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Differential equations of motion of table beet root crop of round shape on the surface of a spiral separator

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Abstract. *An actual problem in the technological process of table beet production is the cleaning of root crops from adhered soil, soil impurities and plant residues after digging them out of the soil. In this paper we have constructed a mathematical model of table beet root crop movement along the working channel of the new construction of the spiral separator developed by us, because at such movement just the cleaning of root crops from these impurities takes place. On the basis of the equivalent scheme developed in this article, a system of differential equations of motion of table beet root crop along the surface of the working channel of the spiral separator is drawn up. The solution of the obtained system of differential equations on the PC makes it possible to investigate the influence of constructive and kinematic parameters of the separator on the speed of movement of the root crop in the working channel before its descent from the spirals. Thus determined constructive and kinematic parameters will provide improvement of the quality of cleaning of table beet root crops from soil impurities and plant residues.*

KEYWORDS: *TABLE BEET, ROOT CROP, SPIRAL SEPARATOR, EQUIVALENT SCHEME, DIFFERENTIAL EQUATIONS, MATHEMATICAL MODEL, DESIGN AND KINEMATIC PARAMETERS.*

1. Introduction

At the time of table beet harvesting, its haulm is in a lodged state. Therefore, the harvesting technology is a continuous cutting of the haulm and further digging of root crops, which requires their cleaning from loose and sticky soil, as well as plant residues. It should be noted that a number of works [1-6] are devoted to the cleaning of potato roots and tubers immediately after digging them out of the soil. This stage should ensure high quality of harvesting with minimal damage to root crops, which makes it possible to store them for a long time.

The most suitable cleaner of table beet root crops from the specified impurities can be a spiral separator. For this purpose, a spiral separator can be used as a prototype [7, 8]. Experimental studies have shown that this separator provides a sufficiently high level of cleaning with minimal damage to root crops, which are within the agrotechnical requirements. However, table beet harvesting takes place in conditions different from potato harvesting. In addition, there is a difference and technological material. Therefore, there is a need to change the technical and technological characteristics of the above-mentioned separator [9].

For this purpose, we have developed a new construction of spiral separator of table beet root crops, which has significant advantages over existing separators.

However, to determine the rational construction and kinematic parameters of our proposed construction of the separator it is necessary to conduct a number of theoretical and experimental studies of the interaction of table beet roots with the working bodies of the separator. Such studies of the spiral separator for potato peeling are presented in [10, 11]. For this purpose, we will make differential equations of motion of table beet root crop along the working bodies (spiral springs) of the mentioned separator. In this regard, it should be noted that the most common form of table beet root is round, i.e. in the form of a ball or slightly flattened along the vertical axis of the ellipsoid. Therefore, in the mathematical model, we will consider the movement of a spherical-shaped root crop.

The developed mathematical model will give an opportunity to carry out numerical modeling with the use of PC, i.e. machine experiment, as a result of which the considered process will be comprehensively studied and rational constructive and kinematic parameters of the separator will be theoretically determined taking into account the non-damage of table beet roots in the process of their cleaning.

2. Results and discussions

To build the mentioned mathematical model, let us consider one of the most probable variants of the root crop location in the working channel of the spiral separator. This is the case when the table beet root crop is located on the lower spiral 1, and its lower part is between two neighboring turns of the mentioned spiral, thus contacting its surface at two points K_1 and K_2 (Fig. 1). The rotation of the spiral 1 causes the root crop to move in said working channel in a longitudinal axial direction before descending from said spiral.

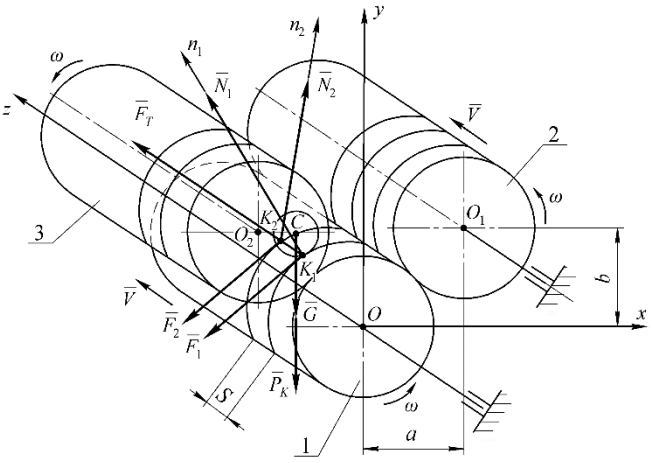


Figure. 1*. Equivalent scheme of interaction of table beet root crop with turns of the separator cleaning spirals*

More precisely, turns of spiral 1 at the points of contact K_1 and K_2 with the root crop at rotation of spirals will slip on its surface, thus involving the root crop in translational motion along the working channel before coming off this channel at the free end of the spiral. In this case, the cleaning of root crops from free soil and plant residues will be carried out by separating impurities through the interscroll space of spiral springs, due to transverse oscillations of cantilever springs in the vertical plane. However, the main movement of the root crop will be its translational movement along the longitudinal axes of the spirals, due to which the pile will be transported along the working surface of the separator. Therefore, it is necessary to theoretically investigate the process of root crop movement along the longitudinal axis of the spiral.

To make differential equations of root crop motion along the longitudinal axis of the spiral, it is necessary to develop an equivalent scheme of its interaction with the surfaces of the spiral turns at the contact points K_1 and K_2 (Fig. 1). As shown in the scheme, the lower part of the root crop is located in the depression between two neighboring turns of the spiral 1. Moreover, the first coil in the direction of movement of the root crop will be pushing and the second coil will be supporting.

As shown in the equivalent diagram, at each point of contact K_1 and K_2 act normal reactions and respectively.

The normal reactions $\overline{N}_1$ and $\overline{N}_2$ are directed along the normals to the surface of the corresponding turns at the contact points K_1 and K_2. The direction of action of the normal reactions is formed by the turns of the helix, the geometrical properties of which are described by the equations of the helical line of the said helix. The mentioned equations of the helical line of the spiral serve as coupling equations, which specify geometrical properties of the

trajectory of movement of the contact points K_1 and K_2 as they move along the turns of the spiral.

At the center of mass of the root crop (point C) is applied its gravity In addition to the already mentioned forces, the equivalent diagram shows friction forces $\bar{F}_1$ and $\bar{F}_2$, applied at the corresponding contact points K_1 and K_2. These forces arise from the slippage of the turns of the spiral 1 on the surface of the root crop. They are directed in the direction of rotation of the spiral along the tangents to the surface of the coils at the points of contact with the surface of the root crop.

In addition, to ensure the movement of the root crop in the direction of the longitudinal axis of the spiral 1 there is a driving force $\bar{F}_T$, applied at the point of contact K_1. This force is directed parallel to the longitudinal axis of the spiral in the direction of movement of the root crop in the working channel.

The equivalent diagram also shows the active force of the crop fed to the spiral separator, which causes the spirals to bend and, because of its variable value due to the change in the mass of the crop fed, causes transverse oscillations of the spirals. It is directed vertically downwards.

To compose the differential equations of motion of table beet root crop in the working channel, we choose a fixed spatial Cartesian coordinate system *xOyz*, the origin of which (point *O*) is located on the longitudinal axis of the spiral 1, axis *Oz* coincides with the longitudinal axis of spiral 1, axis *Oy* is directed vertically upwards, axis *Ox* is directed to the right, perpendicular to the plane *Oyz*, and axes *Ox* and *Oy* are located in the plane of the cross-section of spiral 1 (Fig. 1).

Taking into account the scheme of forces shown in the equivalent diagram, using the basic law of dynamics of a material point, let us write down the equation of motion of the table beet root in vector form:

$$m \cdot \bar{a} = \bar{G} + \bar{N}_1 + \bar{N}_2 + \bar{F}_1 + \bar{F}_2 + \bar{F}_T + \bar{P}_K, \quad (1)$$

where $\bar{a}$ – is the acceleration of the table beet root along the working channel under the action of the forces indicated in the diagram.

Let's write further vector equation (1) in projections on axes of Cartesian coordinate system *xOyz*:

$$\left.\begin{aligned} &m \cdot \ddot{x} = N_1 \cdot \cos\left(x,\wedge\bar{n}_1\right) + N_2 \cdot \cos\left(x,\wedge\bar{n}_2\right) - \\ &-F_1 \cdot \cos\left(x,\wedge\bar{V}_1\right) - F_2 \cdot \cos\left(x,\wedge\bar{V}_2\right), \\ &m \cdot \ddot{y} = N_1 \cdot \cos\left(y,\wedge\bar{n}_1\right) + N_2 \cdot \cos\left(y,\wedge\bar{n}_2\right) - \\ &-F_1 \cdot \cos\left(y,\wedge\bar{V}_1\right) - F_2 \cdot \cos\left(y,\wedge\bar{V}_2\right) - G - P_K, \\ &m \cdot \ddot{z} = N_1 \cdot \cos\left(z,\wedge\bar{n}_1\right) + N_2 \cdot \cos\left(z,\wedge\bar{n}_2\right) - \\ &-F_1 \cdot \cos\left(z,\wedge\bar{V}_1\right) - F_2 \cdot \cos\left(z,\wedge\bar{V}_2\right) + F_T, \end{aligned}\right\} \quad (2)$$

where $\bar{n}_1$ and $\bar{n}_2$ – normal to the surface of the spiral turns at the contact points K_1 and K_2, respectively; $\bar{V}_1$ and $\bar{V}_2$ – velocity vectors of relative movement of the table beet root along the spiral turns at the contact points K_1 and K_2, which are directed along the tangent to the spiral surface in the direction opposite to the circumferential velocity of the turn at the contact points K_1 and K_2, respectively.

Further, we define the directional cosines of the angles included in the system of differential equations (2).

The directional cosines of the angles between the axes of the *xOyz* coordinate system and the direction of the normals to the surface of the coils at the contact points K_1 and K_2 are determined according to [12], which are conveniently represented in parametric form. For this purpose, the parametric equations of the helical line [13] are used.

As a result, we obtain the values of the directional cosines of the angles between the coordinate axes *Ox*, *Oy* and *Oz* and the normal reactions of the spiral turns at the contact points K_1 and K_2 in parametric form:

$$\begin{aligned} &\cos\left(x,\wedge\bar{n}_1\right) = \cos\left(x,\wedge\bar{n}_2\right) = \\ &= \left(L \cdot \sin\omega t + M \cdot \cos\omega t \cdot \sin 2\omega t\right) \times \\ &\times \left(\sqrt{L^2 + \left(2ML + M^2\right) \cdot \sin^2 2\omega t + Q^2 \cos^2 2\omega t}\right)^{-1}, \end{aligned} \quad (3)$$

$$\begin{aligned} &\cos\left(y,\wedge\bar{n}_1\right) = \cos\left(y,\wedge\bar{n}_2\right) = \\ &= \left(L \cdot \cos\omega t + M \cdot \sin\omega t \cdot \sin 2\omega t\right) \times \\ &\times \left(\sqrt{L^2 + \left(2ML + M^2\right) \cdot \sin^2 2\omega t + Q^2 \cos^2 2\omega t}\right)^{-1}, \end{aligned} \quad (4)$$

$$\begin{aligned} &\cos\left(z,\wedge\bar{n}_1\right) = -\cos\left(z,\wedge\bar{n}_2\right) = \\ &= Q\cos 2\omega t \cdot \left(\sqrt{L^2 + \left(2ML + M^2\right) \cdot \sin^2 2\omega t + Q^2 \cos^2 2\omega t}\right)^{-1}. \end{aligned} \quad (5)$$

Where

$$L = -\frac{S^2}{4\pi^2 R} \cdot \cos\left(\frac{S}{2\pi R}\right), \quad (6)$$

$$M = \frac{S^2}{4\pi^2 R} \cdot \cos\left(\frac{S}{2\pi R}\right) - \frac{S^3}{8\pi^3 R^2} \cdot \sin\left(\frac{S}{2\pi R}\right), \quad (7)$$

$$Q = \frac{S}{2\pi} \cdot \cos\left(\frac{S}{2\pi R}\right), \quad (8)$$

where R – is the radius of the helix, S is the pitch of the helical line, ω is the angular velocity of the helix.

Let us further determine the directional cosines of the friction forces.

This is reduced to the determination of the cosines of the angles between the vectors of relative velocities of movement of the root crop along the turns of the spirals at the contact points K_1 and K_2, and the coordinate axes *Ox*, *Oy* and *Oz*, i. e. $\cos\left(x,\wedge\bar{V}_i\right)$, $\cos\left(y,\wedge\bar{V}_i\right)$ and $\cos\left(z,\wedge\bar{V}_i\right)$, ($i$ = 1, 2).

It should be taken into account that vectors $\bar{V}_1$ and $\bar{V}_2$ are collinear. Therefore, the following equations hold:

$$\begin{aligned} &\cos\left(x,\wedge\bar{V}_2\right) = \cos\left(x,\wedge\bar{V}_1\right), \\ &\cos\left(y,\wedge\bar{V}_2\right) = \cos\left(y,\wedge\bar{V}_1\right), \\ &\cos\left(z,\wedge\bar{V}_2\right) = \cos\left(z,\wedge\bar{V}_1\right). \end{aligned} \quad (9)$$

The directional cosines $\cos\left(x,\wedge\bar{V}_i\right)$, $\cos\left(y,\wedge\bar{V}_i\right)$ and $\cos\left(z,\wedge\bar{V}_i\right)$, ($i$ = 1, 2), in the Cartesian coordinate system can be found according to [12] and represented parametrically using the parametric equations of the helical line [13]. As a result, we obtain:

$$\cos\left(x,\wedge\bar{V}_2\right) = \cos\left(x,\wedge\bar{V}_1\right) = \frac{2\pi R \cdot \sin\omega t}{\sqrt{4\pi^2 R^2 + S^2}}, \quad (10)$$

$$\cos\left(y,\wedge\bar{V}_2\right) = \cos\left(y,\wedge\bar{V}_1\right) = -\frac{2\pi R \cdot \cos\omega t}{\sqrt{4\pi^2 R^2 + S^2}}, \quad (11)$$

$$\cos\left(z,\wedge\bar{V}_2\right) = \cos\left(z,\wedge\bar{V}_1\right) = \frac{S}{\sqrt{4\pi^2 R^2 + S^2}}. \quad (12)$$

Substituting expressions (3) – (5) and (10) – (12) into the system of differential equations (2), after a number of transformations we obtain the following system of differential equations in parametric form:

$$\left.\begin{aligned}
&m\cdot\ddot{x}=\left(N_1+N_2\right)\cdot\left(L\cdot\sin\omega t+M\cdot\cos\omega t\cdot\sin 2\omega t\right)\times\\
&\times\left(\sqrt{L^2+\left(2ML+M^2\right)\cdot\sin^2 2\omega t+Q^2\cos^2 2\omega t}\right)^{-1}-\\
&-\left(F_1+F_2\right)\cdot\frac{2\pi R\cdot\sin\omega t}{\sqrt{4\pi^2R^2+S^2}},\\
&m\cdot\ddot{y}=\left(N_1+N_2\right)\cdot\left(L\cdot\cos\omega t+M\cdot\sin\omega t\cdot\sin 2\omega t\right)\times\\
&\times\left(\sqrt{L^2+\left(2ML+M^2\right)\cdot\sin^2 2\omega t+Q^2\cos^2 2\omega t}\right)^{-1}+\\
&+\left(F_1+F_2\right)\cdot\frac{2\pi R\cdot\cos\omega t}{\sqrt{4\pi^2R^2+S^2}}-mg-P_K,\\
&m\cdot\ddot{z}=\left(N_1-N_2\right)\cdot Q\cos 2\omega t\times\\
&\times\left(\sqrt{L^2+\left(2ML+M^2\right)\cdot\sin^2 2\omega t+Q^2\cos^2 2\omega t}\right)^{-1}-\\
&-\left(F_1+F_2\right)\cdot\frac{S}{\sqrt{4\pi^2R^2+S^2}}+F_T.
\end{aligned}\right\}\qquad(13)$$

The system of differential equations (13) is a system of differential equations of motion of table beet root crop under the action of rotating spirals along the working channel formed by cantilever spiral springs, where the root crop is cleaned from soil impurities and plant residues.

As a result of twofold integration of the system (13) taking into account the initial conditions, it is possible to obtain the laws of movement of table beet root crop along the working channel of the spiral separator as functions of time t and values of its parameters.

3. Conclusion

1. The system of differential equations of motion of table beet root crop along the working channel of spiral separator is obtained, on the basis of which it is possible to determine rational design parameters and kinematic modes of operation of the mentioned separator by means of PC.

2. As a result of solving the system of differential equations on the PC will be obtained graphical dependencies of the influence of kinematic parameters of the separator on the speed of movement of root crops along its working channel.

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Development of experimental setup, program and methods experimental research of carrot heads cleaning from root haulm residues

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Abstract. *Mechanized carrot growing technologies involve the use of various operations, in particular, digging by pulling the root and removing it inside the combine, as well as by pre-cutting the green mass of the root and subsequent cleaning of the heads from the remains of the root before digging. Due to the fact that there are high requirements for cleaning carrot root heads from residues, the development of new, more improved cleaners is an important and urgent task. The solution to this problem was implemented by developing a new design of the purifier, which is able to perform the specified cleaning process with high quality. The cleaner consists of two shafts that cover each row of carrots on both sides and rotate in opposite directions. Cleaning shafts are located in a horizontal plane at an angle to each other. As cleaning elements, pairs of rubber blades are used, which are installed on hubs on each shaft, which are fixed on the shafts with the appropriate step. The rubber blades are mounted on hubs hinged and the ends of the blades of one shaft are located between the pairs of blades of the second shaft. By simultaneously hitting the heads of the carrot root crops with flexible blades from both sides, the process of cleaning them from residues is carried out. In order to study the process of cleaning carrot heads from the remains of ghee on the root, an experimental installation was made and a program of experimental studies of this technological process was developed.*
KEYWORDS: *CARROTS, PUMP COLLECTION, REMAINS, EXPERIMENTAL RESEARCH, INSTALLATION, PROGRAM.*

1. Introduction

Among the modern technologies for harvesting root crops, in particular carrots, which are grown industrially, the most common is the technology of separate harvesting, that is, when a separate unit is used to collect the ghee on the root, and then the root crops are dug out of the soil with a root harvester.

Previously, the technology of harvesting the gorse involved its previous continuous cut at an elevated height and the subsequent mechanical cutting of the upper parts of the heads together with the remains. At the same time, the cut parts of the heads were not collected, but, on the contrary, were scattered over the surface of the field, and later, as fertilizers, they were plowed into the soil. However, recently it has been thoroughly investigated and found that along with the cut parts of the heads, the useful parts of root crops are irreversibly lost. Yes, this is especially noticeable when harvesting sugar beets, when up to 14% of sugar can be lost together with the cut root heads. In addition, due to the mechanical cutting of the heads of root crops, juice is almost immediately lost from their bodies, the cut part becomes a place through which microbes and viruses begin to penetrate into the body, causing their subsequent decay and loss. In general, it is impossible to store such root crops, even for a small period of time, and they urgently need to be processed. In addition, even with short-term storage, their marketability is intensively lost. Modern gorse harvesting machines of foreign production provided not only for cutting, but also for grinding the entire massif of cut green gorse and spreading it on the field, also as a plant fertilizer.

In this regard, in the future, the technology of collecting gorse was improved and provided for a preliminary continuous section of the green array of gorse, and then a separate operation was performed to clean the carrot heads from the remains of gorse on the root without damage and to knock out the bodies of root crops from the soil. Recently, carrot husks have been collected, taken from the fields and effectively used in the production of biogas.

The technological process of harvesting scallions and cleaning carrot heads from residues on the roots must meet agrotechnical requirements. Thus, the appropriate operation related to the final cleaning of the heads of carrot root crops from residues involves the waste of parts of the heads of no more than 5% by mass, and contamination by residues should be no more than 0.5% [1].

Thus, careful cutting and harvesting of a solid mass of carrot tops, high-quality cleaning of their heads from residues on the root, ensuring the quality of the root heads, in which they do not have plant remains on their surface, nor their damage, nor the roots themselves being knocked out of the soil, are a very important and urgent problem in the field of vegetable growing.

Research was devoted to the solution of the problem of cleaning the heads of root crops, including carrots, from the remains of ghee on the root, which were reflected in numerous scientific works [2, 3]. In particular, the works of L. V. Pohorily [4, 5] are devoted to the fundamental basis of creating various designs of cleaners and the development of the theory of cleaning the root heads of sugar beet root crops. The works of V.Ya. Martynenko [6, 7] and V.M. Bulgakov [8, 9] are devoted to the creation of the theoretical foundations of mechanical combing and removal of chaff residues from the root heads of sugar beet root crops. The development of various designs of cleaners for the heads of root crops from the remains of ghee on the root and the theoretical and experimental substantiation of their parameters were reflected in the works of M. M. Helemendik [10], B. P. Shabelnyk [11], M. M. Borys [12] and others.

However, a thorough analysis of both the design of the existing cleaners (with horizontal and vertical drive shafts on which the cleaning elements are installed) and studies of their performance indicators, obtained from the results of testing and field experimental studies, shows that the quality of their work is largely depends on the type of root crops and the condition of their crops at the time of harvesting. Thus, even the OGD-6 root head cleaner, which was industrially manufactured and used as a separate cleaning unit, was not under all conditions able to effectively separate all the residue from root heads from 6 rows of crops with a continuous drive shaft with a horizontal axis of rotation and hingedly mounted on it flexible cleaning blades. The more advanced cleaner OGD-6A, which was also manufactured industrially and is still used, already had two successively installed same cleaning shafts, but it was also unable to effectively separate the remains of ghee on the heads of sugar beet root crops, especially their short and strong stems, which remained after the main continuous section of the massif of the haulm.

This is due to the fact that when moving in a straight line along the rows of cut root heads, the flexible cleaning blades have planes of rotation that are parallel to the specified rows. As a result, the ends of the cleaning blades may not touch the rear and side parts of the heads of root crops located above the field surface. Taking into account the increase in the speed of translational movements of modern harvesting units, this drawback is not only insurmountable, but also has the ability to strengthen.

The development of new designs of cleaners, which have individual cleaning working bodies for each row of crops, is also not without the indicated drawback, since the application of cleaning efforts to each head of the root crop can be more directed to the spherical surfaces of the heads of different sizes and shapes, however, with progressive rectilinear movement with at a considerable speed, they are also unable to clear the front and back of the heads located in the row of crops along which they move. In addition, those root crops that have an offset from the center line of the row of crops (this is due to the agricultural techniques of cultivation and the peculiarities of cultivation) may generally be uncleaned by such types of cleaners. This type of cleaners has increased energy costs for this process.

The use of harder materials as cleaning elements also has a negative effect on the quality of cleaning, as the heads and bodies of root crops can be significantly damaged and lost.

Increasing the effort of pressing even flexible cleaning elements to the heads of root crops also negatively affects the quality of the execution of this technological process, as it leads not only to their damage, but most importantly to the intensive knocking out of the bodies of root crops from the soil. Clamping forces must be applied simultaneously from several sides of the heads, but this is not always possible.

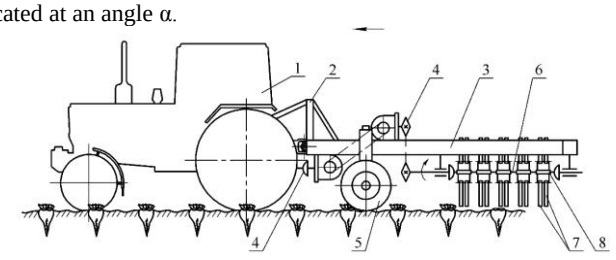
Thus, the search for the most effective constructive solutions for cleaning the heads of root crops from residues on the root should take into account the noted features and shortcomings, and their justified kinematic, constructive and operational indicators should ensure high-quality performance of this technological process.

2. Results and discussions

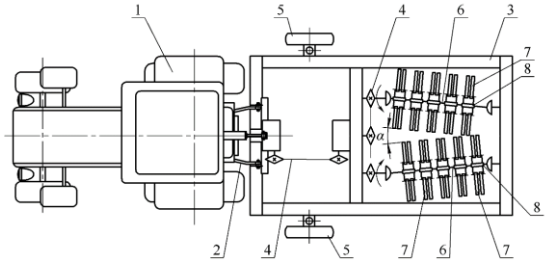
An experimental setup was developed and manufactured for experimental research. In fact, a new carrot head cleaner was developed, which is at once two cleaning shafts, on which working cleaning elements in the form of pairs of rubber blades are hinged. The cleaning shafts in this design cover each row of root crop crops on both sides and, due to counter-rotating movements, they hit the carrot heads with the ends of their working cleaning elements simultaneously from both sides, combing the remaining husks from them. Undoubtedly, the main mass of green gorse from the carrot heads has already been pre-cut by a gore harvester, but there are remnants left on them, in the form of uncut green tips, as well as dry and fallen thin stems of considerable length, which actually lie on the surface of the soil. At the same time, the carrot roots themselves are in the soil and are firmly connected to it. After cleaning the carrot heads from the remains of goo on the roots, the next operation is to directly dig out the root crops from the soil.

To simulate the functioning of this cleaner in real field conditions and, accordingly, study the quality of its work under different parameters and regimes, a construction of a field experimental installation, inside which this cleaner was installed, was developed and manufactured. The experimental setup provides for the study of the quality of cleaning the heads of root crops from one row of crops, it is aggregated by a class 1.4 wheeled tractor, which sets the cleaner, during field experimental studies, different speeds of translational movement along the row of crops of root crops, and different angular speeds of rotational movements of its cleaning workers bodies.

