaCl mM</th>
<th>Seed germination</th>
<th>Seed emergence</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>% ±SD</td>
<td>% ±SD</td>
<td></td>
</tr>
<tr>
<td>Mira</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>93.3 ±2</td>
<td>10.3</td>
<td>83.3 ±2</td>
</tr>
<tr>
<td>50</td>
<td>73.3e</td>
<td>10.3</td>
<td>53.3e</td>
</tr>
<tr>
<td>100</td>
<td>50.0d</td>
<td>30.1</td>
<td>33.3e</td>
</tr>
<tr>
<td>200</td>
<td>42.9d</td>
<td>17.9</td>
<td>13.3e</td>
</tr>
<tr>
<td>500</td>
<td>0</td>
<td>100.0</td>
<td>96.7 ±0</td>
</tr>
<tr>
<td>Zornitsa</td>
<td>50</td>
<td>90.0e</td>
<td>76.2 ±0</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>76.7e</td>
<td>53.3e</td>
</tr>
<tr>
<td></td>
<td>200</td>
<td>60.0e</td>
<td>43.3e</td>
</tr>
<tr>
<td></td>
<td>500</td>
<td>0</td>
<td>96.7 ±0</td>
</tr>
<tr>
<td>Ran 1</td>
<td>50</td>
<td>90.0e</td>
<td>82.2 ±0</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>76.7 ±0</td>
<td>93.3 ±0</td>
</tr>
<tr>
<td></td>
<td>200</td>
<td>83.3 ±0</td>
<td>10.3 ±0</td>
</tr>
<tr>
<td></td>
<td>500</td>
<td>0</td>
<td>13.7 ±0</td>
</tr>
<tr>
<td>a,b,c…..</td>
<td>Duncan’s Multiple Range (p&lt;0.05)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The growth of shoots and roots was also negatively affected by salinity stress in all studied garden pea cultivars (Table 2, Fig. 1). After 14 days of cultivation in culture medium containing 50 mM NaCl, the reduction of shoot length ranged from 3.8% in cultivar Zornitsa to 34.4% in cultivar Ran 1 compared to non-treated control. Increasing the NaCl concentrations in a medium led to decrease of seedling growth between 68.8% in cultivar Zornitsa and over 80% in cultivars Mira and Ran 1. Regarding the root growth the tendency was similar. The root length was reduced with 7.0% in Ran 1, 14.6% in Mira and 43.3% in Zornitsa in the lowest concentration of NaCl (50 mM). The highest level of NaCl (200 mM) decreased the root length between 88.3% and 97.8% compared to the control treatment (0 mM NaCl). Increasing NaCl concentration in the media the weight of the plants significantly decreased from 16.5% at 50 mM NaCl to 89.5% in 200 mM NaCl. The results indicated that cultivar Zornitsa distinguished with the highest tolerance to applied salt stress, followed by cultivars Mira and Ran 1.

3.2. In vivo treatment

The electrical conductivity, i.e. the content of salts in the nutrient solutions used in this experiment is presented in Table 3. First treatment was made with ½ strength solution and the measured EC values are lower compared to the solutions used in the following treatments. As expected, increasing the concentration of NaCl increase the EC of the solution.

Table 3: Electrical conductivity (EC) of freshly prepared saline solutions used in the in vivo experiment.

<table>
<thead>
<tr>
<th>Nutrient solution, NaCl mM</th>
<th>1st treatment</th>
<th>2nd treatment</th>
<th>3rd treatment</th>
<th>4th treatment</th>
<th>5th treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1.52</td>
<td>2.40</td>
<td>2.40</td>
<td>2.38</td>
<td>2.39</td>
</tr>
<tr>
<td>50</td>
<td>4.10</td>
<td>7.39</td>
<td>7.50</td>
<td>7.43</td>
<td>7.38</td>
</tr>
<tr>
<td>100</td>
<td>6.63</td>
<td>12.28</td>
<td>12.48</td>
<td>12.50</td>
<td>12.26</td>
</tr>
<tr>
<td>200</td>
<td>11.61</td>
<td>21.50</td>
<td>21.80</td>
<td>21.70</td>
<td>21.67</td>
</tr>
</tbody>
</table>