In Fig. 1 shows the scheme of the experimental setup for researching the quality of cleaning yorkie heads from the remains of burdock on the root. The experimental setup is a carrot head cleaner on the root installed on frame 3, which is single-row. The frame 3, with the help of the attachment device 2, is installed behind the wheeled aggregate tractor 1. At the same time, the frame 3 in its front part rests on two support-copying wheels 5 with mechanisms for changing the distances of the frame 3 to the soil surface. In the rear part of the frame 3, there is a cleaner, which consists of two horizontal cleaning shafts 6. The drive of the shafts 6 in counter-rotating movements is carried out with the help of drive elements 4 from the rear power take-off shaft of the tractor 1. The cleaning shafts 6 are installed in the transverse plane horizontally, and their longitudinal axes in this plane are located at an angle α.



a)



b)

Figure 1. *Structural and technological diagram of a field experimental installation for researching the quality of cleaning carrot heads from the remains of the root rot: a) side view; b) top view: 1 – tractor; 2 – attachment device; 3 – frame; 4 – elements for driving the cleaning shafts into a counter-rotating motion; 5 – supporting and copying wheels; 6 – drive cleaning shafts; 7 – pairs of rubber cleaning blades; 8 – hubs with articulated cleaning blades*

At the same time, five hubs 8 are installed on each cleaning shaft 6 with the corresponding step by means of a key connection 9. Each hub 8 contains a pair of rubber blades 7 on the outer surfaces, mounted with the help of leashes, hinged on the axes of a pair of rubber blades 7, of which it contains four (located at the ends of mutually perpendicular axes). At the same time, the ends of the rubber blades of one cleaning shaft are located in the gaps between the blades of the second cleaning shaft. The angle α, under which the cleaning shafts are installed, provides a suitable area for root crops in the front part of the cleaner and is of little importance.

The directions of translational movement of the experimental setup and rotational movements of its component elements are shown in the diagram with arrows.

In this cleaner, ordinary rubber blades are used, which have standard dimensions: length 25...33 cm; width 6...8 cm, thickness 1.5...2.0 cm. At the outer ends of each blade, along their entire width, rubber protrusions with a height of 0.3...0.5 cm and a hemispherical shape were arranged in a checkerboard pattern. The place of hinged installation of each blade was reinforced with a thin metal - tin. All blades are made of solid molded rubber.

In Fig. 2 shows the general view of the experimental setup attached to the wheeled aggregate tractor during field experimental research.



Figure 2. *View of the experimental setup*

The method of conducting field experimental studies to determine the quality of cleaning carrot heads from the remains of burdock on the root in some issues was consistent with modern requirements and was as follows [13, 14].

From the very beginning, the area of the field with carrot crops was carefully prepared (for this, the area with crops was most suitable), which was (according to the terms and according to the indicators of agrophysical assessment of the crop) suitable for harvesting. Measurements and a comprehensive analysis of the physical and mechanical properties of the soil with crops were carried out, as well as indicators of the biological state of the root crops themselves. Next, they performed an operation to cut the gorse from the heads of root crops with a regular machine for harvesting gorse. At the same time, the string harvesting machine

itself did not have a head cleaner from residues in its composition. After the passage of the gorse harvesting machine, an assessment of the state of the plantation was carried out based on the results of the first main continuous cut of the green mass of gorse. Here, the main indicator in the evaluation of the work of the gorse harvesting machine was the quality of the cut of the carrot heads itself (the presence of highly cut root bodies, chips, cracks, knocking out of the root bodies themselves from the soil) and the assessment of the presence of those remains of gorse, which the gore harvester was unable to cut and collect qualitatively. Such a thorough assessment of the quality of the work of the gorse harvester gave every reason to conduct further comparisons and reliably evaluate the quality of cleaning the heads of root crops from residues on the roots by the most improved cleaner, that is, to actually "divide" the quality of cleaning during the first and during the second cleaning.

In the future, the process of cleaning the carrot heads with this cleaner took place, while two adjacent rows were immediately selected and similar conditions were determined with the help of a frame that had the contours of one linear meter. Next, manual cutting of all the remains was carried out, both after passing through only the ginseng machine and after simultaneous passage of the ginseng machine and the cleaner. All remains, in both cases, were carefully collected and weighed on electronic scales with an accuracy of ± 0.1 g. The obtained weighing results in both cases, that is, before and after the passage of the cleaner, made it possible to evaluate the quality of cleaning the heads of root crops from residues.

The very degree of cleaning of carrot heads from residues on the root was then calculated using the following formula:

$$\delta = \frac{M - M_{cl}}{M} \times 100, \quad (1)$$

where δ is the degree of cleaning of carrot heads, %; M is the mass of the remaining scum before the cleaner passes, g; M_{cl} is the mass of the residue after passing through the cleaner, g.

The conditions for conducting field experimental studies of the improved purifier were as follows: soil type and name according to mechanical composition – chernozem, low-humus, medium loam; average soil hardness – 2.0...2.8 MPa; average soil moisture – 12.1...14.5%; the relief of the surface is flat; yield of root crops – 53.4 t·ha^{-1}; yield of buckwheat – 13.3 t·ha^{-1}; plant density – 82.9 thousands pcs.·ha^{-1}; the average distance between carrot roots is 8.8 cm.

The following devices and equipment were used during field experimental research: measuring and recording the angular speed of the rotational movements of the driven cleaning shafts was carried out using a strain gauge, the speed of the translational movement of the experimental installation was measured using a travel measuring wheel.

At the same time, the strain gauge was installed on the rear pick-up shaft capacity of the aggregate tractor, which made it possible, with the help of a developed program and connection to a PC using an electronic converter, to immediately fix and measure the angular velocity of its shank. This was followed by recalculation into the angular velocity of the drive shafts of the cleaner and with the help of variable sprockets in its drive to set the required variable angular velocities of the rotational movements of the cleaning shafts themselves. The construction of the drive of the cleaning shafts in the experimental setup was carried out with the help of cardan shafts, a reducer and chain gears, which ensured their counter-rotation in the direction of the axis of the row of root crops. The distance-measuring wheel, which was connected to the frame of the cleaner, also with the help of a developed program and connection through a converter to a PC, gave accurate values of the translational movement of the cleaner during field experimental studies in different modes of its operation. Setting the exact location of the ends of the rubber blades relative to the field surface was carried out each time with the help of a metal ruler, which made it possible to accurately set different values of the height of the location using the screw mechanisms of the copying wheels of the cleaner frame. These measurements were made with an accuracy of 1 mm.

In order to establish the influence of independent factors on the performance indicators of the investigated carrot head cleaner from the remains of burdock on the root, a comparative multifactorial experiment of the FFE P^k type was planned and carried out, where P is the number of levels of variation of the factor; k is the number of factors present in the experiment [15]. The indicator that characterizes the quality of the cleaner is the residue on the running meter (g·m^{-1}) that occurs after it passes through the line section. This parameter in the model of the multivariate experiment was chosen as an optimization function, that is, a dependent variable that can be taken in the form of a functional: $Y = f(x_1; x_2; x_3)$, where Y is the residuals of the hook from the 1-st to the i-th case; x_1, x_2,…, x_i – are natural independent variable factors.

The indicated natural independent factors were selected according to the corresponding conditional plan of the multivariate experiment, the implementation of which was carried out in the following sequence.

In order to determine the value of the remaining Y hooks on each linear meter, independent variable factors were adopted:
– speed of translational movement V, which was coded with the index X_1;
– the angular speed of rotation ω of the cleaning shafts, which was coded with the index X_2;
– height of installation of the ends of the rubber blades relative to the horizontal surface of the soil h, which was coded with the index X_3.

When coding the factors, the factor space will be linearly transformed – the origin of the coordinates is moved to the center of the experiment, the scale along the axes is selected in units of factor variation. Coding of factors was carried out using such a dependence:

$$X_i = \frac{2 \cdot (x_i - x_{i0})}{x_{\max} - x_{\min}}, \quad (2)$$

where X_i is the coded value of the factor (dimensionless quantity); x_i – value of the factor in named (natural) units; x_{i0} – the natural value of the factor at the zero level; $x_{\max}$, $x_{\min}$ – the maximum and minimum value of the factor, respectively.

When constructing the plan-matrix of the multifactorial experiment, coded designations of the upper, lower and zero levels of variation by each factor were entered, which were respectively marked as (+1), (–1), (0). The results of the coding of variable factors and the levels of their variation are given in the table. 1.

Table 1. *Results of factor coding and levels of their variation FFE 3^3*

Factors	Marking		Levels of variation, natural / coded		
	coded	natural			
The speed of translational movement V, m·s^{-1}	X_1	x_1	0.9/–1	1.6/0	2.1/+1
Angular speed of rotary movements of cleaning shafts ω, rad·s^{-1}	X_2	x_2	36.6/–1	56.5/0	76.6/+1
The height of the blade ends relative to the soil surface h, cm	X_3	x_3	0/–1	2/0	4/+1

The coding of natural variables based on the data in Table 1 has the following values:

$$X_1 = 1.67 \cdot V - 2.67,$$
$$X_2 = 0.05 \cdot \omega - 2.81, \quad (3)$$
$$X_3 = 0.5 \cdot h - 1.$$

After coding the factors, a plan-matrix of the appropriate multifactorial experiment of the FFE 3^3 type was drawn up for the total number of experiments $N = 3^3$.

In order to reliably assess the quality of the cleaner of carrot heads from the remains of burdock on the root during field experimental studies, the required number of measurements of controlled indicators (repeatability of experiments) was determined according to the methodology outlined in [16]. In our case, the experiments were carried out in six replicates.

In the implementation of composite plan-matrices, in order to eliminate the influence on the obtained results of the value of the residual amount of the hemlock on the running meter from

uncontrolled and unregulated factors, the randomization of the plan-matrix was carried out using the method of random balance, which was implemented by the method of arbitrarily extracting the serial numbers of experiments, that is, it is carried out randomly.

Statistical processing of the results of experimental studies, which were obtained after the implementation of the multifactorial experiment, was carried out in the following sequence.

Thus, the response function (i.e., the optimization parameter) was adopted in the form of an approximate mathematical model of a full quadratic polynomial [16], which describes a real experimental process:

$$Y = b_0 + b_1 \cdot x_1 + b_2 \cdot x_2 + b_3 \cdot x_3 + b_{12} \cdot x_1 \cdot x_2 + \\ + b_{13} \cdot x_1 \cdot x_3 + b_{23} \cdot x_2 \cdot x_3 + b_{123} \cdot x_1 \cdot x_2 \cdot x_3 + b_{11} \cdot x_1^2 + \\ + b_{22} \cdot x_2^2 + b_{33} \cdot x_{32}^2, \quad (4)$$

where Y – is the value obtained experimentally; b_0, b_1, b_2, b_3, b_{12}, b_{13}, b_{23}, b_{123}, b_{11}, b_{22}, b_{33} – regression coefficients of the corresponding values of input factors x_i; x_1, x_2, x_3 – are input coded factors.

The coefficients of the approximating polynomial, presented in the form of a complete quadratic equation, under the condition of orthogonality and symmetry, were determined by the corresponding general formulas [16].

The statistical significance of the coefficients of the regression equation $b_{i(jk)}$ were conducted according to the Student t-criterion. If the condition of significance was not fulfilled, then such coefficient $b_{i(jk)}$ of the regression equation was taken as insignificant (equal to zero), and the corresponding member x_i of the regression equation was excluded.

Thus, the following regression equation was obtained:

$$Y = 48.6309 + 10.1185 \cdot x_1 - 17.1025 \cdot x_2 + 20.4086 \cdot x_3 + \\ + 4.0951 \cdot x_1 \cdot x_2 - 6.5278 \cdot x_2 \cdot x_3 + 6.1716 \cdot x_1 \cdot x_3 + \\ + 1.6531 \cdot x_1 \cdot x_2 \cdot x_3 - 2.207 \cdot x_3^2. \quad (5)$$

Accordingly, in natural coordinates, the regression equation after transformation and simplification of the expressions will have the following form:

$$Y = 63.498 - 4.9527 \cdot V - 0.8498 \cdot \omega + 19.5504 \cdot h - \\ - 0.2723 \cdot \omega \cdot h + 1.2733 \cdot V \cdot h + 0.2026 \cdot V \cdot \omega + \\ + 0.0688 \cdot V \cdot \omega \cdot h - 0.5518 \cdot h^2. \quad (6)$$

Thus, the obtained regression equation (20) describes the dependence of the residue Y on the heads of root crops when they are cleaned by the improved design of the cleaner on its speed V of translational movement, the angular speed ω of the rotational movement of its two cleaning shafts when they move in the opposite direction and the height h of the location of the ends rubber blades relative to the soil surface, which separate the remains from the heads of root crops.

3. Conclusion

1. Designed and developed an improved design of a carrot root head cleaner from residues on the root, and developed a program and methodology for conducting experimental field studies.

2. According to the results of the field experimental study of the cleaner of carrot heads from the residues on the root, equipped with pairs of rubber cleaning blades, installed on the drive horizontal shafts with appropriate steps along the length, which cover the row on both sides, it will be established that the use of the improved cleaner will make it possible to significantly improve the quality cleaning.

3. When carrying out regression analysis and numerical calculations using statistical methods with the help of a PC, it will be possible to establish the optimal structural, kinematic and operational parameters of the improved purifier, which will provide the highest quality of cleaning (the least amount of residue on the heads of carrot root crops per linear meter of its crops).

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Establishment of training of specialists in agricultural engineering at the kyiv polytechnic institute

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Abstract. *Together with the foundation of Kyiv Polytechnic Institute in 1898, it was introduced at its Agricultural Department to teach the academic discipline "Mechanics in Adaptation to Agriculture", which will be called "Agricultural Mechanics" in the future. Three years later, that is, in 1902, students of this department began to study this subject, having previously studied the subject "Elementary Mechanics" at the beginning of the III year. Soon, after a period of time, the students of the Mechanical Department began to study a subject called "Agricultural Mechanical Engineering". It was from 1906–1908 that students of both departments began to carry out so-called "Special projects" in agricultural engineering during their studies, and in the following years to carry out diploma projects dedicated to this area of science and study. The teaching of the specified subjects, as well as the students' careful study of real agricultural machines and tools that worked in the field at the Kyiv Machine Testing Station at the Polytechnic Institute (the students even took part in the tests themselves) and gives grounds for the assertion that the organization of training specialists in in the field of agricultural engineering began at the Kyiv Polytechnic Institute at the indicated times.*

KEYWORDS: *MECHANICAL ENGINEERING, AGRICULTURAL ENGINEERING, TRAINING, SPECIALISTS, KYIV POLYTECHNIC INSTITUTE.*

In many previous numerous publications, it was claimed that from the moment of the foundation of the Kyiv Polytechnic Institute in 1898, the Department of "Agricultural Machines" immediately existed (under the conditions of that time, a position that was filled by a professor). It was also indicated that students were immediately taught the academic discipline called "...mechanics as applied to agriculture..." (original language of the document) at the Agricultural Department. However, this is not at all true and it is proved in detail in [1]. It is also obvious that the specified subject, which had to be studied only by the students of the "Agricultural Department" of Kyiv Polytechnic Institute (KPI), could not be taught to them earlier than these students will already be studying in the 3rd year. And this was to happen only 3 years after the establishment of this institute, i.e. no earlier than 1901–1902. And of course, for students of other departments of higher education, who had to study according to their own, previously declared and approved programs, this subject was completely unnecessary and it is here was not. It should also be taken into account, and this is generally known, that in the year of the foundation of the Kyiv Polytechnic Institute in 1898, it was originally located in the building of the Kyiv Commercial College, namely, as was reliably stated in the historical documents of that time [2]. By the way, the funds for the construction of the "First Commercial School" in Kyiv (then it had such an initial name) back in 1896 were allocated by rich merchants Lev and Lazar Brodsky, who were the owners of a large number of sugar factories in Ukraine. It is also known that the project of the school building was developed by the well-known Kyiv architect of German origin Shleifer H. P., and the construction of the school, which was originally two-story, was carried out by the Kyiv builder-contractor Ginzburg L. B. So, after its foundation, the Kyiv Polytechnic Institute began its work and the first full academic year was temporarily housed (of course, on lease) in the building of this Commercial School. Although, according to preliminary calculations, the premises of the school building were not enough even for giving lectures and conducting some practical classes for the first full set of students (for the 1st year of study) in the number of 360 people. But, despite such limited conditions, the Kyiv Polytechnic Institute started its work right here, since there were no other necessary premises in Kyiv at that time. Several separate free buildings, but located not far from each other, were also not found at that time, although such a possibility was considered. It was here in the assembly hall of the Commercial School that the ceremonial opening of this university took place. Not about any teaching of subjects related to the systematic study by students of the methods of experimental research of materials and machines, according to the statement of the rector of the higher education professor V. L. Kirpychov, as well as the methods of experimental mechanics in special mechanical laboratories, which must first be studied by students for at least two years, it was out of the question, since the location of the university in this area was temporary and it did not have any laboratory or other equipment at that time [2, c. 16]. Therefore, there were not and could not be here, in the first year of KPI's existence, neither subject laboratories, nor classrooms for the relevant academic disciplines, nor halls for drawing with models, nor pavilions, nor workshops, nor test stations, nor museums, nor any workshops , not even a library.

It is known that after the first academic year, in the fall of 1899, the Polytechnic Institute was forced to vacate the premises of the Commercial School (although the admission of students to the new 1st year of study this year took place within the walls of the school) and the relocation of the institute and its property to the building of the chemical building, which had already been built, was owned by the institute, although at that time it was not yet fully suitable for direct use (mainly the interior work and numerous arrangements, including furniture, etc., were not finished). And although the building of the chemical building of KPI was designed and rebuilt in full accordance with its name and purpose and did not have significant dimensions, the institute was forced to move there.

And so it continued until 1902, since the construction of all the premises of the Kyiv Polytechnic Institute was mostly completed only then, and the commission headed by the rector of the university, Professor V. L. Kyrpychov, accepted them for use and signed the corresponding act. Another period in the life of KPI has begun, associated with the relocation and reconfiguration of its educational units in the new building. Therefore, only in the summer of 1902, all the educational and scientific departments of the institute were finally distributed in the corresponding buildings and buildings that belonged to it. By the way, by this act, in addition to the main buildings on the territory allocated for the institute, in accordance with paragraph 3, Research Field No. 2 was also accepted for use: «…3) On the territory located near the dacha village "Karavaevskie dachi", allocated for the use of the Institute by the Kiev city public administration and indicated on the drawings under the name of experimental field No. 2» (original language of the document), namely:

1) A stone building for testing agricultural implements with a wooden extension for a riding arena and living quarters for workers with a volume of 384 cubic fathoms and an area of 125 square fathoms;

2) A wooden barn for storing agricultural implements with a stone cellar;

3) A wooden shed for agricultural machinery;

4) A wooden cellar;

5) …a place (for sanitary use), a cesspool and a well (original language of the document) [2, c. 141].

Such were the historical events that took place at that time during the organization and the first steps in the foundation and work of the Kyiv Polytechnic Institute. Therefore, there are grounds for confidently asserting that permanent relocations,

construction, reconstruction, furnishing, equipment, etc., had a significant impact both on the implementation of the educational process at the institute and on its quality.

So, taking into account such incredibly complex organizational difficulties that arose from the beginning of the work of the Kyiv Polytechnic Institute, as well as the complete lack of conditions for testing agricultural machines and tools at its own Machine Testing Station (which was organized and built for this purpose) until 1902, there is every reason to believe that that, most likely, it was only after that that the subject, which began to be called "Agricultural Machines", began to be taught to students, and then only at the Agricultural Department. That is, there are no solid grounds to believe that the training of specialists in agricultural engineering began here in 1902. Teaching at the Agricultural Department to students of the last year of study (that is, future agronomists, veterinarians and economists) only one academic discipline "Agricultural machines" does not mean preparing "Agroengineers". This was the case with the training of engineers at the Mechanical Department and the reading of the "Agricultural Machines" discipline to students in the last course of study, which also did not give the right to consider it as the training of "Technological engineers for the field of agriculture". At that time, the Mechanical and Agricultural Department of KPI trained technological engineers and agronomist scientists, according to the training programs according to the Charter of KPI. So, the first graduates of specialists with higher education, i.e. technologists and agronomists at the Kyiv Polytechnic Institute were in no way connected with agricultural engineering. These graduate engineers and agronomists were only familiar with agricultural machinery and implements by taking very short descriptive courses on agricultural machinery in their final training courses. At that time, even the term "agricultural engineering" was not yet used. By the way, in these first years of the institute's work, the name "Machine Testing Station at KPI" was not yet used, pointing to its then name: "Experimental Field No. 2". To conduct tests of some agricultural machines and tools outside the Experimental Field No. 2, for example, on farms that belonged to private landowners (which were located even at a small distance from Kyiv) is another matter, since it is precisely in these very difficult times related to the organization of training in the newly created higher education institution, attracting students for this and taking them to trials to demonstrate and teach this subject directly in the field, most likely, was simply impossible. And testing "on the side" of agricultural machines or tools without appropriate measuring devices, fixing equipment, the necessary adjustment, and most importantly without specialists in the field of testing and technical workers, of which there must be a lot, was unlikely.

As for the theoretical study of the subject "Mechanics in Adaptation to Agriculture", for the students of the Department of Agriculture, its teaching began, most likely, in 1902 or even later. Without a doubt, from the beginning, it was necessary for the students of this department to study the academic discipline "Elementary Mechanics", which was foreseen by the "Regulations" and "Statute" of the university, precisely in the III year, and this was carried out by the acting extraordinary professor of the Department of Mechanics, mechanical engineer Schindler K G., who was employed at the Kyiv Polytechnic Institute since September 1, 1899. It was during this period that Kyiv Polytechnic Institute was forced to vacate the premises of the Commercial School and relocate to the building of its own chemical building.

In this connection, a completely logical and fundamental question arises: "Since the educational subject, i.e.: mechanics in adaptation to agriculture, was intended only for students of the Agricultural Department (as defined in the "Regulations" and "Statutes" of KPI, i.e. official documents of that time), but higher mathematics, descriptive geometry, theoretical mechanics, applied mechanics (theory of mechanisms and machines, resistance of materials, machine parts, etc.) and mechanical engineering (fundamentals of design and construction, machine mechanics, production technology, etc.) they will not study (also according to these official documents), then what kind of "mechanics in agriculture" can we talk about when training agronomist scientists? And therefore, only an elementary study of the basics of mechanics, only familiarization with the designs of existing agricultural machines, only a possible demonstration of the operation of these machines in the field! This situation still exists in agricultural universities of Ukraine during the training of agronomic specialists (they very briefly study the descriptive course of agricultural machines), but now only without demonstrating their work in the field.

On the other hand, the subject "Mechanics in Adaptation to Agriculture" was not at all intended to be studied according to the "Regulations" and "Statute" of KPI by the students of the Mechanical Department who studied according to their program. But after some time, it was introduced and began to be taught in this department in the IV year, as a subject called "Agricultural mechanical engineering" or "Agricultural mechanical engineering". However, the Kyiv Polytechnic Institute did not train mechanical engineers specifically for agriculture, but only technological engineers for other various branches of industry and transport.

So, it turns out that for the students of one of the departments of KPI, the subject "Agricultural mechanical engineering" or "Agricultural mechanical engineering" (as they were later called) was almost superfluous, actually unnecessary during education (what is the benefit of studying this subject for agronomists, soil scientists , animal breeders, veterinarians and economists?), and for students of another department, i.e. Mechanical, these subjects may be useful for general familiarization with the designs and technologies of industrial production of agricultural machines and tools, but to train mechanical engineers for this branch of production (especially engineers , who would work directly in agriculture) was not foreseen according to the existing training programs.

In addition, it should be clearly understood that the content of the academic disciplines "Mechanics in adaptation to agriculture" (or agricultural mechanics) and "Technology of the production of agricultural machines themselves", or "Agricultural engineering" are essentially different subjects. And therefore these subjects for teaching at a polytechnic institute had to be distinguished in the training of different specialists. In the first case, it is the study of technological processes carried out with the help of agricultural machines or tools and their working bodies and the study of their interaction with the soil, plants or other agricultural environment, and these processes take place in the field, on the farm, on the farm, etc. And that is why it is necessary to study the technological regularities of the interaction of working bodies with processing objects, that is, what will be the properties and what will be the condition of the soil, plants, and animals. In the second case, it is a study of the basics of design, construction and industrial production of the same machines and tools at a machine-building plant or at some industrial enterprise. Here it is already necessary to study the basics, based on which preliminary calculations of machines and tools (as well as their constituent elements) can be carried out during construction for strength, wear, questions regarding the selection of materials for working bodies, as well as to know the machines and equipment that will be used in the manufacture . That is, it is necessary to study the technology of manufacturing the components of machines, as well as their subsequent assembly, debugging, and regulation, which should be used in the mass industrial production of this or that agricultural machine.

If we look at such an obvious contradiction, then it is most likely to assume that something similar to the "average" was initially chosen within the walls of the Kyiv Polytechnic Institute: in the main building (and that is where the Agricultural Department was located) students studied "pure" mechanics (or as defined in the Charter for the Agricultural Department – elementary mechanics), and at the Machine Testing Station real designs of existing agricultural machines and tools were studied during practical classes and were shown working in the field,

although the educational subjects had different names. All the more so since the specified official documents of that time "Regulations" and "Statutes" of KPI state that ["Teaching is accompanied by exercises and practical classes in educational and auxiliary institutions." (the original language of the document)], to which since 1902 ["Station for testing agricultural machinery and tools." (original language of the document)] and it was there that practical classes in this academic discipline were to be held. Therefore, to say that within the walls of the Kyiv Polytechnic Institute from the beginning of its establishment, as it were, trained agricultural engineering engineers is, unfortunately, a regrettable mistake of modern historians.

On the basis of a thorough study of the teaching staff of KPI for each academic year, it was established that K. G. Schindler, acting extraordinary professor of the Department of Mechanics, began to teach students of the Department of Agriculture a course on elementary mechanics and did so until the end of the 1900–1901 academic year.

However, it should be assumed that the mechanical engineer K. G. Schindler, acting as an extraordinary professor of the Department of Mechanics even at that time and not yet an adjunct at KPI, began to feel the above-mentioned contradiction, since already in the 1903–1904 academic year he began to teach for students who have just become students of the III and IV courses, the following educational disciplines, namely: agricultural machines for students of the III and IV years of the Agricultural Department and agricultural machines for students of the IV year of the Mechanical Department. This is the same training course for two different departments, since it is not known how "agricultural machines" differ from "agricultural machines", and therefore, obviously, such a different name for essentially the same courses was artificial. At the same time, since 1903–1904, he has been in charge of drawing up special projects (most likely, we are talking about course projects) at the Agricultural Department. It was also noted that the mechanical engineer Schindler K. G. leads practical classes on agricultural mechanical engineering in the III and IV courses of the agricultural department. It should be noted that in this academic year and beyond, he is no longer listed as a lecturer (or teacher) of elementary mechanics at the Agricultural Department. In addition, there were no educational disciplines with the name "Agricultural Mechanical Engineering" at that time.

Therefore, during the first five years from the day of the foundation of KPI, the appropriate adjustment of the educational programs took place, due to which in the last courses of study, students of two departments, Agricultural and Mechanical, began to study at once several educational disciplines in the field of agricultural machinery with different names (but the same in essence) . It should be assumed that the students of the Agricultural Department studied only the structure of most agricultural machines, most likely using the Atlas developed for this purpose and published in 1902 by K. G. Schindler. This assumption is the most reliable, since for future agronomists, soil scientists and veterinarians in the form of sketches and schemes of agricultural machines and tools, which were manufactured at that time in the world, it was the most simple and convenient to study them. In addition, in the practical classes that Schindler K. G. conducts with students of the last years of the Department of Agriculture on the subject called "Agricultural Machine Science", he tries to involve future agronomists in some initial elementary foundations of their theory and calculation. Most likely, during practical classes, students at that time gained knowledge of soil tillage machines and learned to draw plow bodies, made drawings on the rotation of soil strips during plowing, etc. The students of this department did not need more in-depth knowledge of agricultural mechanics. Special projects, which were carried out by students most likely and were devoted to drawing the shelves of plows, probably the working bodies of planters and potato diggers, etc. As for the students of the last years of the Mechanical Department, when studying agricultural machines, they most likely received the same knowledge of the initial foundations of the theory and construction of plowing tools, since K. G. Schindler had already written and almost finished his own monograph on this topic. It was at this time that he performed the duties of the dean of the agricultural department, where he was appointed on August 1, 1904, and definitely had the right to adjust the educational programs with his own hands.

In the following 1904–1905 academic year, the dean of the Agricultural Department and acting extraordinary professor of the Department of Mechanics, mechanical engineer Schindler K. G. performs the same pedagogical work in two departments and manages the station for testing agricultural machines and tools. In addition, he prepares and on October 14, 1905, at the meeting of the Institute's Academic Council, he defends his own scientific work "Theory and Construction of Plowing Tools" and receives the title of adjunct of the Kyiv Polytechnic Institute.

In the following years, in particular in the academic year 1906–1907, Schindler K. G. was no longer the dean of the agricultural department, but left the position of extraordinary professor at the department of mechanics. Protected scientific work and receiving the title of associate professor of KPI gave him such an opportunity. As before, he gives lectures for students of the two departments mentioned earlier, but at the same time, he introduces new courses to the students of the Agricultural Department, in addition to the existing ones, in particular, "Mechanical Science" and "Theory of Agricultural Machines and Tools", "Fundamentals of Mechanical Science", " Machines-tools", "Machines-engines". That's when a new subject called "Mechanical Engineering" is introduced in the Mechanical Department. As we can see, the range of subjects for study by students in the field of agricultural mechanics and agricultural engineering at KPI is gradually expanding, which indicates a significant increase in the knowledge and competencies of graduates of the Kyiv Polytechnic Institute. In addition, it is during this period that Schindler K.G. leads practical classes at the station for testing agricultural machines, and also begins to manage the diploma theses of students of the Department of Agriculture. Therefore, it should be assumed that during the management of the Department of Agriculture, as a dean, Schindler K.G. proposed the completion of diploma theses for a certain group of future scientists-agronomists, in accordance with their desire to more broadly and confidently possess knowledge in the engineering field of agriculture. Although even then future agronomist scientists needed only initial, actually familiar knowledge of agricultural machines, for which their descriptive course was suitable.

In the following academic years, in particular in the 1908–1909 academic year, K. G. Schindler already works as a full professor in the Department of Mechanics, which he received on November 14, 1906, continues to teach all the previously listed academic disciplines, manages special and diploma projects. In addition, studying the designs of various agricultural machines at the Machine Testing Station, which was managed by K.G. Schindler, was very useful for the students of the Mechanical and Agricultural Departments, since not only the visual perception of their real designs, but also the visual demonstration of work in the field gave incomparable advantages in the students' acquisition of knowledge and acquisition of the necessary competencies. At the same time, students of both departments were involved in the tests themselves, performing work on the adjustment of various agricultural machines during their preparation for the tests, participating in various adjustments, setting up devices, obtaining the results of the tests themselves, during measurements, etc. In 1908, the appointment of K. G. Schindler as the dean of the Mechanical Department gave him the opportunity to introduce here in larger volumes educational disciplines and the implementation of special and diploma projects in the field of agricultural engineering. It should be assumed that it was at that time that the work of this scientist in the field of education was very fruitful and, most likely, the time could not be far off when a new separate department (or a new faculty) should be opened at the Kyiv Polytechnic Institute, which would exclusively prepare engineers-designers of agricultural machines, or mechanical

engineers of agricultural production. But the unexpected and forced dismissal of K. G. Schindler from the position of dean of the Mechanical Department of the Kyiv Polytechnic Institute in early February 1911 most likely prevented this.

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Prospects for the application of ceramic beehives in modern apiculture farms

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Abstract: *A brief review of the design characteristics of the main construction types of standard movable frame and traditional beehives applicable in beekeeping farms is presented. The performance of a newly developed innovative movable frame beehive constructed of durable, heat-resistant hollow chamber ceramic structural elements is discussed. A comparison of the functional characteristics of prepared experimental ceramic hive prototypes and the prevailing types of standard beehives made of other materials is carried out. The existing requirements and prospects for equipping beekeeping farms with ceramic hives providing prolonged service life, higher yields and increased sustainability in diverse climatic environments and critical conditions are analysed.*
Keywords: *INNOVATIVE CERAMIC BEEHIVE, BEE FARMS, DADANT-BLATT*

1. Introduction

Bee products find application in culinary practices, the food industry, cosmetics, pharmaceuticals, alternative medicine and many other fields [1]. At the same time, the natural life activity of wild and cultivated honey bees is an essential factor in the pollination process of various plant species [2, 3].

For millennia, the main source for the production of bee products was bee colonies growing freely in natural conditions or artificially colonized in primitive hives (skeps).

With the gradual development of beekeeping as an organized economic activity, different structural types of beehives were designed [4]. Some of the beehive systems developed in earlier periods have been further modified and upgraded to increase their efficiency.

Currently, there are several construction types of beehives made of different materials - wood, plastic, polystyrene and others – commonly in use [5].

The Dadant-Blatt beehive system is a structural type widespread across Europe. It comes in two main versions – for 10 or for 12 frames, which determines the specific sizes of hives of this type. It is characterised by the presence of one main brood box [6]. Volume expansion is achieved by installing honey supers above the brood box. The main disadvantages are the different sizes of the brood and store combs which do not allow their interchangeability, and the relatively limited volume of the hive [5].

In the case of the Langstroth Ruth hive system, volume reduction and increase is achieved by installing separate interchangeable supers [4]. The use of a single type of frame increases efficiency and labour productivity. The increase in the volume of multi-hull hives allows accelerated and full development of the colonies and creates conditions for higher yields. The design features of the Langstroth-Ruth hives make it possible to house several colonies in one hive.

Roger Delon hives are characterised by their relatively low weight, increased functionality of management and ease of transportation [6]. The limited volume makes it easier to maintain appropriate temperature conditions and low humidity during the natural life activity of the colonies throughout the overwintering period. The operation of the Roger Delon alpine hive follows a predominantly classical approach to multi-hull operation. Intensive spring colony development and high productivity are observed. At the same time, the installation of a larger number of supers forms a tall and unstable structure, making servicing difficult [4-5].

Farrar hives are applicable in a variety of climatic conditions. They are equipped with a detachable flat bottom board, compact and light supers of one and the same type and small frames. The supers are mounted frontally on the bottom. The supers are interchangeable, with the hive volume increasing in the vertical direction. This allows the application of the multi-super technology for breeding bee colonies [6].

Lezhak hives are relatively less common in the sector. Structurally, they allow a lateral expansion of up to 18 or 24 frames. Their main advantages are the use of a single frame size and the absence of sections or buildings. This allows for easier maintenance and higher efficiency. The relatively larger hive volume enables the development of active and healthy colonies throughout the year. It is applicable for making colony increase, overwintering two or more colonies together and more [5]. Much of the hive volume has no functional role for most of the year. Lezhak hives have a relatively higher weight, making them difficult to transport.

To a limited extent, traditional hives (skeps) made mainly of natural plant materials and untreated natural clays are still in use. However, because their primitive construction is suboptimal and the combs are fixed, management of colony development is limited. Thus, the use of modern technological methods in the extraction of bee products is inapplicable and risks the integrity of the colony. This results in relatively low yields and limited purity of the bee products [7]. Due to the use of organic, flammable and combustible materials and thermally untreated clays for the main components, traditional reed hives are characterised by unreliability in the event of fires and relatively low resistance in long-term contact with water.

The aim of this paper is to present the main requirements and prospects for the potential application in the equipment of modern beekeeping farms of an innovative ceramic hive. A comparison of the performance characteristics of the prepared experimental ceramic hive prototypes and the prevailing design types of standard and traditional beehives made of other materials is made.

2. Discussion

A study of the current trends and issues in the beekeeping industry was carried out. The possibilities for increasing the long-term serviceability and productivity of the main equipment of beekeeping farms are analyzed. On the basis of the obtained data and long-term research, an innovative movable frame beehive made of ceramic structural elements with air chambers is designed [7-14]. The use of ceramic materials for the manufacture of various structural details of the developed beehive ensures their high durability, fire resistance and other superior characteristics.

Ceramic experimental prototypes of the Dadant-Blatt system (10-frame version) have been prepared, specialized primarily for operation by stationary beekeeping methodology (fig. 1, 2 and 3). The repositioning of the ceramic hives on the territory of the bee farms is carried out manually (using the hull-mounted carriers) or mechanically (by means of lifting equipment - forklift, etc.).

The relatively higher mass of ceramic hives (compared to standard hive types) makes their handling and transportation only slightly more difficult. At the same time, the greater weight of the developed ceramic hives provides significantly higher operational resistance to the impact of extreme environmental factors (strong wind gusts, hurricane winds, storms, etc.).

During prolonged torrential rains and intense floods, existing standard hives (wooden and others) move much easier from their stationary positions, in the direction of the movement of the main water mass. This creates significant risks of damage to the basic inventory of bee farms and irreversible destruction of colonies. In this respect, the higher mass of the ceramic beehives is mainly seen as a favourable characteristic ensuring their operational stability and durability. On the other hand, for the purpose of mobile beekeeping,

a separate modification of a ceramic movable frame beehive with a lower mass is being developed, allowing easier handling and transportation.



Fig. 1. *A prototype of a ceramic beehive.*



Fig. 2. *A prototype of a ceramic beehive.*



Fig. 3. *A prototype of a ceramic beehive.*

The standard hives (made of other materials) used in practice are characterized by a limited lifetime and accelerated depreciation (under the influence of solar radiation and other climatic factors). At the same time, the ageing of the materials reduces the mechanical resistance of the structural components of the hives and in some cases is accompanied by the release of various substances with potentially toxic effects on the normal life activity of the colonies.

The natural processes of wood decay and the formation of cracks create an unhygienic environment and conditions for the development of fungal colonies and various microbiological agents. At the same time, the impact of certain rodents and various insects gradually compromises the integrity of the structural elements of the wooden hives.

Standard maintenance of wood beehives requires periodic treatment with various varnish-type paints and wood preservatives that could affect the condition of the colonies and the quality of bee products.

The low fire resistance of standard hives creates the preconditions for the loss of a large part of the physical stock of beekeeping farms in case of fires of natural or anthropogenic origin. At the same time, the high fire resistance of ceramic materials significantly increases the possibility to preserve the serviceability of ceramic hives in limited or larger fires.

When carrying out a complete decontamination, ceramic beehives allow the use a variety of treatments (through different impact factors). The high temperature resistance of the ceramic structural elements allows the application of thermal treatments (at higher temperature values) which is not feasible and will be destructive for standard hives made of other materials.

The presence of separate air chambers in the structural elements of the developed ceramic beehives increases their thermal and acoustic insulation performance.

Thermographic analysis of hollow ceramic plates, which are the main structural elements of a prototype beehive, was carried out using a thermal imaging infrared camera and a heat source.

Thermographic diagnostics was performed in field conditions on experimental ceramic hives with settled honey bee colonies and a settled standard wooden hive of the Dadant-Blatt system (as a control specimen).

The analysis of the obtained thermograms makes it possible to monitor the temperature distribution in different zones of the individual ceramic parts and across the whole external structure of the ceramic hive.

In the ceramic hives studied, a relatively uniform distribution of temperature values was found across most of the surface of the ceramic plates, with only local areas of contact with other structural elements (slats, lid, base profile) showing specific temperature deviations.

In the case of wood hives, it was found that the wooden walls were not evenly heated and there were distinct temperature zones. Water absorbed in the wooden walls and the formation of different areas of increased humidity create the condition for a more intense local heat transfer (compared to the dry areas) from the inner volume of the hive to the external environment. This causes a relatively more uneven distribution of temperature values in the inner space of the wood hives and affects the colony's condition and activity and the yields obtained. The presence in the wooden walls of zones of increased humidity with different localisation is specific to each hive and is determined by the type and state of the wood and the specific meteorological conditions.

Using the Guarded hot plate method, the coefficient of thermal conductivity of the main structural detail (ceramic hollow chamber plate) of a prototype beehive was determined. A laboratory thermal chamber with an installed heater and four-layer insulation was constructed. The temperature differences between the two opposite sides of the examined ceramic specimen (plate) were recorded until a constant temperature difference was established. Based on the values found, the thermal conductivity coefficient was calculated.

The studies performed prove the thermal insulation effect resulting from the presence of air chambers in the ceramic construction elements and confirm the appropriateness of the design solution.

Acoustic studies were carried out using the two chamber method to determine the air noise insulation index (Rw=23 dB, in

the frequency range 100-3,150 Hz) of a hollow ceramic chamber plate, which is a structural element of an experimental beehive. A dedicated laboratory setup of two equipped acoustic chambers with an experimental specimen mounted between them was constructed to carry out the study. The difference between the sound pressures recorded in the chamber with the presence of an acoustic source and those in the receiving chamber was determined.

Comparative studies and monitoring of the main indicators (over the autumn-winter period) were carried out in settled hives (with lattice and solid bottoms) of the Dadant-Blatt system, made of different materials: ceramic, wood and polystyrene. An electronic system was used to record temperature and humidity, with sensors installed in each hive and another sensor which monitors external temperature and humidity. During the testing period, the temperature (on average for the whole period and by month) in the hives was higher and the humidity lower compared to the temperature and humidity values of the external environment, regardless of the hive material and bottom construction type. The highest average temperature value during the autumn period was found in the solid-bottom ceramic hive (29.15±6.51°C), while the minimum value was recorded in the solid-bottom polystyrene hive (19.01±8.47°C). During the same period, the maximum value of the humidity index for the lattice-bottom hives was observed in the ceramic hive (50.74 ± 8.92%) and the minimum in the polystyrene hive (45.91 ± 9.62%). For the solid-bottom hives, the highest mean humidity was found in the polystyrene hive (55.14 ± 6.96%) and the lowest in the wood hive (44.69 ± 5.00%). During the winter period, the highest mean temperature was found in the wood hives and the lowest in the polystyrene hives, regardless of the bottom type. The greatest difference with respect to the outside temperature (mean 5.11 °C) was observed in the wood hives, 5.04 °C for those with a lattice bottom and 6.78 °C for those with a solid bottom, respectively. The lowest mean value of the humidity index was recorded in the wood hives, regardless of the bottom type, and the maximum in the polystyrene lattice-bottom hive and the ceramic solid-bottom hive.

Further studies were carried out in real field conditions to register the differences between the temperatures of the external environment and that in unpopulated ceramic hives (with different phase composition of the ceramic parts) and unpopulated standard wood hive (made of softwood). The measurements were carried out at different times of the day at ambient air temperatures from around 0℃ to above 30℃. At low ambient temperatures, temperature differences of 0.8℃ to 1℃ higher than the ambient temperature were recorded in the ceramic hive, while a temperature 0.2℃ higher than the ambient temperature was found in the wood hive. At daily outdoor temperatures above 28℃, a temperature difference of 2.0℃ to 2.8℃ (lower than the outdoor temperature) was found for the different ceramic hives, while an average temperature difference of 0.2℃ was reported for the wood hive. At higher temperature values of the external environment, a temperature difference of 2.3℃ to 2.6℃ (lower than the external temperature) was recorded for the ceramic hive, while a temperature difference of 0.3℃ was found for the wood hive.

Feedback from a number of bee product manufacturers on the experience gathered in the process of managing experimental ceramic beehives provided to individual beekeeping farms was analysed. The information obtained established a trend for increasing honey yields (up to 30 %) when using ceramic hives.

Ceramic beehives provide a long service life with negligible depreciation of the structural elements, well-balanced temperature values, appropriate humidity, a hygienic living environment and a relatively low risk of destruction of the main physical equipment of beekeeping farms in critical climatic environments and disasters.

The functional structure of the ceramic hive allows adequate control of the condition of the bee colonies and the application of modern, highly productive methods for obtaining bee products. The hive is compatible with the existing standard specialised equipment typical for beekeeping farms.

The developed experimental ceramic prototypes outperform the existing standard hives in complex indicators and provide a more favorable microclimate for the development of bee colonies and ensure higher yields.

At the same time, the obtained experimental data allow further optimization of the performance of the structural ceramic elements when designing new beehives modifications.

3. Conclusions

The main functional characteristics of the existing systems of standard movable frame and traditional hives are discussed.

The performance characteristics of an innovative movable frame beehive consisting of thermo- and acoustic-insulating ceramic structural parts with separate air cavities are presented.

A generalized comparison of the main characteristics of the constructed ceramic beehive prototypes and the commonly used standard structural types of materials is performed.

The experimental data obtained from the laboratory and field studies confirm the constructive functionality and efficiency of the designed ceramic hive.

The high physical-chemical and thermal performance of the ceramic materials and the design characteristics of the ceramic hives guarantee their long service life, low depreciation, relatively high resistance to fire and full potential for carrying out effective decontamination by applying a variety of sanitary treatments.

The developed ceramic hive is characterized by increased climatic resistance and potential application in dynamic operating environments in regions with extreme temperature values and high cyclic temperature amplitudes.

The relatively greater mass of ceramic hives (compared to that of standard hives) provides significantly higher operational resistance to a variety of disastrous weather conditions (hurricane winds, storms, torrential rains, floods, etc.).

The developed ceramic hive provides a suitable microclimate and a balanced temperature environment for the full development of bee colonies and hygienic living conditions, resulting in a reduced risk of the spread of fungal cultures, pathogenic microbiological agents and others.

The structural characteristics of the ceramic hive meet the requirements for the application of modern economic methods for the production of high-purity bee products and allow systematic control of the different stages of the life cycle of the bee colonies.

The developed movable frame ceramic hive is a superior alternative to the predominant standard (made of other materials) types hives currently found on bee farms.

In prospect, ceramic hives can prove to be a useful major piece of material equipment for many bee farms.

A new modification of the ceramic movable frame hive with a lower mass, applicable to mobile beekeeping, is currently being developed.

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Utilization of solar energy in application of drip irrigation in gardens of mountainous and foothill areas of uzbekistan

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Abstract: *Under the conditions of climate change, the provision of clean drinking water for population and irrigation water for crops has become one of the main problems in the world. With population growth and development of economic sectors, water resources deficit in the Republic of Uzbekistan and Central Asian countries is increasing from year to year. With population growth and development of economic sectors, water resources deficit in the Republic of Uzbekistan and in Central Asian countries increases from year to year. The solution of water deficit problem lies in water saving and rational water use. The main objective of scientific research is application of water and energy saving technologies in fruit orchards located in mountainous and foothill zones and in different soil-reclamation conditions of the Republic of Uzbekistan (Republic of Karakalpakstan, Bukhara, Kashkadarya, Namangan, Surkhandarya and Khorezm provinces), where water and electricity deficit is strongly felt. As a result, water saving in fruit orchards in comparison with traditional irrigation amounted to 67.4 % in the Republic of Karakalpakstan, 76.1 % in Bukhara province, and on average in the republic the saving reached 60÷80 %. In order to reduce the human factor in garden irrigation, all processes were automated. A mobile solar system with a capacity of N=4.0÷4.2 kWh (8 photovol-taic solar panels with a capacity of 500 W each) was manufactured to provide energy to the pumping unit supplying water to the drip irriga-tion system. Also, a system of cooling of solar panels was developed to increase the efficiency factor at high temperatures (t = 40÷50^0 C).*

KEYWORDS: *WATER DEFICIT; WATER- AND ENERGY-SAVING TECHNOLOGIES; GARDENS; DRIP IRRIGATION; SOLAR ENERGY, PANEL COOLING SYSTEM; IRRIGATION AUTOMATION.*

1. Introduction.

Nowadays, providing the rapidly growing population with environmentally friendly food is becoming one of the major problems on Earth. Therefore, all countries of the world, and the United Nations, have food security programs [1]. In our country, the program "On measures to further ensure food security of the country" was adopted by the decree of the President of the Republic of Uzbekistan in 2018 [2].

Agriculture is the main source of food security and the main consumer of water resources. Today, our republic is allocated an average of 51÷53 billion m3 of water resources under the limit, of which: 90÷91 % - for irrigation of 4.3 million hectares of agricultural land; 4.5 % - to the sphere of communal and household economy; 1.4 % - to industry; 1.2 % - to fish farming; 0.9 % - to energy; 1.0 % - for other branches of economy. [3]. With the growth of population and development of economic sectors, water demand also increases. The deficit of water resources in the Republic of Uzbekistan and in Central Asian countries increases from year to year [4]. The most optimal solution of water deficit problem is water conservation and reasonable water use [5].

Application of non-traditional methods of irrigation provides 30÷45% increase in crop yield and 25÷30% increase in labor productivity, 45÷60% decrease in water resources consumption [6]. To date, the following methods of water-saving technologies are applied in our republic: irrigation with short furrows; sprinkling; use of hydrogel granules; land leveling with laser devices; irrigation from under the soil; irrigation with portable flexible plastic pipes and polyethylene trays; irrigation along furrows with film perforated cover; subirrigation (raising the groundwater table); drip irrigation and others.

The use of renewable energy to replace traditional fossil fuels reduces CO_2 emissions and is a greener option to overcome the threat of global warming. These benefits are particularly noticeable in rural and agricultural areas where access to the grid is problematic [7, 8].

In the countries of Central Asia and in the Republic of Uzbekistan, the most available renewable energy source is solar energy. On average, we have more than 300 sunny days per year with a duration of 14÷16 hours, the average temperature is +42^0 C (in desert areas the temperature can rise to +70^0 C); the capacity of solar energy reaches 1900÷2000 kW/m2 [9, 10].

The use of photovoltaic systems will provide the necessary electricity for pumping units and control equipment required for the effective operation of the integrated drip irrigation system [11].

The purpose of the research work is to introduce a complex automated drip irrigation system using renewable energy sources to ensure energy and water resources conservation, timely and efficient irrigation in agriculture. As a result, there will be an opportunity for additional development of new lands, determination of irrigation norms for fruit orchards in 6 regions of the republic, also crop yields will increase, labor costs will decrease, which will reduce poverty and increase profit of rural population, as well as ensure sustainability of food security in the country/region.

The project has been implemented in gardens of water users of the Republic of Karakalpakstan, Bukhara, Kashkadarya, Namangan, Khorezm and Surkhandarya provinces. In future, the project will be implemented in all horticultural farms of the Republic of Uzbekistan and in Central Asian countries.



Table 1: *Objects of the study*

№	Location of research objects
1	Republic of Karakalpakstan, Beruni district, farm "Ozod intensiv bog".
2	Khorezm region, Gurlensky district, "Mevazor gardens" Ltd.
3	Bukhara oblast, Kagan district, "Training and Research Center" of Bukhara Institute of "Natural Resources Management".
4	Kashkadarya province, Kasan district, "Karshi Canal Operation Department".
5	Surkhandarya province, Sariasi district, farm "Mindal Agro".
6	Namangan province, Novonamangan district, "Samarkand Golden Fiber" farming enterprise

To implement an integrated automated drip irrigation system using renewable energy sources to ensure conservation of energy and water resources, timely and efficient irrigation in agriculture, an integrated drip irrigation system consisting of the following three systems is proposed (Fig. 2).