The results from plant morphology evaluation in in vivo experiment were presented in Table 4. Salinity caused depression in plant growth in all studied cultivars. From the three measured growth indexes, shoot fresh weight and root length were affected more strongly than stem length. However, no clear differences were observed between the tested NaCl concentrations. Salinity decreased stem length from 0.0 % to 23.9% compared to the NaCl treatment. Decreases in root length ranged from 2.1% to 28.4%. Variation in shoot fresh weight was between 11.1% and 61.8%. According to our findings, other authors also reported that the continuous presence of NaCl in the nutrient solution, especially in higher concentrations (0.6 and 1.2 mg L⁻¹), shortened vegetation periods and reduced pea growth, and root dry weight, but changes are not statistically significant (Maksimović et al., 2010). The obtained data revealed that Zornitsa was the most tolerant cultivar,
followed by Mira. The most sensitive one was Ran 1. These findings were consistent with that from the in vitro experiment.

Table 4: Morphology evaluation of in vivo grown plants of three garden pea cultivars under salinity stress

<table>
<thead>
<tr>
<th>NaCl mM</th>
<th>Mira</th>
<th>Zornitsa</th>
<th>Ran 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>66.9±3.7*</td>
<td>27.6±2.3*</td>
<td>39.1±6.2*</td>
</tr>
<tr>
<td>50</td>
<td>20.6±1.2*</td>
<td>9.4±1.6*</td>
<td>36.8±5.4*</td>
</tr>
<tr>
<td>100</td>
<td>15.8±3.6*</td>
<td>12.0±3.5*</td>
<td>30.2±6.4*</td>
</tr>
<tr>
<td>200</td>
<td>16.9±3.9*</td>
<td>7.2±4.8*</td>
<td>36.9±9.1*</td>
</tr>
</tbody>
</table>

\* Stem length (cm)

<table>
<thead>
<tr>
<th>NaCl mM</th>
<th>Mira</th>
<th>Zornitsa</th>
<th>Ran 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>29.2±8.5*</td>
<td>14.3±6.0*</td>
<td>19.3±5.4*</td>
</tr>
<tr>
<td>50</td>
<td>18.5±3.5*</td>
<td>11.2±2.9*</td>
<td>24.3±7.3*</td>
</tr>
<tr>
<td>100</td>
<td>26.7±6.6*</td>
<td>10.6±2.4*</td>
<td>28.4±9.4*</td>
</tr>
<tr>
<td>200</td>
<td>7.9±3.8*</td>
<td>13.8±3.6*</td>
<td>6.8±4.6*</td>
</tr>
</tbody>
</table>

\* Root length (cm)

<table>
<thead>
<tr>
<th>NaCl mM</th>
<th>Mira</th>
<th>Zornitsa</th>
<th>Ran 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>5.4±3.1*</td>
<td>2.7±0.9*</td>
<td>5.5±2.7*</td>
</tr>
<tr>
<td>50</td>
<td>33.3±1.3*</td>
<td>4.1±1.1*</td>
<td>51.9±1.9*</td>
</tr>
<tr>
<td>100</td>
<td>50.0±1.1*</td>
<td>1.9±0.7*</td>
<td>29.6±1.5*</td>
</tr>
<tr>
<td>200</td>
<td>11.1±1.6*</td>
<td>2.2±0.4*</td>
<td>18.5±2.6*</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>NaCl mM</th>
<th>Mira</th>
<th>Zornitsa</th>
<th>Ran 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>4.8±1.6*</td>
<td>11.1±1.6*</td>
<td>18.5±2.6*</td>
</tr>
<tr>
<td>50</td>
<td>3.6±1.0*</td>
<td>11.1±1.0*</td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>2.7±1.2*</td>
<td>1.2±0.7*</td>
<td></td>
</tr>
<tr>
<td>200</td>
<td>1.1±0.3*</td>
<td>1.1±0.3*</td>
<td></td>
</tr>
</tbody>
</table>

\* Shoot fresh weight (g)

a,b,c,…: Duncan’s Multiple Range (p≤0.05).
ns – non-significant

4. Conclusions

The obtained results clearly demonstrated that salinity stress induce significant reduction in germination, emergence rate and growth parameters (shoot and root length), in the three pea cultivars in both in vitro and in vivo conditions. The data in present study showed that cultivar Zornitsa was more tolerant to salinity stress than cultivars Mira and Ran 1. The tolerance was associated with higher percentage of developed seeds and the lower depression of shoot and root growth in the highest tested concentration of NaCl (200 mM).