1. Drip irrigation system.
2. Solar energy system with pumping units.
3. Irrigation automation system.

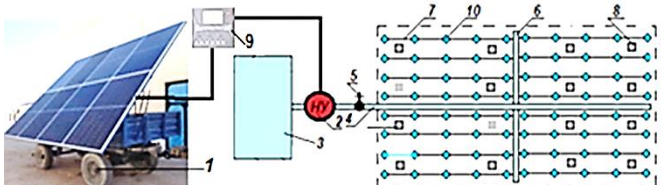


Fig. 1. *Scheme of the complex automated system drip irrigation:*
1-mobile solar power unit; 2-pumping unit; 3-tank for water; 4-pipeline for water supply; 5-crane for water flow regulation; 6-distribution pipes; 7-irrigation pipeline with drippers; 8-automation devices; 9-control unit; 10-fruit trees.

3. Results and discussion

3.1 Drip irrigation system.

Traditional drip irrigation system is a pressure system. It is known that the main sources of surface water resources - Amu Darya, Syr Darya and Zarafshan rivers move large amounts of sediment (Table 2) [13], which quickly clog the drip lines of the system [14]. Therefore, the liquid entering the drip lines must be purified to acceptable values (Table 3). Water is pumped by a pump from the source to the settling tank, and from the settling tank to the filters (Fig. 3).

Table 2. *Size and number of suspended particles in water sources.*

Diameters of suspended sediment fractions (mm) and their quantity (%)									D average, мм
2.0-1.0	1÷0.5	0.5÷0.2	0.2÷0.1	0.1÷ 0.05	0.05÷ 0.01	0.01÷ 0.005	0.005÷ 0.001	>0.001	
Zarafshan River (Hydropost 124, Navaiy, 2015.10.08)									
-	-	20.3	26.3	27.5	3.4	2.5	5.5	14.5	0.133
Sirdaryo River (Hydropost 1, Kal village, 2017.08.06)									
-	22.5	18.5	9.9	15.4	4.9	28.8	-	-	0.264
Amudaryo River (Hydropost 83, Tuyamuyun gorge, 2017.29.06)									
-	7.5	16.8	16.9	22.1	4.6	1.3	17.4	13.4	0.161

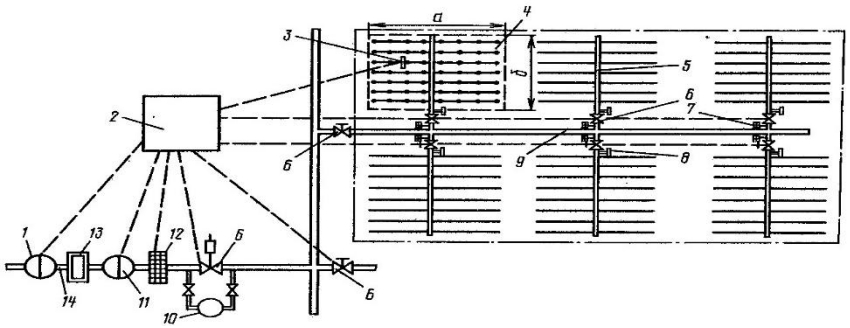


Figure 3. *General scheme of the drip irrigation system irrigation:*
1-main pump; 2-management computing complex; 3-meteorological station; 4-field of experience (module); 5-site pipeline; 6-closing-regulating fittings; 7-"compact" filter; 8-fertilizer connection complex; 9-distribution pipe; 10-fertilizer application device; 11-pump; 12-water cleaning filter; 13-regulating collecting basin; 14-main pipe.

Table 3. *Permissible values of concentration and size of suspended particles contained in irrigation water of drip irrigation systems.*

Size of through holes, mm	Permissible concentration of suspended particles in water and their sizes	
	Concentration, g/l	Particle size, mm
< 1	0.03 - 0.05	< 0.05
1-2	0.05 - 0.1	< 0.07
> 2	0.1 - 0.3	< 0.1

3.1.1 Efficiency of drip irrigation system

As a result of 3-year field studies on drip irrigation conducted in Surkhandarya province, water savings amounted to 39.4÷41.7% in soybean and sunflower irrigation, as well as 58.3÷62.0% in orchards and vineyards [6]. Taking into account saving up to 60% of water under drip irrigation in comparison with furrow irrigation, the purpose of the conducted research works was to develop new irrigation rates for drip irrigation of fruit orchards. Comparison of research results of furrow irrigation and drip irrigation is presented in Table 4.

Table 4. *List of irrigation regime for orchards and vineyards by hydromodule districts of the Republic of Karakalpakstan, Kashkadarya, Surkhandarya, Khorezm, Bukhara and Namangan regions of the Republic of Uzbekistan.*

№	The organization where the project is being implemented	Information about the orchard					Types of irrigation						Water saved, %
							Furrow irrigation			Drip irrigation			
		Mechanical, structure of the soil, %	Groundwater level, m	Type of tree	Age of tree	*Planting scheme	Irrigationperiod/day	Irrigation norm, m^3/ga	Age of tree	Irrigationperiod/day	Irrigation norm, m^3/ga	Number of irrigation	

1	Republic Karakalpakstan, Beruni district «Ozod intensive bog» farm (N-I-A-b-V)	-heavy sand and clay-12,1%; -medium sandy-32,5%; -light sandy-38,0%; -sandy -17,4%.	3,5	apricot	2	4x3	11.05 ÷ 31.08 113	3600	4	11.05 ÷ 31.08 113	1102	18	69,4
2	Khorezm region, Gurlan district «Mevazor gardens» LLC (N-I-A-b-V)	-heavy sand and clay-30%; -medium sandy -47%; -light sandy -19,4%; -sandy -3,6%.	2,5	apple	3	5x3	10.05 ÷ 31.08 114	3600	4	10.05 ÷ 31.08 114	1026	18	71,5
3	Bukhara region, Kogon district, Bukhara Institute of Natural Managament «Educational and scientific center» (C-I-A-b-V)	-heavy sand and clay-18,3%; -medium sandy -30,9%; -light sandy -49,7%; -sandy -5,7%.	2,5	apricot, peach	1	6x5 5x3	21.04 ÷ 15.09 148	5300	6	21.04 ÷ 15.09 148	1265	27	76,1
4	Kashkadarya region, Koson district, «Agrosuvtexmontaj»LLC ,, Department of Exploitation of Karshi Main Canals(C-I-A-b-V)	-heavy sand and clay -14,3%; -medium sandy -32,5%; -light sandy -38,0%; -sandy -17,4%.	3,0	apricot, almond	1	6x5 6x4	11.04 ÷ 26.09 168	4800	6	11.04 ÷ 26.09 168	1566	30	67,4
5	Surkhandarya region, Sariosia district, “Mindal-agro” farm (C-I-A-b-V)	-heavy sand and clay -21,7%; -medium sandy -50,0%; -light sandy -29,0%; -sandy -0,3%.	5,5	apple	7	5x4	16.04 ÷ 15.09 153	4900	7	16.04 ÷ 15.09 153	1350	27	72,5
6	Namangan region, New Namangan district, «Samarkand oltin tolasi» farm (C-II-A-c-IV) .	-heavy sand and clay -39,0%; -medium sandy -39,7%; -light sandy -17,4%; -sandy -3,9%.	3,5	plum	1	5x5	11.04 ÷ 10.09 152	4300	7	11.04 ÷ 10.09 152	1120	28	74,0

*__Planting scheme:__ the first number is the distance between rows; the second number is the distance between trees (seedlings)

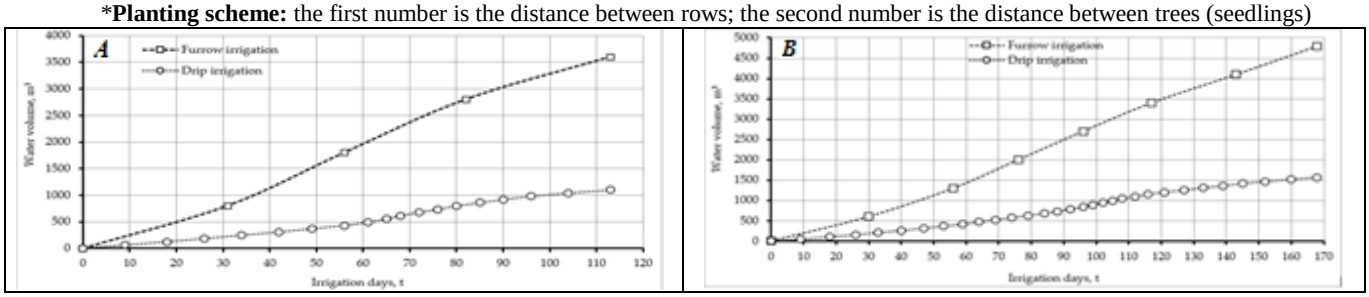


Figure 4. *Relationship between irrigation rate and vegetation period-m=f(T) by regions: A - Republic of Karakalphakistan; B - Kashkadarya region.*

3.2 Solar energy system with pumping units

The use of mobile photovoltaic system will provide the necessary electricity for pumping units and control equipment of drip irrigation system. In summer period the air temperature in the regions of Central Asian countries, in particular in the Republic of Uzbekistan, rises up to t=40÷50^0 C. As a result of temperature increase the efficiency of photovoltaic battery (PVB) decreases up to 80%. To avoid the loss of efficiency, PVBs were equipped with a cooling system, which allows maintaining the temperature at t=25^0 C (Fig. 5 and Table 5) [11].

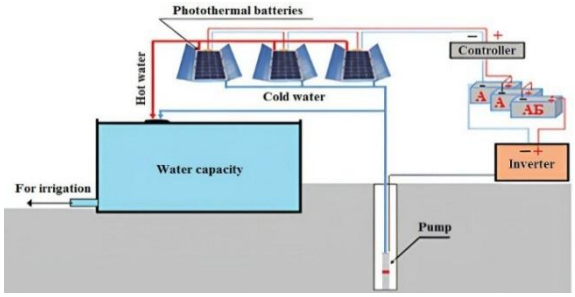


Figure 5. *Schematic diagram of water lifting, redundancy and flow rate using autonomous photovoltaic installation.*

Table 5. *Physical and technical characteristics of FTB parts with power of 4000 W*

Maximum power of PVB, P_{max}	500W	8 PVB
PVB efficiency factor, η	20, 3%	20,3%
PVB no-load voltage, Uoc	22,8V	22,8V
PVB short-circuit current, Isc	8,9 A	8.9 A
Filling coefficient of VAC, ff	0,71-0,73	0,71-0,73
Cellular polycarbonate heat collector (HC) capacitance, V	17 liters	17x8=136 liters
Thermal conductivity of honeycomb polycarbonate, r	0,2÷3,9 W/m·^{o}C	0,2÷3,9 W/m ^{o}C

3.3 Irrigation automation system

To reduce the role of human factor in the drip irrigation system, automation means are introduced, which will control the drip irrigation process on the basis of a special program that takes into account the water demand of plants [12]. By studying the type of soil on the site and its water-physical properties such as water permeability, capillarity, maximum field moisture capacity, volume, comparative soil weight and porosity depending on the growing season, the estimated soil moisture for these crops is established. All these data are put into the irrigation management program.

Conclusions

1. The most cost-effective water-saving technology is drip irrigation, which allows: to achieve savings of water resources up to 50 percent and more; additional development of new agricultural lands; increase crop yields; reduce costs for irrigation works, as well as for the treatment of crops.

2. Application of mobile solar photo thermal battery (PTB) for power supply of drip irrigation systems will allow its implementation in hard-to-reach mountainous and foothill regions.

3. The efficiency of the mobile PTB system is ensured by the possibility of its universal use throughout the year and for a variety of purposes (not only for irrigation systems).

4. Due to cooling of PTB in summer time (at t = 40÷50^0 C) it is possible to increase its efficiency up to 50 percent.

5. Application of the integrated drip irrigation system will increase incomes and improve the living standards of agricultural producers and the population, which will lead to poverty reduction, to increase the reliability and stability of food supply to the population.

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GIS-Based Multi-Criteria Decision Making Approach as a Tool for Land Suitability Analysis - A Review

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Abstract: *Land suitability analysis plays a crucial role in land use planning and decision-making processes. The utilization of Geographic Information Systems (GIS) in land suitability analysis has become increasingly prevalent in recent years. GIS combined Multi-criteria decision analysis (MCDA) is a powerful process that integrates geographical data to make informed decisions. By considering multiple spatial factors, this method generates a comprehensive map highlighting the optimal locations for specific land-use purposes. This review paper aims to examine the application of GIS-based MCDA in land suitability analysis, based on a comprehensive review of the literature. Moreover, the review examines case studies that have applied GIS-based MCDA in land suitability analysis across various disciplines, including agriculture, urban planning, and environmental management. Overall, this review paper provides valuable insights into the role of GIS-based MCDA as a tool for land-use suitability analysis, highlighting its significance in sustainable land management practices.*
Keywords*: LAND SUITABILITY ANALYSIS, GIS, MCDA*

1. Introduction

Land suitability analysis is an essential component of effective land use planning, aimed at identifying the best uses for land based on its inherent characteristics and potential [1]. As urbanization and population growth intensify pressures on land resources, there is an increasing need for sophisticated analytical tools that can provide deeper insights into land evaluation processes. Geographic Information Systems (GIS) have emerged as a pivotal tool in this arena, enabling the integration of spatial data and analytical processes that enhance decision-making capabilities [2].

The integration of GIS with Multi-Criteria Decision Analysis (MCDA) represents a substantial advancement in land suitability assessments. This synergistic approach not only allows for the incorporation of diverse data sources including socio-economic, environmental, and physical criteria but also facilitates a more participatory decision-making framework by engaging stakeholders in the evaluation process [3]. This approach results in the creation of comprehensive suitability maps that guide land use decisions in a transparent and informed manner [4] . The versatility of GIS-based MCDA has led to its application across diverse fields, from agriculture, where it helps optimize crop production [5] to urban planning, where it aids in identifying optimal locations for infrastructure development [6]. In environmental management, it supports the identification of areas suitable for conservation or restoration [7]. Each of these disciplines benefits from the ability to incorporate a wide range of criteria, analyze trade-offs, and visualize complex spatial relationships, making GIS-based MCDA an invaluable tool for sustainable land use. However, despite its widespread adoption, the application of GIS-based MCDA is not without challenges. Issues such as the availability and quality of data, the appropriate selection of criteria, and the subjective nature of weighting decision factors can affect the accuracy and reliability of land suitability models [8].

Despite its growing adoption, the methodologies and effectiveness of GIS-based MCDA in land suitability analysis warrant further examination. This review aims to provide a comprehensive assessment of GIS-based MCDA applications in land-use suitability analysis, drawing on a range of case studies across different disciplines. By synthesizing existing research, this paper seeks to highlight the role of GIS-based MCDA in promoting sustainable land management and to offer insights into its future potential for improving land-use decisions.

2. Methodology

This literature review follows a systematic approach to identify and evaluate studies that utilize GIS-based MCDA in land suitability analysis. A Boolean search utilizing keywords and phrases was employed to navigate scientific research engines and platforms. The search strategy involved querying academic databases, including Google Scholar, Scopus, and Web of Science, using keywords such as: *GIS; Multi-Criteria Decision Analysis; Multi-Criteria Evaluation; site suitability; land suitability; and land use planning* focusing on publications from 1999 to 2024. However, we referred to a few articles prior to the year 2000 that are important to understanding concepts or methods. Each identified study was assessed based on its methodological, the clarity of its MCDA framework, and the integration of GIS technology.

3. GIS in Land Suitability Analysis

3.1 Principles of Geographic Information System

GIS is an essential tools that facilitate the collection, management, analysis, and visualization of spatial data [9], playing a vital role in various fields such as urban planning, environmental management, agriculture, forestry, geology etc. Three fundamental principles of GIS are: data collection, data management, and spatial analysis. Each of these components contributes to the system's ability to handle and interpret complex spatial datasets effectively.

The first principle, data collection, involves gathering geographic information from a variety of sources including remote sensing technologies, field surveys, and existing databases. Geographic data can be divided into two primary types: vector and raster. Vector data represent discrete geographic features via points, lines, and polygons, which are particularly useful for depicting unique objects like roads and land parcels. In contrast, raster data consists of a grid of cells, with each cell containing value information, enabling the representation of continuous variables [10].

After collecting data, managing it well is crucial. This means setting up a strong database that effectively organizes, stores, and retrieves different types of spatial data. Relational database management systems (RDBMS) are commonly used to handle attribute data, linking it to geographic features through unique IDs. It is also important to keep metadata, which documents where the data comes from, its accuracy, and how it has been processed, ensuring transparency and the ability to replicate results [11]. Good data management is vital due to the complexity of spatial datasets, which often involve combining information from many sources. GIS help users integrate various datasets of different scales and formats, allowing for comprehensive analysis, particularly in assessing land suitability.

The third principle, spatial analysis, serves as the core functionality of GIS, enabling users to examine relationships, patterns, and trends within spatial data. Various analytical techniques can be applied, such as overlay analysis, buffering, and spatial interpolation, which help derive meaningful insights. For example, overlay analysis allows users to superimpose different layers of information to evaluate land suitability based on combined criteria [12] Additionally, GIS supports advanced capabilities such as network analysis, which helps assess transportation networks and optimize routes, and suitability modeling, which utilizes weighted factors to

identify the best locations for specific land uses based on multiple criteria [4].

Moreover, GIS excels in visualizing complex spatial datasets through diverse formats such as maps, charts, and 3D representations [13] [14].This capability enhances the interpretability of spatial relationships and is essential for effective communication of findings to decision-makers and stakeholders.

The fundamental principles of GIS encompass systematic data collection, effective data management, and thorough spatial analysis, enabling the handling and interpretation of complex spatial datasets. Through these principles, GIS significantly enhances our ability to derive insights into spatial relationships and patterns, making it an invaluable tool for land suitability analysis and numerous other applications across various domains.

3.2 Applications of GIS in Land Suitability Analysis

GIS have become indispensable in land suitability analysis, where they facilitate the evaluation of various factors influencing land use. One of the primary applications of GIS in this context is the integration of environmental data, including hydrology and soil types, which significantly affect land productivity and sustainability. For example, GIS can be employed to analyze watershed characteristics, assess drainage patterns, and identify flood risk areas, providing essential insights for planning agricultural land or urban development [15]. Soil characteristics, such as texture, pH, and fertility, can also be mapped to determine the most suitable crops for specific locations, enabling optimal agricultural practices [16]. In addition to environmental considerations, socio-economic data plays a critical role in land suitability analysis [17]. GIS allows researchers to incorporate population density, land ownership patterns, and access to essential services such as transportation and healthcare. By overlaying these socio-economic factors with environmental data, decision-makers can identify ideal locations for housing development, commercial establishments, or infrastructure projects. Furthermore, GIS helps in the evaluation of regulatory constraints, such as zoning laws and land-use policies, which can impact land development decisions. By mapping these constraints alongside other data layers, planners can make informed choices that align with legal and environmental sustainability standards [18].

GIS has many uses in land suitability analysis that help us understand how physical and social factors interact. This overall perspective not only helps find the best ways to use land but also encourages collaboration among stakeholders by providing clear visual data. This promotes better decision-making for sustainable land management.

4. MCDA in Land Suitability Analysis

4.1 Understanding Multi-Criteria Decision Analysis

MCDA is a systematic approach used to evaluate and prioritize conflicting criteria in decision-making processes, especially in complex scenarios such as land use planning. MCDA is important because it can take many different factors into account at the same time, just like how real-life problems are often complex and involve many aspects. The methodology begins with the identification and definition of relevant criteria, which can encompass a diverse range of factors including environmental, economic, social, and regulatory considerations [4]. The criteria must be carefully selected to ensure they align with the objectives of the decision-making process and adequately capture the various dimensions of land use suitability.

Once the criteria are defined, the next step involves assigning weights to reflect the relative importance of each criterion in relation to the decision objectives. Weighting can be performed through various techniques, which aim to derive a consensus on the significance of each factor [19]. This weighting process is critical, as it directly influences the outcomes of the analysis and ensures that more crucial factors have a proportionate impact on the final decision.

After establishing criteria and weights, alternatives are evaluated against these criteria using a range of quantitative and qualitative assessment methods. Common techniques include scoring systems, where alternatives are rated based on how well they meet each criterion, and aggregation methods that synthesize these scores into a singular value representing overall performance [20]. The results of an MCDA give a clear way for everyone involved to see the trade-offs between different goals, helping them make better land use decisions. This makes MCDA an important tool for managing the complexity of land use planning, ensuring that various interests and goals are considered in the decision-making process [21].

4.2 Common MCDA Techniques Used in Land Suitability Analysis

MCDA techniques are vital in land suitability analysis, particularly when integrated with GIS. One of the most widely used methods is the Analytic Hierarchy Process (AHP), which allows decision-makers to structure complex problems into a hierarchy, facilitating comparisons among various criteria [19]. One significant strength of AHP is its ability to integrate both qualitative and quantitative data. However, AHP has limitations, particularly in managing subjective biases in the pairwise comparison process. The technique can also become difficult when dealing with a large number of criteria or alternatives due to the exponential growth of pairwise comparisons [22].

Another common technique is the Weighted Sum Model (WSM), which aggregates different criteria by applying weights according to their importance. WSM is straightforward and easy to understand [23], making it accessible for various stakeholders. The WSM excels in addressing single-dimensional problems; however, challenges arise when applied to multidimensional scenarios [24].

The Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) [25] is another effective MCDA method used in land suitability analysis. This method determines the best option by comparing the geometric distance from each alternative to an ideal solution and a negative-ideal solution. TOPSIS is advantageous due to its intuitive approach and ability to incorporate both benefit and cost criteria simultaneously. The TOPSIS method has two main drawbacks. Firstly, the normalization of the decision matrix often results in a narrow scale for the criteria, which can hinder effective ranking and fail to accurately represent the true superiority of options. Secondly, the method does not incorporate risk assessment for decision-makers, limiting its comprehensiveness in evaluating alternatives [26].

Another technique involves Fuzzy Multi-Criteria Decision Making (FMCDM) [27], which enhances conventional MCDA methods by integrating fuzzy logic to address uncertainty and imprecision in the assessment of criteria. While FMCDM provides a robust framework for dealing with uncertainty, it can be more complex to implement and may require advanced statistical and computational skills, which might limit its accessibility for some users.

5. Integration of GIS and MCDA

5.1 Synergistic Benefits

The combination of GIS and MCDA provides unique synergistic advantages that greatly improve land suitability assessments. The synergistic benefits of combining GIS and MCDA can be summarized as follows: *(i) Improved Accuracy*: Enhanced spatial analysis leads to more precise assessments of land suitability; *(ii) Visual Clarity*: GIS visualizations make complex data more accessible improving stakeholder understanding and engagement; *(iii) Getting stakeholders involved:* Supporting community participation in the planning process; *(iv) Comprehensive Analysis.* This approach brings together different aspects of land use, leading to a more detailed understanding [28].

5.2 Case Studies of GIS-Based MCDA in Land Suitability Analysis

The study by Hussain et al. in 2024 [29] investigates agricultural land suitability in Southern Punjab, specifically the Multan region, using the AHP and MCDA methods. The researchers defined clear objectives and relevant criteria, created a hierarchical framework, and conducted pairwise comparisons to assess the relative importance of various factors. The findings revealed that 43% of the land was highly suitable for agriculture, with the most fertile areas characterized by silty clay or clay soils. The study produced a detailed suitability map, serving as a valuable resource for sustainable land use planning and agricultural policy decisions.

The research conducted by Chenying Li et al. in 2022 [30] focuses on the site selection for urban parks in Nanjing, China, emphasizing sustainable urban development. This study employs a combination of GIS and the Fuzzy-Analytic Hierarchy Process (F-AHP) to evaluate multiple criteria, including environmental factors, accessibility, and human activity. Key findings highlighted that areas in western and eastern Nanjing demonstrated the highest suitability for urban parks, with carbon storage being the crucial factor influencing site choice. The combined approach helps urban planners make better decisions by creating helpful maps for choosing park locations.

Kumi-Boateng, B. et al. in 2016 [31] address the urgent need for irrigational reservoirs in the Upper East Region of Ghana, where agriculture heavily depends on increasingly unreliable rainfall and drying rivers. Employing a MCDA within a GIS framework, the researchers evaluated five factor criteria alongside three constraint criteria to identify optimal sites for irrigational dams. The findings revealed that only 3.69% of the area was deemed suitable initially; however, applying the constraint criteria narrowed this down to just 0.45%, pinpointing optimal locations for dam construction. The optimal sites were primarily concentrated in the central part of the region, highlighting critical areas for enhancing agricultural resilience. This research offers valuable insights for water resource management and agricultural sustainability.

The research conducted by [32] Sayed Ishaq Deliry and Hakan Uygucgil in 2020 focuses on land suitability analysis for sustainable urban development in Eskisehir, Turkey. Urban planning necessitates careful consideration of various criteria, making GIS a crucial tool for effective site selection. This study identifies suitable locations based on six primary criteria: safety, connectivity, socio-economic factors, compactness, topography, and eco-environmental conservation alongside ten sub-criteria. By integrating the AHP with GIS, the researchers assessed geophysical and socio-economic data. The findings revealed that 44% of the area is of low suitability for sustainable development, while 42% is deemed unsuitable. Only 0.01% of the region is highly suitable, highlighting significant challenges for future urban growth in Eskisehir. This research underscores the importance of GIS-based methodologies in navigating complex urban planning landscapes.

The study conducted by Karakuş, C.B. and Yıldız, S. in 2022 [33] focuses on identifying suitable dam sites in Sivas, Turkey, utilizing GIS and the AHP as part of a MCDM framework. The research evaluates various criteria, including elevation, slope, proximity to infrastructure, and hydrological factors, to determine optimal locations for dam construction. The findings indicate that a significant portion of existing and planned dams falls within varying levels of suitability, highlighting potential challenges for future developments. The suitability mapping produced serves as a valuable resource for decision-makers in regional water resource management, emphasizing the importance of incorporating multi-faceted criteria to support sustainable development in the area.

The research by Debasish Roy et.al in 2022 [34] addresses the critical issue of landfill site selection for municipal solid waste management in Siliguri, West Bengal. The study employs a GIS and MCDA to evaluate potential sites based on various factors, such as elevation, geology, and proximity to rivers and residential areas. Utilizing the AHP, the authors prioritized these criteria and conducted an overlay analysis to identify suitable locations. The findings provide essential

insights and guidelines for urban planners, facilitating effective waste management while addressing environmental and public health concerns.

6. Challenges and Limitations

Using GIS-based MCDA for land suitability assessment faces several challenges and limitations. A significant issue is the availability of reliable and accurate data, which can negatively influence the results of the analysis [35]. High-quality, up-to-date, and accurate data are often essential for effective MCDA. Additionally, the subjective nature of criteria weighting leads to potential prejudices, given that stakeholders may assign different levels of importance to specific factors [36].

Bringing together different types of data makes things more complicated. When the data comes in different sizes, formats, or categories, it can make it hard to analyze everything clearly. To fix this problem, a lot of preparation work is needed, which can take a lot of time and resources.

Lastly, computational demands can be a significant limitation, as advanced GIS analyses with multiple criteria may require considerable processing power and time, especially for large datasets. Addressing these challenges is crucial for enhancing the reliability and effectiveness of GIS-based MCDA in land suitability studies.

7. *Future Directions*

Future research in GIS and MCDA should prioritize several key areas to enhance effectiveness. Technological advancements, particularly in machine learning and artificial intelligence, can improve data processing within GIS-MCDA frameworks [37]. Additionally, enhancing stakeholder involvement is essential for more effectively meeting community needs and achieving fair outcomes. Moreover, enhancing the adaptability of GIS-MCDA frameworks to cope with changing environmental conditions is essential, utilizing real-time data and predictive modeling to offer resilient solutions. These efforts will contribute to creating a more robust framework for land suitability assessments amongst ongoing environmental changes.

8. Conclusions

In this study, we have conducted a comprehensive review of the existing literature to highlight the essential role that GIS and MCDA play in land suitability analysis. This examination reveals that the integration of GIS and MCDA significantly enhances the decision-making process for a variety of spatial issues, encompassing site selection, land susceptibility assessments and land-use planning. Specifically, *Table 1* and *Table 2* which include 45 research papers and 6 Proceedings of International conferences reviewed, illustrates the importance of GIS-based MCDA in facilitating informed decision-making across these fields.

The application of MCDA techniques proves to be particularly beneficial in addressing complex environmental and civil engineering challenges. *Table 3* delve deeper into the practical applications of MCDA, showcasing its relevance in diverse fields such as environmental management and infrastructure development, along with a discussion of various weighting methods and their impact on MCDM models.

Figure 1 outlines the distribution of reviewed publications over the years, emphasizing the growing interest in GIS-based MCDA. Our literature review indicates a significant rise in the use of GIS-integrated MCDA methodologies to address various spatial challenges in recent years, reflecting an increasing trend in their adoption. *Figure 2* showcases the range of references included in this review.

Table 1. *References on Multi Crieria Decision Analyisis*

Number	Refer.no.	Author/Year of publication	Application	Method used
1	[38]	Johnny K.W. Wong , Heng Li (2008)	Selection of Intelligent building system	MCA/AHP
2	[39]	Sarath.M et al. (2018)	Site suitability	MCA/AHP/GIS
3	[33]	C. B. Karakuş, S. Yıldız (2022)	Dam site selection	MCA/AHP/GIS
4	[40]	Sallwey, J. et al. (2019)	Site suitability (aquifer recharge)	Review (GIS-MCDA)
5	[41]	Joshua, Jonah Kunda et al. (2013)	LSA for agriculture planning	MCDA/AHP/GIS
6	[42]	Sarı, F., & Koyuncu, F. (2021)	Suitability of agricultural crops	MCDA/GIS
7	[43]	Maddahi, Zeinab, et al. (2017)	LSA for rice cultivation	MCDA/Fuzzy AHP/GIS
8	[44]	Villacreses, Geovanna, et al. (2017)	Wind farms suitability	MCDA/AHP/GIS
9	[45]	Martine Nyeko (2012)	Land Use Resource Planning	MCDA/GIS
10	[46]	Owusu, Seth, et al. (2017)	Land suitability for aquifer storage/recharge	MCDA/GIS
11	[47]	Balew, Abel, et al. (2022)	Suitable landfill site selection	MCDA/GIS
12	[48]	Hamide Aliani et al. (2021)	Urban development suitability	TOPSIS/WLC/ANP/GIS
13	[49]	Octaviansyah, Decky, et al. (2024)	Best road selection	MCA
14	[50]	Withanage, Neel Chaminda, et al. (2024)	Suitable areas for ecotourism	GIS-integrated MCDA
15	[51]	Rashid Ahmad et al. (2024)	Rainwater harvesting (RWH) structure	MCDA/AHP+FAHP/GIS
16	[52]	Muhammad, Akhtar Malik, et al. (2023)	Potential Groundwater recharge zones	MCDA/GIS+RS
17	[53]	Rashwan, Mohamed, et al. (2024)	Landslide susceptibility	MCA+GIS
18	[54]	Md. Saalim Shadmaan et al. (2023)	Earthquake vulnerability	GIS based MCDA (AHP)
19	[55]	Rikalovic, Aleksandar et al. (2014)	Industrial site selection	MCDM/GIS
20	[56]	Akay, A. E., & Erdoğan, A. (2017)	Forest fire risk	MCDM/GIS based AHP
21	[57]	Hansen, H. S. (2005)	Wind Farm Development	GIS-based MCDA
22	[58]	Hammami, Salma, et al. (2019)	Flood susceptibility	MCDA based AHP/GIS
23	[59]	Prasetyo, Daniel Hary (2018)	Public school - site selection	MCDA based AHP/GIS
24	[60]	Abdul Rasam, A.R. (2016)	Risk map	GIS-based MCDA
25	[61]	Das, P. T., & Sudhakar, S. (2014)	LSA for orange & pineapple	MCDM/GIS
26	[62]	Perveen, F., et al (2007)	Crop-land suitability analysis	MCDA based AHP/GIS
27	[63]	Kamau, Samuel W., et al. (2015)	Land suitability analysis	GIS-based MCE/RS
28	[64]	Quinta-Nova, L. C., et al. (2020)	Fruits suitability	MCDA based AHP/GIS
29	[65]	Saeedavi, Z., et al. (2017)	LSA for urban green space planning	MCA (AHP)/GIS
30	[66]	Ullah, K. M., & Mansourian, A. (2016)	Urban land-use planning	GIS-based AHP
31	[67]	Granados-Dieseldorff, P.A.B.L.O. (2009)	Habitat suitability	GIS
32	[68]	Beedasy, J., & Whyatt, D. (1999)	Tourism planning	SDSS
33	[69]	Gorsevski, Pece V., et al.(2013)	Wind farm site selection	SDSS
34	[70]	Nurda, Nety, et al. (2020)	Extension of Potential Forest Areas	MCDA/GIS+RS
35	[71]	Malczewski, J. (2006)	GIS- based MCDA	Review
36	[72]	Abu-Taha, R. (2011)	Renewable energy analysis	MCDA-review
37	[73]	Dalalah, Doraid et al. (2010)	Construction	MCDM-AHP
38	[74]	MASRON, Tarmiji, et al. (2015)	Tourism planning	SDSS (GIS)
39	[75]	Prakash, T. N. (2003, December)	Land Suitability Analysis	MCDM-Fuzzy AHP/GIS
40	[76]	Yohannes, H., & Soromessa, T. (2018)	Land Suitability Analysis	MCDM-ANP/GIS
41	[77]	Hussain, S. et al. (2024)	LSA for agriculture	MCDM-AHP/GIS
42	[31]	Kumi-Boateng, B. et al. (2016)	Site selection-irrigational reservoirs	MCDM-AHP/GIS
43	[30]	Chenying Li et al. (2022)	Site selection for urban parks	GIS based Fuzzy AHP
44	[78]	Fu Yang et al. (2008)	Urban land management	GIS/RS/AHP
45	[79]	Hossen, B. et al. (2021)	Land suitability analysis	GIS-based MCDA

One important finding from this review is that GIS-based MCDA can handle different types of data, which helps provide detailed information about land suitability. This flexibility allows everyone involved—from local planners to decision-makers—to make smarter choices that address both current needs and future sustainability goals. The ability to see data on maps helps engage stakeholders better and encourages teamwork in planning. It also makes it easier to share results and explain the reasons for land-use decisions.

Despite its advantages, this review also acknowledges several limitations and future challenges associated with GIS-based MCDA. The accuracy of assessments can be affected by the quality and availability of data, especially in areas where information is scarce. Additionally, the subjective nature of the MCDA methods can lead to inconsistent results. To overcome these issues, future research should focus on improving data integration, refining decision-making processes, and creating standardized methods to ensure more reliable analyses. Ongoing study in this area is crucial for enhancing the effectiveness of GIS-based MCDA in adapting to changing land-use needs and environmental challenges. By addressing these limitations, GIS-based MCDA can become an even more valuable tool for sustainable land management.

Table 2 *References from the Proceedings of the International Conference on MCDA*

References	Author	Title
[80]	Eltarabishi F et al.(2020)	Multi-Criteria Decision Making Methods And Their Applications– A Literature Review
[81]	Radulescu, C.Z. et al.(2010)	A hybrid multi-criteria method for performance evaluation of romanian South Muntenia Region in context of sustainable agriculture
[82]	Ziaei M, Hajizade F. (2011)	Fuzzy analytical hierarchy process (FAHP): a GIS-based multicriteria evaluation/selection analysis
[83]	Abujayyab SK (2017)	GIS modeling for landfill site selection via multi-criteria decision analysis: A systematic review
[84]	Kuznichenko, S. (2020)	Suitable site selection using two-stage GIS-based fuzzy multi-criteria decision analysis.
[85]	Wigati SS et al. (2019)	Bibliometric analysis for site selection problems using geographic information systems, multi-criteria decision analysis and fuzzy method.

Table 3 *Bibliographic References for Books on MCDA*

References	Author	Book title
[86]	Dean, Marco (2020)	Advances in Transport Policy and Planning
[87]	Ozsahin, Dilber Uzun, et al., (2021)	Application of MCDA in environmental and civil engineering
[88]	Zardari, Noorul Hassan, et al. (2014)	Weighting methods and their effects on MCDM model outcomes in water resources management

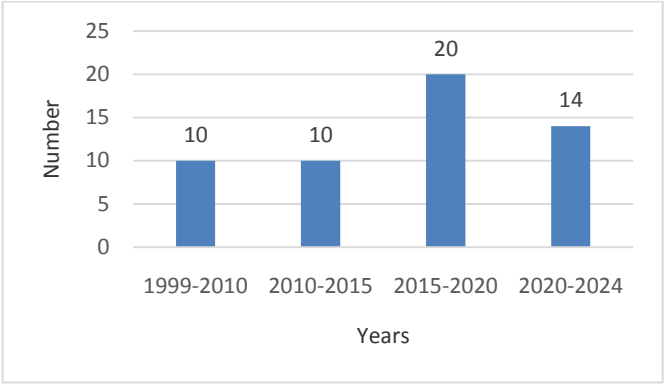


Fig.1 *Number of reviewed papers, books and conference proceedings over the years*

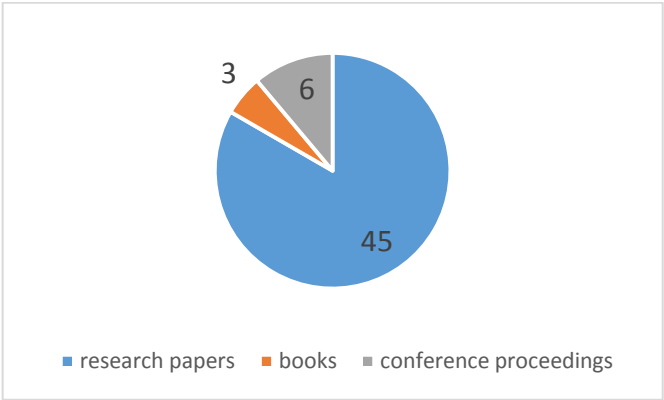


Fig.2 *Number of referred references*

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Research on the conditions of reclamation of agricultural soils disturbed by military operations

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Abstract. *The article studies and analyzes the impact of military operations on the soil cover, in particular, damage and destruction of the fertile soil layer as a result of detonation of various explosive objects (missiles, bombs, artillery shells, etc.) and its contamination with heavy metals and other harmful substances. A method is proposed for the technical reclamation of damaged land as a result of bombing. It involves first cleaning the craters from damaged and contaminated soil with heavy metals and other hazardous substances. It is proposed to use a new working body for this purpose. If a dangerous concentration of heavy metals and other hazardous substances is found on the surface of the crater, the removed contaminated soil layer must be disposed of. If the removed layer of the sinkhole surface contains an acceptable concentration of contaminants, the removed layer can be left at the bottom of the funnel. A flexible screw conveyor with a sectional auger working body can be used to dispose of the removed contaminated soil layer. To restore the relief, it is necessary to backfill the craters, i.e. level the surface. After that, the land can be disked and cultivated, and plowed if necessary.*
KEYWORDS: *AGRICULTURAL SOILS, CONTAMINATION, RECLAMATION, EXCAVATION, WORKING BODY, EXCAVATOR BOOM.*

Thousands of hectares of Ukrainian land were bombed during the aggressor's full-scale invasion of Ukraine. Military actions lead not only to mechanical and physical deterioration of the soil, but also to its chemical contamination.

Deformation of the soil cover due to the formation of craters from bombing or demining of territories, movement of military equipment, troop movements, construction of protective structures, and bombing sites lead to disruption of the soil structure. The consequence of this impact is compaction, waterlogging, and contamination of the territory with war products [1]. The main mechanical impact on the soil is compaction with damage to the humus layer, which has direct negative consequences, such as disruption of the soil's water balance and the development of wind and water erosion. Physical impact involves changes in the physical parameters of the soil as a result of the use of weapons and military equipment, i.e. vibration, radioactive and thermal effects. Chemical impact changes the natural physical and chemical parameters of the soil cover, primarily pH, cation exchange and humus content. It also increases the concentration of toxic chemicals [2].

The combination of various impact factors leads to a cumulative negative effect. The consequences are the loss of the soil's buffer capacity for recovery, loss of humus and a decrease in natural fertility.

Currently, about a third of Ukraine's agricultural land has been affected by the hostilities. During explosions and the operation of military equipment, large amounts of toxic explosives and heavy metals enter the soil. The soil is chemically damaged [3].

A very negative aspect is that pollutants can move around. This happens in two ways:

– horizontal, which occurs immediately after the bombing, primarily due to air transport;

– vertical, due to factors such as ion diffusion, transfer with the flow of moisture or plant root systems, soil mesofauna, and human activities [4].

Most often, pollutant migration occurs through groundwater, which has the ability to retain heavy metals through selective uptake (adsorption). Many factors influence the proportion of heavy metals that migrate. In particular, soil composition, organic matter in the soil, moisture, microbiological activity, etc. are important. The presence of plants also affects the mobility of explosives and heavy metals [2].

In craters caused by missiles, bombs and mines, and in places where military equipment burned, the content of heavy metals in soil samples exceeds the norm by 10-20 times. These include mercury, arsenic, lead, iron, copper, and chromium [3].

Rocket and bomb explosions pollute not only the air. Harmful substances do not stay in the air for long, but return as precipitation and accumulate in the soil. Sulfur, which is a component of a large part of ammunition, remains in powder form not only in the craters but also around them, and in contact with precipitation it turns into sulfuric acid. And this is very bad for the soil, because millions of organisms that form the upper living layer of the soil and the ecosystem are burned in this acid.

Toxic elements such as lead, cadmium, arsenic, and mercury will be absorbed by plants with background levels ten times higher than normal. Other elements, such as zinc and nickel, will seriously inhibit crop growth [5].

So, soil contamination can be a hidden danger. If potential areas of contamination are not identified and recorded in time, harmful substances will leach into grain or other agricultural products and poison the crop. This is a direct threat to food security and export opportunities.

Physical and mechanical damage can be seen with the unaided eye, but to determine the chemical impact, it is necessary to analyze it, because heat, explosion, and soil rupture all have an impact. This also destroys the biological component of the soil - the microbiota, humus, and other substances responsible for the biological activity of the soil are practically “burned out”. For example, high concentrations of hydrocarbons can cause symptoms of poisoning in earthworms [2].

Products grown on such lands may be unsafe for consumption, so such lands require measures appropriate to the level of contamination: reclamation or even conservation. Conservation is recommended for the most damaged lands (i.e., those with more than 75% of the land area damaged), as the cost of remediation for this level of damage is so high that it is no longer economically feasible.

Fig. 1 shows a field damaged by artillery shell craters [5].

The conservation of the most damaged areas also allows communities to improve soil biodiversity, increase their ability to adapt to climate change, and reduce the risks of wind and water erosion. In other words, conservation, in addition to the natural restoration of the sites themselves from pollution, has a number of related environmental benefits for the entire territory [6].



Figure 1. *A field disfigured by artillery shell craters*

However, if the level of heavy metal contamination due to explosions is high, and a dangerous pollutant can easily migrate

into groundwater (depending on soil and climatic conditions), then improvement measures are unavoidable! The issue here is not one of economic feasibility, but of environmental safety of the state. Before conservation of the most damaged areas, it is necessary to remove or clean the damaged soil layer and then utilize it. Almost all studies show highly contaminated profiles of the topsoil (0-10 cm). With increasing depth, the level of contamination decreases, except for those potentially toxic elements that have relatively higher levels of accumulation with increasing depth. Contamination is generally limited to the first half meter of depth [7].

If the damage to the surface of the plots is 75-100% of the area, the damaged plots can be preserved and nature can start the process of self-healing, as further import of good quality soil is costly. If the damage amounts to 50-75% of the area of the plots, the land is subject to reclamation.

In order to carry out reclamation, i.e. to transform contaminated land into a usable area, it is necessary to conduct thorough monitoring of the areas of soil damaged and contaminated as a result of hostilities, which will allow timely measures to be taken to rehabilitate them, as well as to establish the boundaries of contaminated areas in order to restore them [8, 9].

Land monitoring to maximize coverage of the entire potentially affected area using modern technologies:

– high-precision satellite data for remote monitoring and digitization of areas affected by hostilities;

– drones for both photo and video recording and magnetometric surveys for remote detection and identification of metal and explosive objects for further demining and neutralization.

This will allow you to record, digitize, and determine the level of damage to each potentially dangerous area of the field. Progressive farms and holdings that already use precision farming elements on their fields can digitize damaged areas, sinkholes, etc. with their own resources. Next, you need to take samples in the affected area (separately) and the surrounding area (separately). Based on the analysis of pollutants (especially heavy metals), the optimal reclamation option can be selected [10].

To restore the areas damaged by the explosions, it is necessary to remove or clean the surface soil layer, as in addition to chemical contamination with heavy metals, the fertile soil layer burns out, dehydration and “sterilization” occurs, killing both pathogenic microorganisms and beneficial biota. If the surface contaminated layer is not cleaned off, but the sinkhole is mechanically sealed with bulldozers and graders, soil fertility restoration will take decades and require serious investments in organic fertilizers, ameliorants, phytomelioration, etc. [11, 12].

If dangerous concentrations of heavy metals and other dangerous substances are found on the surface of the crater, the removed contaminated soil layer must be disposed of. If the removed layer of the sinkhole surface contains an acceptable concentration of pollutants, the removed layer can be left at the bottom of the sinkhole [13, 14].

Shallow sinkholes (up to 0.5 m) can be filled with soil mass remaining at the explosion site (at an acceptable concentration of pollutants) or mineral soil (loam, loess loam, sandy loam, sand), followed by leveling the surface.

Deep sinkholes (more than 0.5 m) should be covered with soil mass, but the order of soil layers should be close to the undamaged areas, so the sinkhole should be covered with mineral soil first, and the top layer (20-30 cm) should be covered with fertile chernozem. If backfilled in a chaotic manner, such a site will be low-productive for crops, and its restoration will require additional measures (application of organic fertilizers, ameliorants, phytomelioration, etc.). Based on the measurements of the parameters of explosion craters, the need for mineral and fertile soils is calculated in the working land management project.

Fig. 2 shows the appearance of craters from air bombs.



a



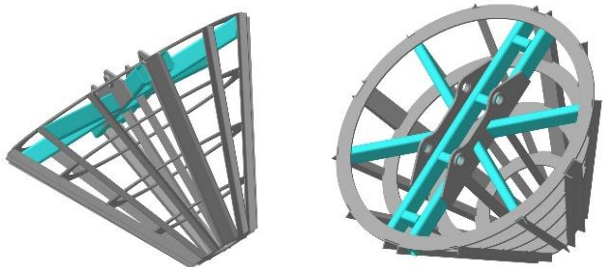
b

Figure 2. *The appearance of craters caused by bombs: a – shallow crater (0.5 m); b – deep crater (8 m)*

To remove and clean the damaged surface layer of soil in the crater formed as a result of explosions, it is recommended to use a working tool that will allow mechanizing this process. This working tool is attached to the boom of an excavator with a hydraulic system. Fig. 3 shows a general view of an excavator with a working body installed to clean the damaged soil inside the craters and a general view of this working body. It contains a frame made in the form of circles to which channels and angles are welded.



a



b

Figure 3. *General view of an excavator with an excavating tool for cleaning damaged soil inside sinkholes (a) and general view of this tool (b)*

This working body can be rotated by a hydraulic motor connected to the excavator's hydraulic network and can be rotated at an angle to the horizon. As the working body rotates, the angle of the sinkhole whose surface needs to be cleaned will be selected. The ribs of the channel shelves and angles welded to the working body will allow you to remove the top layer of the sinkhole surface from damaged contaminated soil containing heavy metals and other harmful substances.

To dispose of the removed contaminated soil layer, a flexible screw conveyor with a sectional auger working body can be used, which will allow it to be transferred to the truck body.

The working body is made in the form of a cut-off cone, the inner surface of which is hollow, and is attached to the excavator boom with brackets.

The excavator operation scheme with the working body installed is shown in Fig. 4.

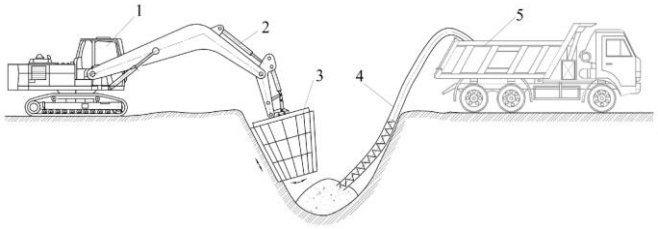


Figure 4. *Schematic of an excavator with an installed working body for cleaning damaged soil inside sinkholes: 1 – excavator; 2 – excavator boom; 3 – working body; 4 – screw conveyor with a sectional auger working body; 5 – truck*

In this way, technical land reclamation can be carried out, which involves first cleaning the craters from damaged and contaminated soil with heavy metals and other dangerous substances. After that, it is necessary to backfill the craters, i.e. level the surface. After that, the land can be used for disking and cultivation, and, if necessary, plowing.

Subsequently, to restore land productivity and soil fertility after technical reclamation, it is necessary to carry out a set of agrotechnical, agrochemical and phytomeliorative measures by deoxidizing soils, applying organic and mineral fertilizers and sowing perennial grasses.

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Migration ability and bioaccumulation of 152Eu from Calcaric Chernozem soil to peppermint (*Mentha Piperita L.*) and its transfer to tincture and tea

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Abstract: *Europium is widely used in industry and improper waste management in its recycling can cause environmental pollution. ^{152}Eu is obtained as a result of neutron activation of the control rods of nuclear reactors and may enter the soils after nuclear accident. The distribution of ^{152}Eu in the environment and its transfer through the food chain can threaten the human health through its beta and gamma radiation. Therefore, knowledge of the geochemical forms of Eu and its transfer from soil to plants is important for the risk assessment in case of environmental pollution. The paper presents the results of a model study on the mobile geochemical forms and bioaccumulation of ^{152}Eu from chernozem soil to peppermint (Mentha Piperita L.). Peppermint plant was planted in a pot with Calcaric Chernozem soil, taken from the 0-10 cm surface layer. Aqueous solution of $^{152}EuCl_3$ was spiked in the soil, simulating radioactive contamination. The peppermint was grown during 8 months and samples of the soil and peppermint stems and leaves were taken at the 5th and 8th month after the radioactive contamination. The transfer factors (TFs) soil-to-plant were determined. The water-soluble, exchangeable and bound to humic and fulvic acids forms of ^{152}Eu were studied after the 1st, 5th and 8th month after the contamination. The transfer of ^{152}Eu from the mint leaves to tea and tincture was examined. The results showed higher TFs for the soil-leaves than soil-stems system. More than 40% of ^{152}Eu, accumulated in the dry leaves was found to be extracted in the tea, while no radioactive europium was found in mint tincture.*

Keywords: EUROPIUM-152, PEPPERMINT, HUMIC AND FULVIC COMPLEXES, TRANSFER FACTORS, WATER EXTRACT, TINCTURE

1. Introduction

Europium (Eu, Z=63) belongs to the group of the light rare earth elements and has two characteristic oxidation states: Eu(II) and Eu (III). It is present in the Earth's crust at a concentration of about 1.8 milligrams per kilogram (mg/kg), while its concentration in seawater is about 0.00013 micrograms per liter. Traces of ^{152}Eu and ^{154}Eu are found in soil from radioactive waste. It can also be present in some nuclear facilities, such as reactors and spent fuel reprocessing plants [1]. Eu has wide industrial applications, such as in the production of fluorescent glass, phosphors, mobile phones, smartphones, portable wireless installations and optical fibers. Europium is also used in old fashioned TV-screens (cathode ray tube TVs, CRTs) or luminescence lamps [2-5] and may enter the nature during recycling process. Europium can enter the human body through food, drinking water or inhalation. Gastrointestinal absorption from food or water is a major source of internal intake of europium in the general population. Europium is not well absorbed in the body after ingestion, only about 0.05% of the ingested amount is absorbed into the bloodstream through the gastrointestinal tract. Of the europium that reaches the blood, 40% is deposited in the liver, and another 40% is deposited on the bone surface, where it can irradiate the bone cells. Thus, deposited europium is preserved in the body with a biological half-life of almost 10 years (3500 days). An additional 6% of absorbed europium is deposited in the kidneys, where it is retained with a short biological half-life of 10 days. The rest of the absorbed europium is released [1].