Acknowledgment

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References


IRRIGATION REGIME FOR LONG-FRUIT CUCUMBERS GROWN UNDER GREENHOUSE CONDITIONS

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SUMMARY: The deficit of the irrigation water requires irrigation technologies of more efficient water use. For cucumbers the most suitable is the drip irrigation. For establish the appropriate irrigation schedule of cucumbers under the soil and climate conditions in the village of Chelopechene, near Sofia city, research was conducted with drip irrigation adopting varying irrigation schedules - from fully meeting the daily crops water requirements cucumbers to reduced depths with 20% and 40%. Have been established irrigation schedule, irrigation water productivity and yields of in plastic unheated greenhouses of the Sofia plant.

KEY WORDS: IRRIGATION, YIELD, IRRIGATION SCHEDULING, DRIP IRRIGATION, PLASTIC UNHEATED GREENHOUSE, LONG-FRUIT CUCUMBERS

Introduction

Climate change due to global warming has a significant impact on water resources, including groundwater and surface water (Ziad A. M. and S. A. Jamous, 2010). Drought periods vary in duration and time of manifestation.

Climate change in agriculture as a result of climate change necessitates the use of appropriate systems and technologies for growing and irrigating crops in accordance with soil, climate, environmental and economic conditions. Under the new conditions of agricultural development, water is a limiting factor and becomes extremely important from an environmental and economic point of view. It is also a decisive factor in achieving the maximum productive capacity of crops in the optimal provision of plants with water.

Reducing crop water consumption can be achieved by: optimizing the parameters of the applied irrigation regime, irrigating crops with reduced irrigation rates and applying water-saving irrigation technologies such as drip irrigation.

In this aspect, it is unrivaled in greenhouse vegetable production. This technology fully meets the requirements for sustainable agriculture and environmentally friendly fruit production, ensures high yields and quality of production, reduces unwanted side effects. (Branson, R.L., 1981)

It has been proven that vegetable crops respond very well to drip irrigation, both in terms of quality and quantity of production, and in terms of irrigation water productivity.

One of the most common - the cucumber is demanding on soil and air humidity. This is due to its relatively poorly developed root system and to the arrangement of its leaf apparatus with a poorly developed cuticle (Shaban, H. et al, 2014)

For their normal development and fruiting, soil moisture is required to be above 80% of the WHC (Murtazov et al., 1975), with the best results in the use of plant water obtained by drip irrigation, and the increase in yields reaches from 15% to 18% against rain and gravity irrigation (Clark, 1979)

Concerning the cultivation of vegetables in the Sofia region, the following more important conclusions can be drawn regarding the natural conditions:

- the area is suitable for growing vegetables, as the temperature conditions meet their requirements. The duration of the period with steady retention of average daytime air temperatures above 10C is 180 - 200 days. The temperature sum for this period is 33 - 35C. This temperature sum is sufficient for the development of basic vegetable curls. (Hershkovich and Stefanov, 1982)

- to obtain earlier production in the area, it is necessary to use plastic greenhouses to prevent late spring and early autumn frosts. (Mihov et al., 1981)

Research on irrigation regimes of vegetable crops, incl. and long-fruit cucumbers grown in cultivation facilities continue to be relevant, given the objective changes that occur in agriculture.

The purpose of the forthcoming research is to establish the optimal values of irrigation parameters of long - fruited cucumbers irrigated by drip - irrigation and irrigation norms, inter-irrigation periods and number of irrigations.

● MATERIAL AND METHODS

In order to determine the drip regime in terms of the amount of water supplied, the irrigation period, the amount of irrigation rate, and the influence of irrigation regimes on the yields of long-fruit cucumbers. The Gergana variety was chosen for the experiment because of its widespread distribution, high quality, taste and quantity indicators. The experiment was carried out in unheated plastic greenhouses of the type "Polymerstroy" in an experimental field in the village of Chelopechene - Sofia, as follows:

1st variant - irrigation with 120% of the irrigation rate determined in the optimal variant (120% m);
2nd variant - irrigation with full irrigation rate (100% m) - optimal irrigation (control);
3rd variant - irrigation with 80% of the irrigation rate, determined in the optimal variant (80% m);
4th variant - irrigation with 60% of the irrigation rate, determined in the optimal variant (60% m);

The irrigation in the optimal variant (variant 2) is applied when the soil humidity drops to 85% of the WF in the layer 0 - 0.5 m, and the amount of irrigation rate is calculated for wetting up to the WF of the entire active soil layer (0 - 60 cm).