Radioactive europium poses both an external and an internal health hazard. The strong gamma-radiation from ^{152}Eu and ^{154}Eu causes external irradiation. While in the body, europium poses a health hazard from both gamma rays and beta particles, with the primary health hazard associated with an increased likelihood of causing liver and bone cancer [1].

Therefore, the data on the migration ability, bioavailability and transfer of radioactive isotopes of europium in food and beverages is important when preparing predictive risk assessments in case of pollution. Knowledge of the soil to medicine plant transfer of contaminants is important to prevent pollutant's uptake in the human body above the permissible levels.

The subject of investigation in the present paper is the accumulation of radioactive europium from chernozem soil to one of the most popular herbs – the peppermint (*Mentha Pipertia L.*).

Mentha Piperita L. has established choleretic, antispasmodic, local anesthetic and antiseptic effects. Peppermint is used for pain in the stomach and intestines, for biliary dyskinesia, liver diseases, flatulence, as well as for removing the symptoms of intoxications of gastrointestinal origin [6-10]. Although less common, peppermint is used for headaches, epilepsy, and depression. Peppermint, and especially peppermint oil, is used alone and in combinations to treat hemorrhoids by topical application. A very common form of peppermint oil with chlorophyll is in oral breath lozenges. The most essential in the action of mint and the essential oil contained in it is their cholagogic and choleretic action. It is experimentally established that the infusion of mint leaves increases bile secretion [11].

Peppermint is a widely used herb and the accumulation of pollutants in it from contaminated soils is of interest in a number of studies [12, 13].

To assess the transfer of pollutants in the soil-plant system, are used the transfer factors (TFs). They are defined as the ratio of the radionuclide content in the plant (or in part of the plant) to that in the soil (Bq kg^{-1} dry weight plant tissue/Bq kg^{-1} dry weight soil). Their values can vary significantly, depending on the soil characteristics, plant species and agricultural practice [14].

The use of radionuclides as tracers of stable isotopes is an efficient approach to trace the path of the elemental contaminants through the soil phases and via the food chain.

The aim of the present study is to investigate the bioaccumulation of ^{152}Eu from Calcaric Chernozem soil to stems and leaves of peppermint (*Mentha Piperita L.*) and its transfer to peppermint tea and tincture. Water-soluble and exchangeable forms of ^{152}Eu, as well as its complexes with humic and fulvic acids in soil were determined.

2. Materials and Methods

Peppermint plant was sampled and transplanted into a plant pot filled with Calcaric Chernozem soil, taken from the 0-10 cm surface.

The main characteristics of the soil are presented in Table 1.

Table 1. Main characteristics of the studied Calcaric Chernozem soil

Soil texture	**pH**		**Humus, %**	**Sand, %**	**Silt, %**	**Clay, %**
	KCl	**H_2O**				
Clay loam	7.1	7.8	2.59	32.9	36.8	30.3

Aqueous solution of $^{152}EuCl_3$ (pH 5.5) was spiked into the plant pot, simulating radioactive contamination.

The peppermint was grown at 15-22 ^oC and 20-30 % soil moisture during 8 months. Samples of the soil and peppermint stems and leaves were taken at the 1^{rst}, 5th and 8th months after the radioactive contamination. The plant parts and the soil samples were air dried to constant weight and the transfer factors (TF) soil-plant were determined.

Water-soluble, exchangeable and bound to humic and fulvic acids forms of ^{152}Eu were determined by using the following extraction procedures:

Water-soluble forms of ^{152}Eu: 2 g dry weight of the studied soil samples were mixed with 20 cm^3 of distilled water. End-over-end extraction was performed by shaking at about 20 ^oC for 2 h at 200 rpm, followed by vacuum filtration of the leachates through 0.2 μm cellulose nitrate filters.

Exchangeable forms of ^{152}Eu: 2 g dry weight of the studied soil samples were mixed with 20 cm^3 of 0.01 M $CaCl_2$, as described in [15]. End-over-end extraction was performed by shaking at about 20 ^oC for 3 h at 30 rpm, followed by vacuum filtration of the leachates through 0.2 μm cellulose nitrate filters.

Complexes of ^{152}Eu with humic and fulvic acids: 5 g dry weight of the soil sample were shaken twice for 1 h with 15 ml 0.1 M $Na_2P_4O_7$ (pH = 9) to extract the complexes with humic (HA) and fulvic acids (FA) as described in [16]. The fulvic complexes were separated by adding k.H_2SO_4 to the extracts, which caused precipitation of the humic complexes. The extracts were filtered by 0.20 μm cellulose nitrate filters.

The radionuclide content in the different fractions was measured in the supernatant, and the extraction yield was determined by dividing it by the initial radioactivity of the sample.

All the extracts, soil and plant samples were measured by γ-spectrometry. HPGe detector Canberra 7221 coupled to a 16000-channel analyzer DSA-1000 was used to measure ^{152}Eu by its gamma peak at 121.78 keV.

The preparations of the tincture and the peppermint tea were carried out as follows:

Tincture: 2 g dry leaves were mixed with 30 ml 86 % C_2H_5OH, left for six weeks (at 18 ^oC) in darkness and filtered. Afterwards the radioactivity of ^{152}Eu in the tincture was determined by γ-spectrometry.

Water extract (Peppermint tea): 0.5 g dry leaves were added to 200 cm^3 distilled water and were gently boiled for 20 minutes. The leachant was filtered and the radioactivity of ^{152}Eu in it was determined by γ-spectrometry.

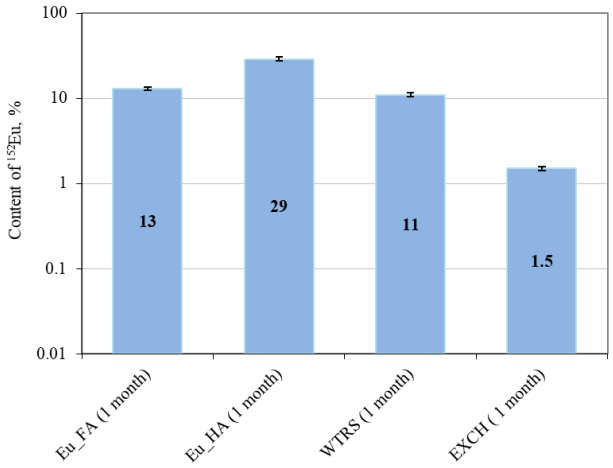


Figure 1 *Content of ^{152}Eu in % in the extracted fulvic complexes (Eu_FA), humic complexes (Eu_HA), watersoluble forms (WTRS) and exchangeable forms (EXCH) after 1 month after the soil contamination.*

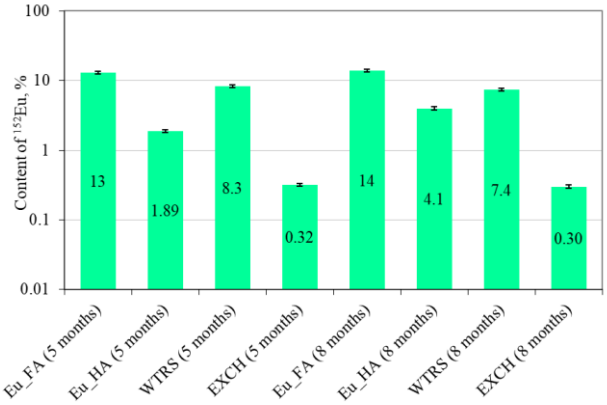


Figure 2 *Content of ^{152}Eu in % in the extracted fulvic complexes (Eu_FA), humic complexes (Eu_HA), watersoluble forms (WTRS) and exchangeable forms (EXCH) after 5 and 8 months after the soil contamination.*

3. Results and Discussion

3.1. Distribution of ^{152}Eu in the soil phases

The results from the extraction of the complexes of ^{152}Eu with humic and fulvic acids and the water-soluble and exchangeable forms of the radionuclide after 1, 5 and 8 months after the soil contamination are presented in Figs. 1-2.

The data presented in Fig. 1 show that 42% of europium was bound to humic and fulvic acids in the first month after contamination. Its exchangeable form is only 1.5% of its total radioactivity, while the water-soluble form amounts to 11%.

Tracking the change in the geochemical forms of ^{152}Eu over time (Figs. 1-2) shows that its % content in the complexes with fulvic acids on the fifth and eighth months after the pollution does not change significantly and remains 13-14%. In contrast, the humic acid complexes significantly decreased with the time and amounted to less than 2% at the fifth and about 4% at the eighth month after europium application to the soil. This corresponds to a 15- and 7-fold decrease in europium content in this form compared to the data from the first month after the contamination.

The content of radioactive europium in the water-soluble fraction was also reduced by 24% from the first to the fifth month and by 33% to the eighth month after contamination. The europium content in the exchangeable soil fraction also decreased fivefold. These changes can be explained by the redistribution of ^{152}Eu between soil phases with the time and binding in less mobile forms.

3.2. Transfer factors values after 5 months and 8 months vegetation on the contaminated soil

The values of TFs in the soil-leaves and soil-stems systems, determined on the fifth and eighth months after the pollution are presented on Fig. 3.

It can be seen that the values of the TFs of ^{152}Eu for the leaves are four to five times higher than the TFs for the stems of the peppermint. The data show that TFs from the fifth to the eighth month increased by 75% for the soil-leaves system and by 39% for the soil-stems system. The accumulation of ^{152}Eu from the soil to the plant determines the need to investigate the degree of transfer of the radionuclide to products for consumption. It is necessary for assessing the danger of its entry into the human body in case of radioactive contamination of the soil.

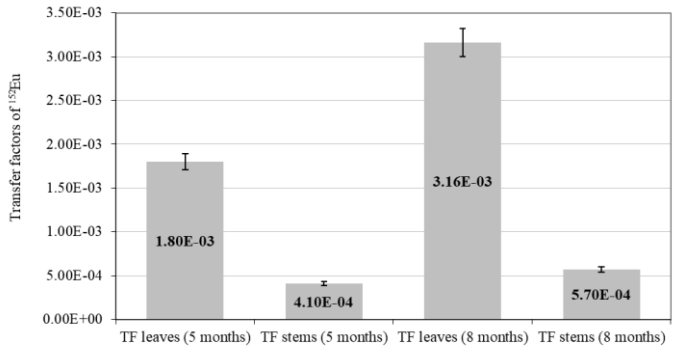


Figure 3 *Transfer factors of ^{152}Eu from soil to mint leaves and mint stems after 5 and 8 months after the soil contamination.*

3.3. Leaching of ^{152}Eu from peppermint to alcohol tincture and tea

The results, obtained from the measurements of the peppermint tea samples showed that 42 ± 2% from ^{152}Eu was leached.

No ^{152}Eu was detected in the tincture. This result showed that the radionuclide is bound to the hydrophilic part of the plant.

4. Conclusions

The present study showed that the entrance of radioactive europium solution to Calcaric Chernozem soil over a period of 8 months resulted in bioaccumulation by *Mentha piperita* L. that was 4 to 5 times greater in leaves than in stems.

An increase in the soil-stems and soil-leaves TFs was measured with the increase of the exposure time of the plant to the soil pollutant. The amount of ^{152}Eu bound to fulvic acids in the soil was found to remain constant from 1 to 8 months after the contamination. The content of the radionuclide bound in complexes with humic acids, as well as in water-soluble and exchangeable geochemical form, significantly decreased with the time.

42 % from ^{152}Eu, accumulated in the peppermint dry leaves was found to be leached in the mint tea and could endanger the human health. No danger of contamination of 86 % C_2H_5OH peppermint tincture with ^{152}Eu was found, when radioactive contaminant entered the soil in aqueous solution.

The data obtained from the present study can be used in the assessment of the danger of internal radiation exposure with radioactive europium in case of nuclear contamination.

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Conditions for restoration of agricultural land after the bombing

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Abstract. *The main indicators of the impact on agricultural fields of the military actions that are currently taking place in Ukraine are determined. In particular, not only the damage to the surface relief, but also the contamination of fields with chemicals has been established. The indicators of soil contamination, as well as the directions of further use of the fields and general rehabilitation measures for agricultural land affected by chemicals are determined.*
KEYWORDS: *FERTILE SOILS, CHEMICAL CONTAMINATION, RECOVERY, SINKHOLE, MECHANICAL CLEANING*

As a result of the ongoing hostilities in Ukraine, agricultural land is being severely damaged and destroyed, and its condition, especially its environmental condition, has deteriorated significantly.

The explosions create a blast wave and sinkholes on the field that destroy the terrain, as well as chemical contamination. The consequences of the blast wave are the formation of sinkholes of various sizes, soil compaction, destruction of vegetation and death of soil fauna. All of this causes a change in the hydrolytic regime and destruction of the soil structure, and ultimately provokes soil erosion and desertification. Military weapons and explosives use chemical compounds that are not biodegradable and can contaminate soil and surface water [1].

In this case, chemical pollution is considered based on three components. These include contamination by potentially toxic elements, contamination by explosives, and conventional contamination due to high temperatures.
In addition, chemical contamination of agricultural land can have different degrees: from acceptable to moderately dangerous and hazardous. In this case, uprooting the standard: «DSTU 7243:2011 Soil quality. Technogenically contaminated lands. Inspection and use» land plots with very dangerous and extremely dangerous degrees of chemical contamination are subject to conservation for a certain period of time depending on the decomposition of chemicals or their decontamination [2].

The degree of land contamination with chemicals is determined based on the results of a survey of such land and a rapid soil analysis on the land plot based on the results of the analysis of samples taken on the land plot [3].
The approaches most commonly used in soil sampling are as 5 cm. Thereafter, the sampling intervals should be close enough to each other, such as 5-10 cm or 20-30 cm, to ensure relevant depth segregation. Almost all studies show highly contaminated profiles of the topsoil (0-10 cm). With increasing depth, the level of contamination decreases, except for those potentially toxic elements that have relatively higher accumulation levels with increasing depth. A thorough study of soil contamination is usually limited to the first half meter of its depth [4].

Another important point is the following. It is also necessary to take into account the depth of groundwater when determining the sampling site, since the mechanisms of pollutant migration in the zone saturated with organic or mineral substances are different. In the case of surface contamination, the presence of organic matter can affect the migration of pollutants to deeper layers.

To assess the degree of contamination, agricultural soils are classified by comparing them to the maximum permissible concentration and background content of hazardous substances that pollute the soil. In this case, the main calculated indicators of the degree of pollution are the concentration coefficient K_c and the total pollution indicator Z_c [2]. These indicators are determined by calculations based on field measurements.

Thus, the concentration factor K_c is calculated using the following simple formula:

$$K_c = C_i \cdot (C_f)^{-1}, \qquad (1)$$

where C_i is the actual content of the i-th chemical element; C_f is the background content of the i-th chemical element.

After that, it is possible to determine the total pollution index Z_c which can be calculated using this expression:

$$Z_c = \sum K_c - (n-1), \qquad (2)$$

where n is the number of chemical elements that meet the condition $C_i > C_f$.

Based on the measurements and analysis of soil samples taken near the towns of Sloviansk and Shchastia (Donetsk Oblast), directly in the areas of fields where shells hit and 500 meters away, the average value of chemical contamination indicators was generally at the level of background values. At the same time, soil samples were taken from the test site using the «envelope» method with an average of 5 points. Systematic exceedances of 1.1 to 1.3 times were recorded for mercury, vanadium, cadmium, non- radioactive strontium and gamma radiation. The maximum exceedance for some indicators was 1.2-2.0 times the background level, and only in some cases the exceedance reached 7-17 times.
As for the chemical analysis of the soil conducted on the territory of the Kreidova Flora reserve as part of the same study, the concentration of titanium in the soil sample at the site of the shell explosion was 150 times higher than the background. The concentration of vanadium was 100 mg·kg^{-1}, and there was no vanadium in the clean sample at all. Titanium-based alloys with vanadium additives are used in aviation and missile technology.
There was also a 2.3-fold exceedance of sulfates, and mobile forms of heavy metals: lead – 1.3 times, cadmium – 1.5 times. In addition, strontium was found to be exceeded in Zakvitne village at the site of shell bursts. Its concentration was 150 mg·kg^{-1}. The content of sulfates in the same sample exceeded the norm by more than 4 times, and cadmium – by 9 times. At the site of shell bursts in Donetsk region, excesses were recorded for mobile forms of heavy metals, including manganese, copper, iron, lead, cadmium, chromium, and zinc [6].

Heavy metals can get into crops from the soil and then into food. Therefore, it is impossible to give up on soil analysis and cultivate the fields. Otherwise, people will simply refuse to buy the products. Commission Regulation (EC) No. 1881/2006 of December 19, 2006 laying down maximum levels of certain contaminants in foodstuffs sets the following permissible levels of lead (mg·kg^{-1}) of wet weight):
– Vegetable (cabbage), leafy and cultivated mushrooms – 0.30;
– Cereals, wheat, rice, legumes, soybeans, and berries – 0.20;
– Fruits and vegetables (excluding cabbage and leafy vegetables) – 0.10.

Strict restrictions in this document also apply to other heavy metals, including cadmium, tin, and others. If animal feed is grown on the fields, contaminated soils can indirectly affect the quality of livestock products.
Based on the above, pollution indicators, areas of use and rehabilitation measures were formulated for agricultural land damaged by military operations in cases where chemical contamination occurred [2].

Table 1. *Indicators of contamination, areas of use and remediation of agricultural land*

Total soil pollution index Z_c	**Level of contamination (% of the area) of the**	**Categories of land suitability**	**Areas of application**	**Proposed rehabilitation measures**
Acceptable pollution index Z_c less than 16	Very low level contamination up to 10% of the land area	Definitely suitable	Growing crops without restrictions	Not conducted
Moderately hazardous pollution index Z_c up to 32	Low-level pollution (10-25% of the land area)	Suitable for	Growing crops without restrictions, subject to product quality control	Agronomic measures, liming, application of organic and mineral fertilizers
Dangerous pollution index Z_c from 32 to 64	Medium level pollution (25-50% of the land plot area)	Not very suitable	Use for industrial crops without obtaining food from them	Agrotechnical measures, phytoremediation, chemical reclamation
Very dangerous pollution index Z_c from 64 to 128	High-level pollution (50-75% of the land area)	Conditionally suitable	Use for pastures and cultivation of essential oil crops	Physical and chemical reclamation
Extremely dangerous pollution index Z_c more than 128	Very high level of pollution (75-10% of the land area)	Not applicable	Withdrawal from intensive use. Preservation	Involvement or natural recovery

Determining and analyzing pollution indicators makes it possible to choose the optimal reclamation option. In this case, the choice of land remediation methodology is based on a cumulative assessment of the level of damaged land, which involves determining the category of land use suitability.

To carry out this restoration of agricultural fields damaged by explosions, it is first and foremost necessary to digitize the areas using satellite / UAV / ground monitoring with reference to the coordinate system of each specific field. All areas should be digitized, regardless of the state of damage and the extent of the impact. This is also necessary because, even if the physical damage to the soil of an agricultural field is minor, it may be chemically contaminated. So, we can recommend this approach. In case of damage to the surface of a field where 75-100% of the area is affected, it is recommended to preserve the damaged areas and allow the process of self-healing to occur naturally, since removing the damaged soil and bringing in high-quality soil in its place will be quite costly from an economic point of view.

Furthermore, if the damage amounts to 50-75% of the area of the plots, the soil cover requires mandatory reclamation.

Next, samples should be taken from the affected area (separately) and the surrounding area (separately) and analyzed for contaminants. First of all, heavy metals.

Based on this data on the level of agricultural land contamination, a decision should be made on the possibility of farming and further intended use.

After agricultural fields have been cleaned from the source of contamination and debris, it is necessary to take measures to restore the soil damaged by explosions. According to the developed recommendations, if there are relatively shallow craters, up to 0.5 m in size, they can be covered with the soil mass remaining at the explosion site (at the permissible concentration of pollutants) or mineral soil (loam, loess loam, sandy loam, sand), followed by leveling the surface [7, 8].

If there are deep sinkholes on damaged agricultural fields, measuring more than 0.5 m, they should be filled with soil in the following sequence. It is necessary to ensure that the order of soil layers is close to the order of undamaged areas, so the sinkhole should be filled with mineral soil first, and the upper fertile soil layer up to 30 cm deep should be filled with already fertile soil. If the soil is backfilled in a chaotic manner, it is likely that such a field will be low-productive for further crop cultivation and its full restoration will require additional measures, such as additional application of organic fertilizers, ameliorants, phytomeliorants, etc. Based on measurements of the parameters of explosion craters, the required need for mineral and fertile soils is calculated in the working land management project [7, 8].

To restore the areas damaged by explosions, it is necessary to remove or clean the surface soil layer, as in addition to chemical contamination with heavy metals, the fertile soil layer burns out, dehydration and "sterilization" occurs, killing both pathogenic microorganisms and beneficial biota. If the surface contaminated layer is not cleaned off, but the sinkhole is mechanically sealed with bulldozers and graders, soil fertility restoration will take decades, requiring serious investments in organic fertilizers, ameliorants, phytomelioration, etc. [9, 10]. Subsequently, after leveling the surface of the damaged area, to restore its fertility, it is possible to loosen the soil to increase oxygen penetration and redox reactions, apply organic and mineral fertilizers and sow grasses to intensify natural biochemical treatment processes.

Conclusions.

1. Based on the study of literary sources and their analysis, the conditions for restoring agricultural land after bombing have been formed, which should be carried out in the following sequence:
   - after cleaning agricultural fields from the source of contamination and debris, it is necessary to monitor their size;
   - Based on the analysis of the monitoring, develop specific measures to be taken in each case of soil damage.
2. The following algorithm is recommended for the restoration of soils damaged by explosions by mechanical means:
   - relatively shallow craters, up to 0.5 m in size, are recommended to be filled with soil mass left at the explosion site (at an acceptable concentration of pollutants) or mineral soil (loam, loess loam, sandy loam, sand), followed by leveling the surface;
   - sinkholes larger than 0.5 m should be backfilled with soil mass in an order of soil layers that is close to the order of undamaged areas, so the sinkhole should first be filled with mineral soil;
3. Restoration of agricultural fields damaged by explosions and contaminated with heavy metals and hazardous chemicals is recommended in the following sequence:
   - First, it is necessary to remove or clean and remove for disposal the damaged surface soil layer inside the explosion crater, since this layer of damaged soil, in addition to chemical contamination with heavy metals, also contains a burnt (baked) fertile soil layer, dehydration and "sterilization" occurred, which kills both pathogenic microorganisms and beneficial biota;
   - Further restoration should be carried out in the manner described above, with the obligatory observance of alternating layers of the grant.

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Resilience in Water Management: Addressing Climate Change Challenges in Albania

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Abstract: *Albania has significant water resources, yet seasonal fluctuations and inefficient usage increasingly threaten these. This study examines the repercussions of changes in the hydrological cycle on the country's land and ecosystems, as well as the broader social, economic, and environmental pressures. Through qualitative and quantitative analyses of industrial and agricultural practices, alongside the effects of urban population growth, we highlight how these factors exacerbate climate change impacts on water resources. Specifically, we investigate shifts in water quality and quantity, alterations in precipitation patterns, and the intensification of temperatures, evaporation, humidity, and soil aridity. The National Strategy for Water Resources Management (2018–2027) aims for sustainable water usage and improved quality across all resources by 2027, while also addressing disaster risks associated with droughts and floods. However, Albania faces escalating challenges in water resource management, impacting both supply and demand. Climatic trends indicate a decline in rainfall and river flows, particularly during summer, as well as increased soil dryness and more frequent extreme weather events. Currently, hydropower plants generate nearly 90% of the country's energy, further straining water resources. According to the SPEI Annual Drought Index, by 2100, Albania is projected to face a marked decline in precipitation, compounded by heightened dryness and reduced moisture levels. Recent data shows that the number of days exceeding 20°C has doubled and tropical nights have tripled compared to historical averages. Over the past three decades, floods and landslides have accounted for significant economic losses, with 40.2% and 33.5% of damages respectively. To address these challenges, urgent and long-term measures are required, including the sustainable management of water resources, modernization of distribution networks, and enhanced water efficiency to mitigate waste.*
Keywords*: CLIMATE CHANGE, WATER RESOURCES, METEOROLOGICAL CONDITION, RESILIENCE, HYDROLOGICAL CYCLE*

1. Introduction

A historical approach to water management (drinking water, rainwater, and wastewater) emerged early in human history, gaining significant momentum in industrialized cities in Europe and the United States during the late 19th century [1-2]. In the early 20th century, population growth and economic development directly impacted the water supply-demand balance [3]. Moreover, the projected impacts of climate change are expected to undermine the ability of many existing water supply systems to meet the future and current needs of populations [4-5].