Irrigation rates are calculated by the formula:

\[ m = \left[ 10 \cdot H \cdot \alpha \cdot (\delta_t \cdot \sigma_{WFD} - \delta_r \cdot \sigma_{WFD}) \right] K_i K_i \]

where:
- \( m \) is the magnitude of the irrigation rate in mm;
- \( \alpha \) is the bulk density of soil in gr / cm3;
- \( H \) is the depth of the active soil layer in m (in the experiment \( H = 0.5 \) m);
- \( \delta_t \) of WFD - field moisture limit in% relative to the absolutely dry soil weight;
- \( \delta_r \) of soil moisture limit in% relative to the absolutely dry weight of the soil;
- \( K_i \) is the water use efficiency of irrigation, which for cucumbers is 1.8 - 2.0.
K - the rate of reduction of the irrigation rate, taking into account the area occupied by plants in 1 dka. In the experiment, K = 0.525, i.e. 52.5% of the area is irrigated.

Drip irrigation does not convey the size of the entire irrigation rate, as with other irrigation methods. Reduction is made at the expense of the non-irrigated area. The Ferckman formula, Grazoli [6] was used for this purpose, taking into account the planting scheme. After calculating the irrigation rate for variant 2, the norms of the other variants are determined by its size.

The irrigation was done with an Agroadrip drip irrigation installation. The pipelines of this type of irrigation systems are polyethylene, consisting of two pipes inserted into each other with a long screw channel formed for the movement of water with an outside diameter of 20 mm, the openings for supplying water through 30 cm, the water quantity of one opening is 2.4 l/h at a working pressure of 0.1 MPa.

Soil moisture dynamics is monitored by sampling soils that have been processed by the thermostatic weight method in the 100% version of the irrigation rate. 100% irrigation rate is the rate calculated on the basis of water - the physical properties of the soil and its mechanical composition, the biology of the crop, the soil WHC, the over-humidity.

The experiment was performed by block method in four repetitions on leached cinnamon forest soil, characterized by the following water-physical properties: PPV - 20.2 relative to the absolute weight of the soil, bulk density at WHC 1.54 g/cm³ and humidity 10.38%, by weight of absolutely dry soil.

**Results and discussion**

Studies on irrigation standards, taking into account the water-physical characteristics of the soil type, make it possible to determine the extent to which the biological needs of the crop are fully met without significant loss of water.

The results obtained from the experimental years are unidirectional, since the experiment is performed under controlled conditions and the experimental years have similar meteorological conditions. In terms of air temperature, the years during which the experiment was taken are characterized as warm.

The presented results of the replanted irrigation and irrigation norms show that to maintain soil moisture in the range between 85-100% of the WHC in long-fruit cucumbers, they were realized with 21 irrigations average over the study period. Under the conditions of the Sofia Field, they were implemented from the beginning of April to the end of July. The inter-irrigation periods during the different phases of the culture's development are different. At the beginning of the growing season, the needs of the plants for humidity are small, there is little and the tension of meteorological factors and irrigation are carried out in 7 - 10 days. During this period, the plants had a small leaf area and lacked fruting organs and fruits. The root system is poorly developed. With increasing leaf area and the formation of fruting organs and fruits, the needs of plants for soil moisture increase. During this period the tension of the meteorological factors in both the open air and the greenhouse increased. Waterings are made every 3-4 days.

In Option 2, where the calculated irrigation rate is submitted, it is found that the over-humidity is maintained on average 85-90% of the WHC.

Maximum irrigation rates in individual years during the period of maximum water consumption can be submitted in 3-4 days and meet the needs of the plants. Under 1.5 atmospheres, they are realized within 2 - 3 hours.

Irrigation rates by year varied from 11.6 to 22.1 mm for the individual variants, and irrigation rates from 230 to 450 mm averaged over the study period (Table 1). The main part of the water consumption of greenhouse vegetables is evapotranspiration, which is not significantly different from irrigation norms, since it is formed almost entirely from them.

The yields that are obtained from vegetables in cultivation facilities of the type of heated greenhouses depend to some extent on the weather conditions of the particular year (temperatures) and the factors tested. In the present development, the test factor is the size of the irrigation rate.

The irrigation regimes implemented influenced the formation of yields of long-fruit cucumbers. The highest yields in the soil and meteorological conditions for the Sofia, field average over the study period were obtained in the variant irrigated with 120% realization of the irrigation rate. Its yield is 8391 kg/dka, followed by the variant with 100% irrigation rate - 8010 kg/dka.

The lowest yields were obtained with the variant with 40% reduction of the norm - 6055 kg/dka. A 20% increase in the irrigation rate led to a slight increase in yields by 5%, which is economically unreasonable compared to the cost of the water supplied. In the face of water scarcity and costly irrigation water, the information collected proves that the increase in irrigation rates of the studied crop grown in a plastic greenhouse is not justified.

A 20% reduction in the irrigation rate resulted in an 8% decrease in yields compared to the 100% irrigation option. This irrigation mode can be used in case of water shortage.

**Table 1:** Number of irrigations, watering’s and irrigation norms in variants

<table>
<thead>
<tr>
<th>Variants</th>
<th>Number of irrigations</th>
<th>Irrigation norm, mm</th>
<th>W.norm mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.120% M</td>
<td>21</td>
<td>19</td>
<td>22</td>
</tr>
<tr>
<td>2.100% M</td>
<td>21</td>
<td>19</td>
<td>22</td>
</tr>
<tr>
<td>3. 80% M</td>
<td>21</td>
<td>19</td>
<td>22</td>
</tr>
<tr>
<td>4. 60% M</td>
<td>21</td>
<td>19</td>
<td>22</td>
</tr>
</tbody>
</table>

**Table 2:** Yield of the long-skirted on variants end years

<table>
<thead>
<tr>
<th>Variants</th>
<th>2001</th>
<th>2002</th>
<th>2003</th>
<th>2004</th>
<th>2001 - 2004</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Yield, kg/dka</td>
<td>Yield, kg/dka</td>
<td>Yield, kg/dka</td>
<td>Yield, kg/dka</td>
<td>Relative, yield %</td>
</tr>
<tr>
<td>120% M</td>
<td>8728</td>
<td>8189</td>
<td>8597</td>
<td>8051</td>
<td>8391</td>
</tr>
<tr>
<td>100% M</td>
<td>8320</td>
<td>7836</td>
<td>7938</td>
<td>7946</td>
<td>8010</td>
</tr>
<tr>
<td>80% M</td>
<td>7780</td>
<td>7327</td>
<td>7351</td>
<td>7184</td>
<td>7411</td>
</tr>
<tr>
<td>60% M</td>
<td>6520</td>
<td>5662</td>
<td>6204</td>
<td>5834</td>
<td>6055</td>
</tr>
</tbody>
</table>
Experiments conducted under greenhouse conditions with long-fruit cucumbers show that cost-effective irrigation yields for irrigation water are obtained while maintaining soil moisture within 85-90% of WHC, which best meets the biological needs of the crop and its water-physical properties. The 20% increase in the irrigation rate led to a slight increase in yields from 2% to 5%, which is economically unreasonable compared to the cost of the water supplied. In the face of water scarcity and costly irrigation water, the information collected proves that the increase in irrigation rates of the studied crop grown in a plastic greenhouse is not justified.

Conclusions:
1. To maintain soil moisture in the range of 85 - 90% of WHC when growing long-fruit cucumbers in plastic unheated greenhouses, 21 irrigation irrigation rates of 18.3 mm and irrigation rate of 374 mm are required.
2. For the study period, the highest yield of long-fruit cucumbers was obtained at 120% irrigation rate - 8391 kg / dka and the lowest at 40% reduction in irrigation rate - 6055 kg / dka.
3. The increase of the irrigation rate by 20% resulted in a slight increase in yields from 2% to 5%, by 5%, which does not compensate for the consumption of water. In the face of water scarcity and expensive irrigation water, it was proved that the increase in the irrigation norms of the studied crop grown in a plastic greenhouse was not justified.
4. The results of the experiment give us reason to recommend that irrigation of long-fruit cucumbers under greenhouse conditions should be carried out with an irrigation rate of 18 mm or a total of 374 m3 / dka irrigation rate. In case of water shortage, apply a irrigation regime with a 20% reduction in the irrigation rate, in which a satisfactory yield of 7411 kg / dka is obtained.

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