The concept of "sustainable water resources management" was defined [6] as “the use of water that supports the ability of human society to endure and thrive into the indefinite future without compromising the integrity of the hydrological cycle or the ecological systems that depend on it.” This principle emphasizes considering climate change and incorporating both supply and demand strategies while accounting for the impacts of anthropogenic activity. Undoubtedly, spatial planning can play a critical role in implementing water quality management and adapting to climate change in the water supply sector. The concentration of pollutants in soil and water has serious consequences for the well-being of residents [7].

From a spatial planning perspective, economic and service sectors—such as housing, energy, economic development, water transport, urban waste, and social and health welfare—affect land use in social, economic, and environmental contexts [8]. This perspective recognizes that natural and environmental resources support human societies, and land-use decisions are made within the broader social and economic context.

This paper aims to demonstrate the correlative relationship between the potential of spatial planning under climate change impacts and the promotion of sustainable water resource management.

Albania is considered a country rich in relatively abundant water resources, with freshwater flowing from east to west [9]. The country’s major rivers contribute a total annual water flow volume of 39,220 x 10^6 m³/year [10] with 95% of this flow discharging into the Adriatic Sea and 5% into the Ionian Sea [11].

The hydrological cycle is a dynamic and integrated component of the Earth’s geophysical system, continuously influenced by climatic conditions. Changes in temperature affect evaporation rates, cloud characteristics, soil moisture, and precipitation and snowmelt patterns. Shifts in precipitation impact the timing and magnitude of floods and droughts, alter flow regimes, and change groundwater recharge characteristics. Groundwater supplies 80% of the population's drinking water needs and contributes 23% of the annual flow. On a broader scale, climate change can alter major regional atmospheric circulation patterns and the frequency and intensity of storms. While much global climate research focuses on how climate change will affect the water balance—particularly precipitation, evaporation, and runoff—it remains unclear exactly how hydrology and water management systems will be impacted, and how these challenges can be addressed [12]. According to the Intergovernmental Panel on Climate Change [13], the water sector will bear the brunt of most climate change impacts. These impacts on the urban water sector can be categorized into two main aspects: water as a resource and water as a hazard. As a resource, the availability of good quality water is essential for the well-being of the growing urban population. It is also vital for many economic activities in and around cities, including peri-urban agriculture, food production, and other industrial operations [14].

Since the early 1990s, the IPCC has identified anthropogenic influences on climate, which have led to catastrophic global changes such as rising temperatures, sea-level rise, and ocean acidification [15-16]. Clean, sufficient, and fresh water is critical for population well-being and natural ecosystems. It plays a vital role in human health, industrial production, energy generation (both directly and indirectly), transportation systems, extensive outdoor recreation, and waste disposal [17].

The population's capacity to safeguard water resources and maintain water quality is fundamental to supporting livelihoods, ensuring human well-being, and driving socio-economic development. This includes protecting against water pollution [18], mitigating water-related disasters, and maintaining ecosystems in the face of climate change [19].

2. Materials and Methods

This study analyzes climate data on average monthly temperatures and precipitation for the period 2020–2021, compared to the 30-year average from 1961–1990. Meteorological measurements from various climatic zones and subzones of the country were used to assess several factors influencing the quality and quantity of surface and groundwater, such as soil moisture, soil dryness, evaporation, and transpiration. By integrating findings from literature reviews and qualitative methodologies, water data and results were compared over a specific period. Climatic pressures were examined for their interactions across different

spatial and temporal scales, impacting water availability. This availability depends not only on the quantity of water in various sources but also on its quality. The structure of this study focuses on analyzing parameters to conceptually describe the relationships between extreme weather conditions and water availability in nature (see Fig. 1).

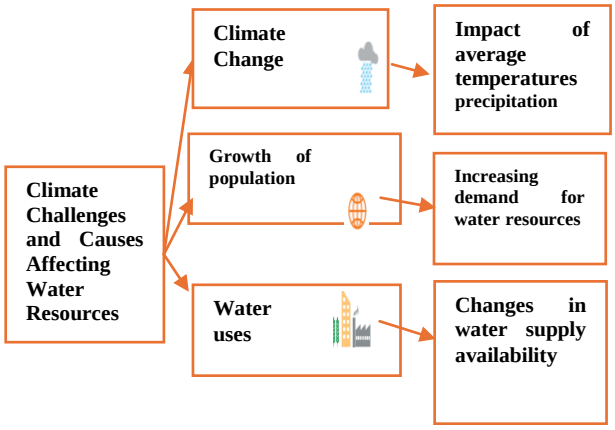


Fig. 1 *Structure of study methodology*

3. Results and discussions

Albania is characterized by relatively abundant freshwater resources. The country's hydrographic basin covers an area of 43,305 km², of which 14,557 km² is within the Drin and Vjosa river basins, shared with neighboring countries such as Greece, North Macedonia, and Kosovo. Major rivers, including the Drin, Buna, Mati, Ishmi, Erzeni, Shkumbini, Vjosa, and Semani, are grouped into six watersheds that flow from east to west across the country [20]. These rivers are a vital source of hydropower, with several artificial lakes constructed for electricity generation. The energy sector utilizes approximately 14 billion m³ of water annually through the hydroelectric power system. Additionally, these artificial lakes are used for irrigating agricultural lands. Along the Adriatic-Ionian coastal zone, numerous lagoons play a critical role in tourism, ecosystem protection, and fishing [21].

Human activities are driving increases in atmospheric concentrations of greenhouse gases and aerosols, which, if left unchecked, will continue to rise, exacerbating climate-related challenges. Albania faces mounting difficulties with water quality due to growing demand for water resources, particularly in regions where inland waters are scarce. As atmospheric greenhouse gas concentrations increase, global average precipitation is also expected to rise, directly affecting the quality and quantity of surface water. Changes in river flow could have dual effects: improving water quality by diluting pollutants when flows are high or worsening it when flows are scarce [17].

Future changes in runoff and water resources depend on a variety of factors, particularly precipitation and temperature. These climate variables have a direct impact on surface and groundwater systems. Rising global average temperatures, coupled with increasing monthly average temperatures in Albania, will intensify greenhouse gas concentrations. If emissions remain unchecked, temperature increases will become more pronounced. Consequently, the region may face a significant rise in wildfires, droughts, food shortages, and environmental and human risks [22].

Numerous studies indicate that climate change will increase the frequency and intensity of precipitation events. Reduced snowfall and earlier snowmelt into watercourses are expected to heighten the probability of flooding earlier in the year and reduce water flow during late spring and summer. Increased atmospheric CO_2 concentrations will influence vegetation's water use, potentially reducing transpiration rates in some plant species under certain conditions. Other factors influencing plant transpiration include vegetation type, soil conditions, and groundwater interactions. Projected trends of more frequent droughts and floods are anticipated to alter water flow patterns, potentially causing reduced spring flows and increased winter flows. These changes will have significant implications for agriculture and water management. Additionally, more intense rainfall, river erosion, and flooding are likely to damage water management infrastructure and services [23].

According to a study [24] data from 10 meteorological stations across Albania showed that during 2020, the average maximum annual temperatures increased by +2.8°C above the multi-year average of 1961–1990. Concurrently, the average annual precipitation decreased by 300 mm [25]. Comparisons of minimum air temperatures in 2021 revealed an increase of +1.1°C above the same multi-year average. Similarly, the average maximum temperature in 2021 increased by 2.3°C, while the minimum temperature rose by 0.9°C. These findings indicate a consistent trend of rising temperatures and declining precipitation.

The analysis reveals that Albania is increasingly experiencing conditions of reduced precipitation and elevated temperatures. River flows, particularly during the summer, have significantly decreased. For instance, measurements at the Rogozhin Bridge on the Shkumbin River show that summer season flows (June–August) account for only 8% of the annual flow, compared to 77% during the winter and spring seasons [26].

Furthermore, the study [27], analyzed precipitation data from 21 meteorological stations, revealing that in 2020, precipitation ranged from 122.9 mm to 959.7 mm less than the 30-year averages (1961–1990), with only four stations recording higher values. Precipitation data for 2021 also showed a reduction in rainy days compared to the 30-year average, exacerbating drought conditions. These findings suggest that precipitation levels are likely to decrease in a more stable and intensified manner throughout the year, with negative implications for Albania's water resources and agricultural productivity.

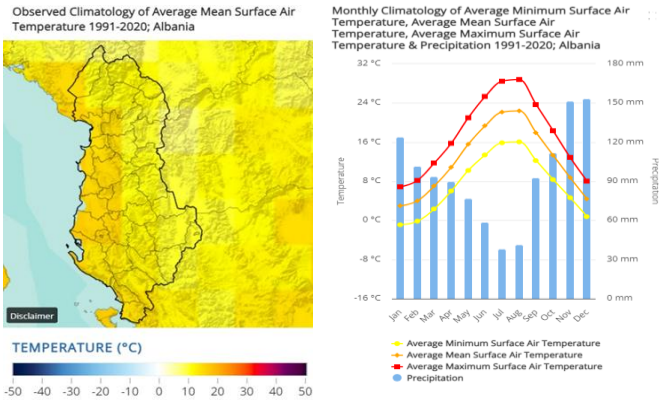


Fig. 2 *Average air temperature and precipitation in Albania for the period 1991-2020 (CCKP, 2022)*

Fig. 2 shows the average air temperatures and precipitation in Albania for the period 1991-2020, highlighting a significant increase in temperatures. The circulation of water back to the atmosphere occurs through evaporation from land and water surfaces, as well as transpiration from plants. The process of water evaporation depends on several factors, including climatic and landscape conditions such as humidity, wind speed, water and energy availability, vegetation and soil characteristics. As temperatures rise, the energy available for evaporation increases, and the atmospheric demand for water from land and water surfaces also grows.

Increasing average temperatures generally lead to an increase in the potential for evaporation, although factors such as lower radiation and increased atmospheric water vapor content may reduce evaporative demands. Vegetative cover is also crucial, as

plants absorb precipitation and return water to the atmosphere. Different types of vegetation have distinct characteristics in terms of evaporation. With rising temperatures, soil moisture deficits are likely to increase, as well as the amount of precipitation in a given area.

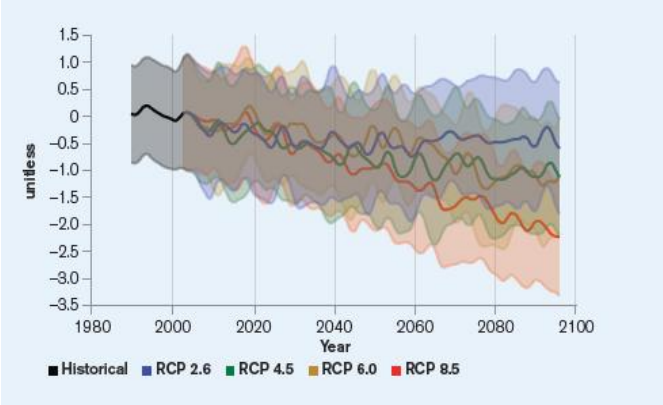


Fig. 3 *Annual drought index SPEI, Albania (CCKP, 2020).*

According to the Climate Change Knowledge Portal [28], (see Fig. 3) presents the Standardized Precipitation Evaporation Index (SPEI), which measures the extent of water deficits in Albania. Negative values on the graph represent dry conditions, with values below -2 indicating severe drought. Positive values indicate increasing wet conditions. Based on the graph, the significant decline in the SPEI, by more than 2 units from the baseline period to the end of the century, suggests a strong correlation between reduced precipitation and an increased probability of drought.

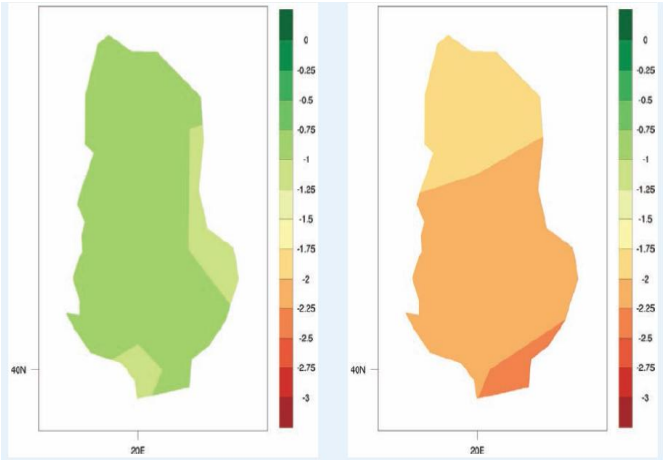


Fig. 4 *Spatial representation of SPEI across Albania for the period 2040–2059 (left) and 2080–2099 (right), according to RCP8.5*

Additionally, the report [28], specifies that Albania will experience water stress by the 2050s and severe water stress by the 2090s, with the greatest droughts occurring in the central and southern regions. This phenomenon is illustrated in Figure 3, which shows the spatial variation of the annual drought index across Albania.

Water quality and quantity significantly impact natural ecosystems, human health, and economic activities. Conversely, human activities directly affect both water quality and quantity. Global climate change has the potential to substantially alter water resources by changing temperature patterns, flow rates, timing, and the ability of watersheds to assimilate waste and pollutants. The sustainability of water bodies, land use, and agricultural practices is heavily influenced by these changes [29].

In regions sensitive to climate change, particularly those vulnerable to increased temperatures and variability in precipitation, there will likely be even greater impacts on both surface and groundwater quality and availability.

The amount of water accumulated and stored in soil is influenced by factors such as vegetation type, soil composition, porosity, evaporation rates, and rainfall intensity. Soil moisture is a critical hydrological variable of particular importance to sectors like agriculture. Groundwater use in agriculture accounts for up to 8.7% of total consumption.

When atmospheric precipitation falls, part of it flows into rivers, lakes, or seas, while another portion is absorbed by vegetation, and a smaller amount infiltrates to replenish groundwater. According to the study [24], a reduction in precipitation of up to 8% by 2050 will require increased water storage capacities for agriculture. Additionally, increased temperatures will raise transpiration and evaporation rates, potentially causing a moisture deficit in Albania of up to 18%—roughly equivalent to 700 m³ of water per hectare for agricultural use. The combination of reduced precipitation and rising temperatures will intensify drought conditions and reduce available water for irrigation, with agricultural productivity per unit area potentially decreasing by 25-35%. In areas with decreased precipitation, soil moisture may be significantly reduced. Conversely, in areas with increased precipitation, soil moisture may rise, though this will depend on the rate of evaporation driven by higher temperatures.

The primary source of groundwater is atmospheric precipitation. In some areas, current groundwater usage is already unsustainable. The impacts of climate change on specific groundwater basins, as well as on the overall dynamics of groundwater recharge and water quality, can significantly affect long-term basin sustainability.

A decrease in precipitation in the future, similar to the conditions observed in 2020 and 2021, could reduce groundwater recharge, adversely affecting energy and agricultural production. Increased monthly temperatures will likely shorten the infiltration period and accelerate evaporation. Projections indicate that precipitation will continue to decline across all seasons, exacerbating irrigation shortages, particularly in saline soils, where salinity levels could increase to 10 times the maximum limit [27].

4. Conclusion

The study emphasizes the need for collaboration among all water users and stakeholders to achieve a shared vision for the protection, conservation, and sustainable management of water resources. It is recommended that water resources planning, and adaptation strategies be integrated into the development strategies for key sectors such as agriculture, energy, and infrastructure—sectors that are most vulnerable to the impacts of climate change, affecting economic, social, environmental, and foreign exchange balances at the national level. Ministries should coordinate efforts across sectors to develop climate change adaptation strategies and action plans.

Particular attention should be given to ensuring the productivity and sustainability of irrigation and drainage systems, improving water use efficiency, and mitigating the risks of floods and droughts. Climate change impacts place significant pressure on water resources, with potential negative effects on human health, economic stability, and the environment. These impacts are driven by extreme weather events, including floods and fluctuations in temperature extremes across the country.

Adaptation strategies for water resources must be tailored to specific regions, as they are closely linked to local climatic conditions. Therefore, decisions related to land use, drainage, infrastructure planning, and water supply and treatment are influenced by a variety of public and private stakeholders. Effective adaptation to climate change requires coordination and cooperation among various actors and interest groups, along with the fulfillment

of responsibilities by local municipalities, especially following the transfer of many competencies from the central government to local authorities for water management.

5. Summary

Albania is characterized as a country with a relatively high presence of water resources. However, resources and reserves are vulnerable due to seasonal variations and inefficient water use. This study aims to analyze and evaluate the possible consequences of a drastic change in the hydrological cycle, causing a series of impacts on the land in the context of the pressures exerted on the social, economic, and environmental sectors. A qualitative and quantitative analysis of industrial, agricultural activities, etc., together with a growing population and concentration in the country's big cities, contribute to climate change processes. Also, it affects water resources in terms of their quality and quantity, variability and time, form and intensity of rainfall as well as increasing temperatures, evaporation, humidity, and soil dryness. In the National Strategy for Water Resources in Integrated Management (2018–2027), sustainable use of water resources was foreseen, for achieving water quality in all water resources by 2027, reducing and managing disaster risk for drought, and floods, and increasing scientific knowledge on water. And yet, the challenges the country is facing in terms of water resource management are worsening both in supply and demand for providing sufficient water resources.

Climatological conditions in Albania have shown variability in reducing the amount of rainfall and its intensity, decrease in river flows, mainly during the summer months, decrease in water penetration into the ground, predicted trends for droughts, more frequent floods, etc. Almost 90% of energy production is provided by hydropower plants, which brings a serious problem to the country's water resources. According to the SPEI Annual Drought Index, our country, by the year 2100, is likely to experience a significant increase in reduced precipitation, increased dryness, and lack of moisture. The data shows that the number of days with temperatures of 20 °C has doubled and the number of tropical nights has tripled, compared to the long-term average rate. During the last 30 years in Albania, almost 40.2% of economic damage was caused by floods and 33.5% by landslides. Therefore, sustainable management of water resources, modernization of the distribution network, reduction of wastage, and increase of water efficiency are some of the emergency and long-term plans that should be undertaken.

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Low intensity fertilization with organic and complex mineral fertilizers and their influence on the organic matter content of haplic chernozems

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Abstract: The use of complex mineral, organo-mineral and organic fertilizers on Haplic Chernozems for 8 years leads to changes in the composition of soil organic matter. Certainly the organic fertilizer Excell^{Orga} and its combination with the complex mineral fertilizer Suprefos increase the content of soil organic carbon, and humic acids, related with calcium. A positive trend is also the increase of carbon in insoluble residue. A statistically reliable positive influence of organic and organo-mineral fertilization on individual groups and fractions compared to those in the control variant was established. The trend is especially well expressed on the carbon values of humic acids and those related to calcium. This leads to a sustainable level of humification and an increase in the share of agronomically valuable groups and fractions in the organic carbon of the soil.

KEYWORDS*: ORGANIC, ORGANIC-MINERAL AND MINERAL FERTILIZATION WITH COMPLEX FERTILIZERS, ORGANIC CARBON, GROUP AND FRACTIONAL COMPOSITION OF SOIL ORGANIC MATTER*

Introduction

Soil is one of the most important natural resources and is the basis of life on the planet. In addition to productivity and quality requirements, modern managed ecosystems face a number of challenges - regulating and conserving water flow, protecting its physico-chemical properties, soil organic matter and its genetic potential.

The main component of soil organic matter is the general hemes substances, which are characterized by high biological activity. From a chemical point of view, they are heteropoly (oligo)mers having different molecular weights. They are a very important structure former of the individual fragments of organic macromolecules [1]. The application of modern agrotechnical practices, regardless of the method of agricultural production - conventional or biological, require not only maintaining, but also increasing the content of organic C in the soil [2].

For decades, research at the DAI-G. Toshevo has included this topic in its scientific program, including the influence of the ways of utilizing the plant remains of the predecessor on the state of soil fertility [3-12].

The purpose of the present study is to characterize the changes in the concentration of organic carbon in the soil, as well as the changes occurring in the composition of the soil organic matter as a result of the application of complex mineral, organo-mineral and organic fertilizers.

Materials and Methods

In the experimental field of Dobrudzha Agricultural Institute - General Toshevo on Haplic Chernozem, in a long-term study, the influence of fertilizers for basic soil fertilization - Suprefos and ExcellOrga - was studied. The experiment is a continuous wheat monoculture and does not include the application of nitrogen fertilizers during the growing season. Suprefos is a combined mineral fertilizer containing: 12% N; 24% P_2O_5; 0.5% Mg; 14% Ca; 25% S. The all-organic fertilizer ExcellOrga is manufactured by Angibaud & Specialites (France). It represents composted waste from the fishing industry and guano, and its composition is 50% organic matter, org.N-4%, P-2%, K-6%, Mg-3%. It is produced in the form of pellets - 6 mm. Fertilizers were applied before the last pre-sowing treatment of wheat at the rate of 350 kg/ha (physical). The experimental setup consists of 4 backgrounds of soil fertilization: 1. Control; 2. Mineral Fertilization (Superfos -350 kg/ha)-MF; 3. Organo-Mineral Fertilization (Superfos + Excel^{Orga} (175+175 kg/ha)-OMF and 4. Organic Fertilization (Excel^{Orga} 350 kg/ha)-OF.

At the end of the study, the changes in the group and fractional composition of the organic matter were tracked. From the tested variants, soil samples were taken in three replicates from the layers 0-20 cm, 20-40 cm and 40-60 cm.

To determine the composition of soil organic matter, we used the method of Kononova-Belchikova [13;14]. The carbon content (C%) was determined by the modified Tyurin method (oxidizing with $K_2Cr_2O_7/H_2SO_4$ solution in thermostate at 125^0 C, 45 min, in the presence of Ag_2SO_4 and titration with $(NH_4)_2SO_4.FeSO_4.6\ H_2O$ [13; 15]. The methods of Konnova [14] and Filcheva & Tsadilas [16] were used to determine the composition of soil organic matter by groups.

Results and Discussions

Before discussing the obtained results, it is necessary to recall some of the characteristic features of the soils in the area. Southern Dobrudja, according to its geomorphological zoning, refers to the Danube epiplatform plain. It is distinguished by a low layer-denudation and accumulation relief. The Southern Dobrudja Plateau is formed by Sarmatian limestones. According to Ismail& Dimov [17] the emergence of the modern black soil dates back to the middle of the Bronze Age (III millennium BC). Medium-thick leached and weakly leached chernozems, developed on loess-like, sandy clays and loess, layered on highly fractured Sarmatian and Lower Cretaceous limestones, prevail. Their characteristic feature is their more pronounced washing regime and more powerful profile compared to carbonate and typical chernozems. In some areas, the humus-accumulative horizon can reach 80 or more than 80 cm.

The results of the analyzes of the variances of the composition of the soil organic matter (SOM) along the depth of the humus-accumulative horizon up to 60 cm show the strong influence of the nutrient regime of the soil created by fertilization (Table 1). Both tested factors influence the values of the tested indicators, and the types of fertilizers included in the study for basic soil fertilization with maximum statistical reliability influence all the tested indicators characterizing the composition of the SOM. Depth as a factor in the study has a strong impact on some of its main characteristics - C_{org}, THS, FA, HA_{R2O3}, HA_{Ca} and $C_{residue}$. This, in turn, affects the credibility of the interaction between the two factors. The same is most clearly expressed for fulvic acids at an early stage of formation, free and associated with – R_2O_3, as well as their share relative to C_{org}. The proven influence of the interaction between the factors on THS, HA, HA_{Ca}, HA/C_{org}, $C_{residue}/C_{org}$ also deserves significant attention.

The eight-year application of the tested fertilizers reflects not only the absolute values of carbon in individual groups and fractions, but also their share relative to the organic C of the soil, respectively humus. For the most part, the tested indicators are subjected to statistically reliable changes, which are preserved according to the depth of the root-inhabited horizon.

The used fertilizer products have a significant influence on the values of Sorg compared to the control variant (Table 2). In the surface layer 0-20 cm OMT and OT definitely lead to its increase compared to the variant with MT. Fertilization with the tested fertilizer products has a positive effect on Sorg values in the 40-60 cm layer as well.

Table 1. *Analysis of the variances of the indicators characterizing the composition of SOM by depth and depending on the type of fertilizers used*

	Depth (1)			Fert. variants (2)			1 x 2		
Dependent Variable	df	F	Sig.	df	F	Sig.	df	F	Sig.
C_{org} (Organic Carbon)	2	69,809	,000***	3	12,293	,000***	6	,881	,515^{NS}
FA_{agr} (Agressive Fulvic Acids)	2	3,412	,039*	3	72,101	,000***	6	4,041	,002**
THS (Total humic substances)	2	15,074	,000***	3	7,737	,000***	6	2,767	,019*
HA (Humic acids)	2	1,982	,147^{NS}	3	9,445	,000***	6	2,338	,043*
FA (Fulvic acids)	2	9,917	,000***	3	29,977	,000***	6	,179	,982^{NS}
HA/FA ratio	2	2,973	,059^{NS}	3	16,088	,000***	6	,466	,830^{NS}
HA_{R2O3} (connected with sesqui oxides)	2	106,439	,000***	3	11,198	,000***	6	1,243	,297^{NS}
HA_{Ca} (connected with calcium)	2	5,937	,004**	3	15,719	,000***	6	2,597	,026*
$C_{residue}$ (insoluble residue)	2	11,787	,000***	3	21,574	,000***	6	1,978	,083^{NS}
FA_{agr}/C_{org}	2	3,933	,025*	3	54,956	,000***	6	4,973	,000***
THS/C_{org}	2	,154	,857^{NS}	3	16,455	,000***	6	2,644	,024*
HA/THS	2	2,894	,063^{NS}	3	26,814	,000***	6	,381	,888^{NS}
FA/THS	2	2,894	,063^{NS}	3	26,814	,000***	6	,381	,888^{NS}
HA/C_{org}	2	1,816	,171^{NS}	3	6,427	,001***	6	2,622	,025*
FA/C_{org}	2	3,523	,036*	3	34,304	,000***	6	,186	,980^{NS}
HA_{R2O3}/HA	2	43,713	,000***	3	19,322	,000***	6	1,581	,168^{NS}
HA_{Ca}/HA	2	43,713	,000***	3	19,322	,000***	6	1,581	,168^{NS}
$C_{residue}/C_{org}$	2	,154	,857^{NS}	3	16,455	,000***	6	2,644	,024*

Table 2. *Content of organic C in individual groups and fractions of POV by soil layers depending on the type of fertilizers used*

Fert. variants	Depth, cm	C_{org}	FA_{agr}	THS	HA	FA	HA/FA	HA_{R2O3}	HA_{Ca}	$C_{residue}$
Control	0-20	1,7785 a	,0353 a	,9549 b	,6061 a	,3488 b	1,83 a	,3205 b	,2856 a	,8236 a
	20-40	1,7473 a	,0353 a	,9383 b	,6061 a	,3322 b	1,90 a	,2657 b	,3404 a	,8090 b
	40-60	1,5951 a	,0311 a	,7844 ab	,5148 a	,2696 b	2,13 a	,1777 a	,3371 a	,8106 ab
MF	0-20	1,8305 a	,0398 b	1,0144 c	,6958 b	,3186 b	2,34 ab	,3152 b	,3806 b	,8161 a
	20-40	1,7606 a	,0377 a	,9892 b	,6539 ab	,3353 b	1,97 a	,2649 b	,3890 ab	,7714 a
	40-60	1,6104 a	,0377 b	,8970 b	,6371 ab	,2599 b	2,49 a	,1760 a	,4611 a	,7134 a
OMF	0-20	1,9283 b	,0563 d	,9345 ab	,7259 b	,2086 a	3,82 b	,2720 a	,4539 b	,9939 b
	20-40	1,8200 a	,0459 b	,8635 a	,6841 b	,1794 a	3,90 b	,2186 a	,4655 b	,9565 c
	40-60	1,6349 a	,0542 d	,7424 a	,6091 a	,1333 a	5,40 b	,1769 a	,4322 a	,8925 b
OF	0-20	1,9353 b	,0501 c	,8927 a	,6858 b	,2069 a	4,20 b	,2770 a	,4089 b	1,0426 b
	20-40	1,8375 a	,0528 c	,8886 a	,6842 b	,2044 a	4,00 b	,2002 a	,4839 c	,9489 c
	40-60	1,7190 a	,0459 c	,9119 b	,7692 b	,1427 a	5,48 b	,1352 a	,6340 b	,8072 ab

As a result of fertilization, changes also occur in the values of total humic substances (THS), with their absolute values being the highest in the 0-20 cm layer in the variant with MF application. Their certain reduction was found when using OT. At the same time, in comparison with the control variant and the one with MT, an increase in CHA and a decrease in SFC were observed in the variants with the use of organo-mineral and organic fertilizers. This fact applies to all three studied layers by profile depth. Ultimately, there is a change in the HC/FC ratio. From the fulvate-humate type in the control variant (0-20 and 20-40 cm) the values increased more than 2 times and in the variants with the use of OMF and OF the type of humus is already markedly humate.

Changes were found in both main fractions of HC - free and sesquioxide-bound oxides and those with calcium. In the variants with OMF and OF, C of HA_{R2O3} decreases along the profile depth compared to those found in the control variant. At the same time, a positive trend was expressed for the increase of those related to calcium. Positive changes in the direction of increasing Cresidue were also found when using OMF and OF in the 0-20 and 20-40 cm layers.

Soil organic carbon in the 0-20 cm layer is in very strong positive correlations with $C_{residue}$ and HA_{Ca} carbon (Table 3). A clear correlative relationship with the most dynamic and low molecular fraction of organic matter, called the fraction of "aggressive" fulvic acids" (0.807**) was also established. In the 20-40 cm layer, the correlations keep their direction, but the correlation values slightly decrease. In the layer below, a large part of the correlations between Corg and the indes characterizing the composition of the POV are statistically unreliable. However, at this depth, the correlation between C_{org} and HA and between C_{org} and HA_{Ca} still remains very well pronounced. Correlative dependencies between Cresidue and other indicators characterizing the composition of the POV are also clearly expressed.

Throughout the studied depth, carbon of the insoluble residue is strongly negatively correlated with THS, FA HA_{R2O3}.

One of the main characteristics of SOM - C_{org}, THS and $C_{residue}$ clearly show that their values gradually decrease with depth of the investigated layers (Fig. 1). The constituent components of THS - HA and FA also show a tendency to decrease along the depth of the profile. The established changes in HA are unreliable. However, FA carbon has higher values in the surface layers and at a depth of 40-60 cm it reliably decreases. On average for the tested factors in the experiment over the entire studied depth, the type of humus is markedly "humate".

The obtained results show that the slightly leached Chernozem in this section retains a high degree of humification of the organic matter - from 36.31% (0-20 cm) to 38.58% (40-60 cm). The presented results give us an opportunity to obtain information about the behavior of the HC factions. With depth, the sesque-related HA oxides decrease, and the differentiation by layers is very well expressed. The fraction bound to calcium inversely increases. In the surface layer 0-20 cm their level is defined as "average" (56.34%), while in the following layers according to Orlov and Grishina [18] is defined as "high" and reaches 73.68% of the THS.

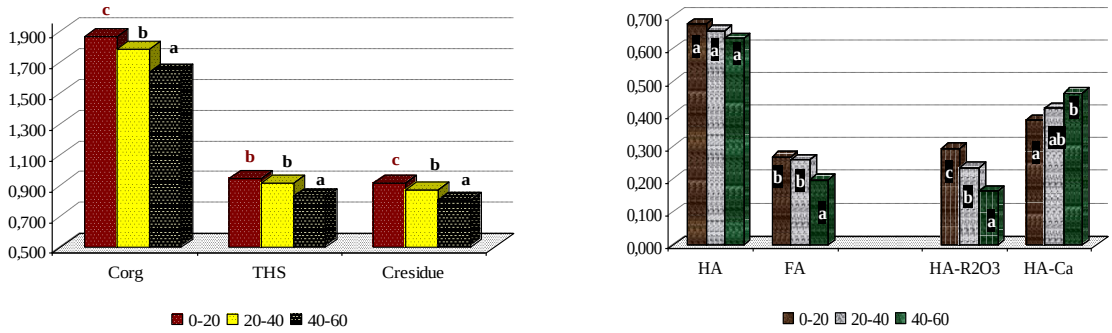
The tested types of fertilizers for the period of their application also influence the studied indicators (Fig. 2). Application of complex mineral fertilizer does not lead to proven changes in Corg. The application of OMF and OF increased the values of the indicator by 5.1% (1.794%) and 7.2% (1.831%) compared to the control (1.707%), respectively. Regarding THS, the differences are insignificant, only the variant using MT stands out, where the increase is credible. The carbon of the insoluble residue (humin, or also called the "guard" of the humus) shows a tendency towards a reliable increase in the variants with the introduction of OMF and OF.

Against this background, the used fertilizer products lead to changes in the carbon values of HA and FA. The most significant increase was found in the use of OF, where the increase was 23.8% compared to the control variant. In the case of FA carbon, the differentiation in the average values for the study period is less pronounced.

The variants using OMF and OF were distinguished by lower levels of FA carbon compared to the control and MF. This, in turn, leads to the formation of a fulvate-humate type of humus in the control variant and a gradual increase in the values of the HA/FA ratio. This fact leads to consolidation of the "humic" type of humus of this soil type.

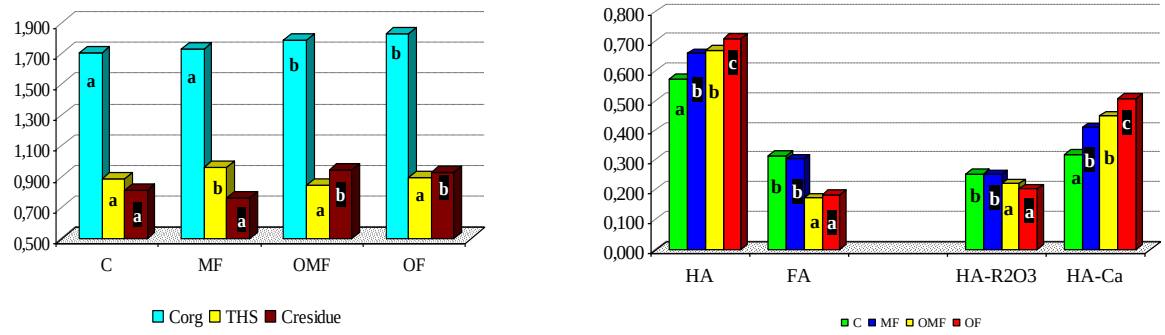
Table 3. *Correlations between C_{org} and some indices, characterizing soil organic matter composition in depth layers (Pearson Correlation)*

Indices	OrgC			THS			$C_{residue}$		
	0-20	20-40	40-60	0-20	20-40	40-60	0-20	20-40	40-60
C_{org}	1	1	1	-,579(**)	-0,285	,504(*)	,919(**)	,757(**)	0,335
FA_{agr}	,807(**)	,462(*)	0,335	-0,364	-,590(**)	0,031	,692(**)	,662(**)	0,263
THS	-,579(**)	-0,285	,504(*)	1	1	1	-,854(**)	-,842(**)	-,645(**)
HA	,586(**)	,616(**)	,646(**)	-0,098	-0,008	,833(**)	,422(*)	0,352	-0,337
FA	-,786(**)	-,637(**)	-0,323	,726(**)	,702(**)	0,159	-,853(**)	-,837(**)	-,460(*)
HA/FA	,737(**)	,597(**)	0,276	-,795(**)	-,547(**)	0,073	,855(**)	,709(**)	0,164
HA_{R2O3}	-,591(**)	-,406(*)	0,153	,522(**)	,699(**)	0,085	-,630(**)	-,705(**)	0,042
HA_{Ca}	,644(**)	,617(**)	,578(**)	-0,261	-0,328	,774(**)	,538(**)	,571(**)	-0,333
$C_{residue}$	,919(**)	,757(**)	0,335	-,854(**)	-,842(**)	-,645(**)	1	1	1



Main group of SOM — Humic acid fractions

Figure 1. *Composition of SOM depending on the depth of the studied layer, C%*



Main group of SOM — Humic acid fractions

Figure 2. *Composition of SOM depending on the type of fertilizers used for main fertilization, C%*

The degree of humification of SOM is between 30 and 40% and is defined as "high". However, the differences between the tested fertilizer variants compared to the control are very well expressed, with the use of OF approaching a "very high" rating. Another positive trend is observed, expressed in an increase in the carbon of calcium-related HA, as well as their share of total HA and that in soil organic carbon.

Of the many correlative dependencies between the complex of tested indicators, we present the most clearly and reliably standing out (Fig. 3).

A well-expressed negative correlation was established between the "aggressive" FA and the group of FA, as well as between the fractions of HA associated with sesquioxides and those associated with Ca. The highest positive correlation was found between the HA group and the fraction of the same related to Ca. The correlative dependence of the latter with the HA/FA ratio is also high. A strong positive correlation between C_{org} – $C_{residue}$ was also found.

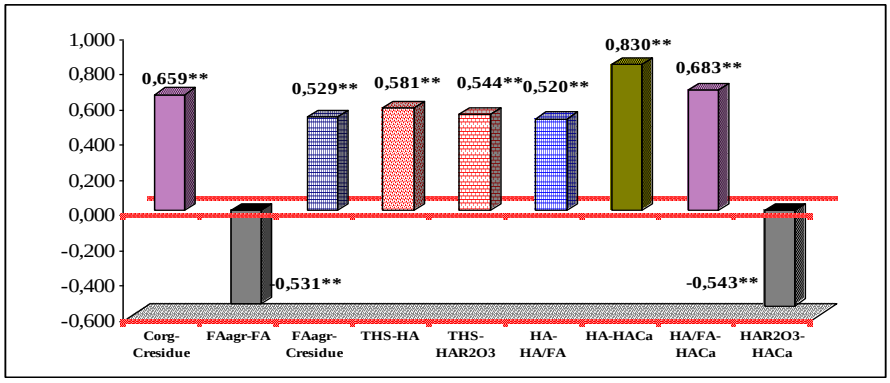


***Figure 3**. Strong correlative relationships between some of the components characterizing the composition of the SOM (Pearson Correlation)*

Conclusions

The long-term application of different types of fertilizer products leads to changes in the organic carbon of the soil at the depth of the root layer. The upper soil layers 0-20 cm and 20-40 cm are richer in organic carbon, in total humic substances and in insoluble residue compared to the 40-60 cm layer.

In addition to the depth of the studied profile, differences were found depending on the type of tested fertilizer products. Certainly the organic fertilizer Excell^{Orga} and its combination with the complex mineral fertilizer Suprefos increase the content of soil organic carbon, and humic acids, related with calcium. A positive trend is also the increase of carbon in insoluble residue. A statistically reliable positive influence of organic and organo-mineral fertilization on individual groups and fractions compared to those in the control variant was established. This trend is especially well expressed on the carbon values of humic acids and those related to calcium. This leads to a sustainable level of humification and an increase in the share of agronomically valuable groups and fractions in the organic carbon of the soil.

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Influence of effective microorganisms on the biological activity of the soil in greenhouse pepper cultivation

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Abstract: *The article presents the results of a study of the influence of effective microorganisms Trichoderma viride, Bacillus subtilis and Enterobacter cloaceae on the biological activity of the soil when growing pepper on the plot with mineral fertilization (fertilizer rate N_{22} P_{16} K_{20} kg/da). The experiment was carried out at the Maritsa Vegetable Crops Research Institute, Plovdiv in an unheated steel-glass greenhouse with the Pirouette F1 variety, planted according to the scheme (90/60/40 cm). The studied microbial substances were used as 0.1% aqueous solutions of the standardized biological preparations "Trichodermine" (Trichoderma viride, strain Trv1, titer 2.10^{10} c/ml); "Extrasol" (Bacillus subtilis, titer 1.10^{10} CFU/ml) and a bacterial preparation based on Enterobacter cloaceae (titer 1.10^{10} CFU/ml) at a consumption rate of 10 L of solution per 20 m^2. The biological activity of the soil in the experiment was followed in different phenological phases of the development of the culture using the methodology for cultivating diluted aqueous soil solutions on solid nutrient media. As a result of the studies, it was established that the use of bioproducts based on Trihoderma viride, Bacillus subtilis and Enerobacter cloacae leads to optimization of the structural composition of the microbiome in the soil. Among the tested biopreparations with the greatest efficiency is the biopreparation "Trichodermine". The introduction of the biopreparation "Trichodermine" increases the biogenicity of the soil by 12% towards the middle and by 74% - towards the end of the growing season. The agrochemical effectiveness of the application of the biopreparation "Trichodermine" to regulate the nitrogen-phosphate-potassium nutritional regime has been established. During the period of active harvesting, the content of mineral forms of nitrogen in the variant with "Trichodermine" increases to 50%, of mobile phosphorus - to 40%, of mobile potassium - to 71%. An article confirms the expediency and effectiveness of the application of biological preparations to optimize the structural composition of the microbiome in the soil and regulate the nitrogen-phosphate-potassium nutritional regime.*
***KEYWORDS**: CAPSICUM ANNUUM, TRICHODERMA VIRIDE, BACILLUS SUBTILIS, ENTEROBACTER CLOACEAE, MINERAL NUTRITION, SOIL MICROORGANISMS*

1. Introduction

The use of fertilizers and chemical products for plant protection in agrocenoses is one of the main sources of anthropogenic impact on the soil cover. Crop productivity depends 2/3 on mineral fertilizers and 1/3 on organic fertilizers [1]. The main requirements when choosing a system for fertilizing crops are optimizing the nutritional regime and meeting the needs of plants for macro- and microelements during the growing season, especially during the critical periods of plant growth and development [2]. The application of mineral fertilizers compensates for the loss of soil minerals after their extraction from the crop. In recent years, fertilization is considered not only as a means of increasing yields, but also their use is associated with the quality of the produced products. The correct selection of nutrients changes the direction of biochemical processes in plants and makes them resistant to diseases [3, 4]. Mineral fertilizers influence the biological activity of the soil. The excessive use of mineral fertilizers and pesticides leads to suppression of the protective functions of the soil and an increase in the infectious background of phytopathogens [5, 6, 7]. When growing greenhouse vegetable crops, fast-acting fertilizers containing basic mineral elements NPK are used. They increase yield, but nitrogen and phosphorus fertilizers applied in large quantities can serve as pollutants of wastewater, soil and produce [8**,** 9]. To optimize plant nutrition and reduce soil toxicity, biological products containing antagonists or hyperparasites of phytopathogenic fungi can be used. Fertilizers affect the process of soil colonization with antagonists [10 - 14]. Nitrogen fertilizers increase the accumulation of the saprophytic fungi *Trichoderma* and *Gliocladium* [15, 16]. In turn, Trichoderma fungi help to absorb the difficult-to-dissolve forms of phosphorus from the soil [17, 18]. The aim of the work was to evaluate the influence of the effective microorganisms *Trichoderma viride, Bacillus subtilis* and *Enterobacter cloaceae* on the biological activity of the soil and the agrochemical efficiency of the system of basic mineral fertilization in the cultivation of greenhouse pepper.

To achieve this goal, the following tasks were solved:
study of the influence of the biopreparations "Trichodermin", "Extrasol" and a bacterial preparation based on *Enterobacter cloaceae* on the biological activity of the soil;
to determine their influence on the agrochemical efficiency of mineral fertilization with NPK;
among the studied biological products, to choose the most effective one for optimizing the structural composition of the soil microbiome in the studied fertilization system.

2. Materials and methods

The experiment was carried out on the territory of the Maritsa Vegetable Crops Research Institute, Plovdiv in an unheated steel-glass greenhouse with the Pirouette F1 variety, planted according to the 90/60/40 cm scheme. The studied microbial substances were used as 0.1% aqueous solutions of the standardized biological preparations "Trichodermin" (*Trichoderma viride*, strain Trv1, titer 2.10^{10} c/ml); "Extrasol" (*Bacillus subtilis*, titer 1.10^{10} CFU/ml) and a bacterial preparation based on *Enterobacter cloaceae* (titer 1.10^{10} CFU/ml) at a consumption rate of 10 L of water per 20 m^2. As a standard, organic fertilizer "Humustim" (humic acids) was used, applied as an aqueous solution at a consumption rate of 5 ml/10 L of water for 20 m^2 after transplanting and during mass flowering. Agrochemical analysis of the soil samples was done before planting the experiment and one month after transplanting the plants to a permanent place, which coincides with the period of the first pepper harvests. The nitrogen content (NH_4–N + NO_3–N) was determined by the distillation method; mobile P_2O_5 and mobile K_2O according to Egner–Riem, soil reaction $pH_{/H2O/}$ - potentiometrically. The applied norms of mineral NPK fertilizers were carried out in accordance with the recommendations of the laboratory of Agrochemistry based on primary agrochemical analysis of the soil. The one-month fertilizer rate N_{22} P_{16} K_{20} kg/da according to the Technical Content: (N1.8 P0.7 K2.4 g/plant ammonium nitrate 34%, triple superphosphate 18% and potassium sulfate 50%) was introduced according to the following scheme: in the first application - 5 kg/da ammonium nitrate + 10 kg/da triple superphosphate + 4 kg/da potassium sulfate; second application - 5 kg/da ammonium nitrate +2 kg/a triple superphosphate + 5 kg/da potassium sulfate; third application - 5 kg/da ammonium nitrate + 2 kg/da triple superphosphate + 5 kg/da potassium sulfate; fourth application - 7 kg/da ammonium nitrate + 2 kg/da triple superphosphate + 6 kg/da potassium sulfate with an interval of 10 days.
Total soil microbiological activity (CFU/g) and number of fungal colonies in 1 g of dry soil in percent (%) were read. For this purpose, soil samples were taken from each variant at the beginning, middle and end of the growing season. Selection of the soil samples was made according to the following methodology: samples for analysis were taken from five locations on the "envelope" principle from a depth of 0–20 cm [19], after which they were mixed to obtain a total

sample. Samples dried to 60% of the marginal field moisture (MFM) were used for the analysis of the number of soil microorganisms. The biological activity of the soil was determined according to the generally accepted microbiological method for cultivating diluted aqueous soil solutions on solid nutrient media [20], the taxonomic affiliation of the fungi - according to the key determinant of Pidoplichko [21]. Aqueous solutions of the soil samples with a dilution of 1.10^3 were sown on agarized nutrient media - PDA, Czapek, Saburo in Petri dishes and were incubated at a temperature of + 23°C for 10 days in a thermostat. Number of bacterial colonies - on the third day, actinomycetes and fungi - from the third to the tenth day after sowing, inclusive. Microbiological analysis and diagnosis of the fungi were made according to morphological signs after the formation of the colonies. The number of microorganisms (thousand/g soil) was determined by counting the colonies of bacteria, actinomycetes and fungi on individual sectors.

$$X = \frac{A\ x\ D^2\ x\ 20}{d\ x\ 5}$$

X- number of fungal colonies in 1 g of soil; A - number of colonies on 5 agar circles; D- diameter of Petri dish; d- diameter of agar circle.

3. RESULTS AND DISCUSSION

3.1. Study of the influence of the biopreparations "Trichodermin", "Extrasol" and a bacterial preparation based on *Enterobacter cloaceae* on the biological activity of the soil.

The microbiological analysis of the soil samples showed that the biological activity of the soil in the experiment changed throughout the vegetation period (Table 1). The highest values of the total biological activity of the soil (TBAS) were obtained in the variants with the introduction of the bioproducts "Trichodermine", "Extrasol" and organic fertilizer "Humustim". Among the biopreparations studied, the biopreparation "Trichodermin" is the most effective. The introduction of the biopreparation "Trichodermin" increases the biogenicity of the soil by 12% towards the middle and by 74% - towards the end of the growing season. The study of the composition of soil microorganisms in this variant shows that the amount of bacteria increases - from 0.48 mill/g at the beginning to 1.18 mill/g of dry soil towards the end of the growing season, of actinomycetes - from 1.43 mill/g g to 5.19 mill/g, respectively. The structural composition of micromycetes in the soil is reduced to four functional groups: saprophytes, pathogens, antagonists and toxin-producing fungi [22]. The use of bioproducts leads to optimization of the structural composition of micromycetes in the soil and to suppression of pathogenic microflora [23]. In the course of the experiment, it was established that in the soil samples taken from the variant with mineral nutrition, the composition of the micromycetes was dominated by toxin-producing fungi of the genera *Penicillium*, *Aspergillus* and *Fusarium* (Table 2). The content of fungal colonies in the soil taken from the variants with the introduction of the biological preparations "Trichodermine" and "Extrasol" is significantly weaker than in the control, and in the composition of the micromycetes, fungi of the genus *Trihoderma* are more often found (Figure 1). The content of micromycetes in the soil is maximum at the beginning of the growing season, after which a reduction of the fungal colonies is observed both in the variant with mineral fertilization and in the variants with bioproducts. The obtained results show that biological products have an impact on the soil biome. The introduction of 0.1% aqueous solutions of the standardized biological preparations "Trichodermine" (*Trichoderma viride*, strain Trv1, titer 2.10^{10} s/ml); "Extrasol" (*Bacillus subtilis*, titer 1.10^{10} CFU/ml) and a bacterial preparation based on *Enterobacter cloaceae* (titer 1.10^{10} CFU/ml) at a consumption rate of 10 L of water per 20 m^2 ensures stability of the functional relationships between the main ecological-trophic groups of microorganisms.

Table 1: *Biological activity of the soil in a greenhouse experiment with bioproducts during the growing season. Pirouette F1 variety, 2022*

Variant/Phase	million/g	thousands/g	million/g	mycetes, million/g
	Before conducting the experiment			
General sample	1,770000	50,000	0,240000	1,490000
The first harvest				
E. cloaceae	3,380000	340,000	0,600000	2,440000
Effect	**47,63**	85,29	60,00	38, 93
B. subtilis	3,180000	160,000	0,600000	2,420000
Effect	**44,34**	68,75	60,00	38,43
T. viride	2,010000	370,000	0,480000	1,430000
Effect	**11,94**	86,49	50,00	0,00
Humustim	9,680000	300,000	1,970000	7,410000
Effect	**81,71**	83,33	87,81	79,89
Conrtol ($N_{22}P_{16}K_{20}$)	2,560000	440,000	0,440000	1,680000
Effect	**30,86**	88,64	45,45	11,31
End of vegetation				
E. cloaceae	2,190000	60,000	0,160000	1,970000
Effect	**19,18**	16,67	0,00	24,37
B. subtilis	2,280000	50,000	0,290000	1,940000
Effect	**22,37**	0,00	17,24	23,20
T. viride	6,440000	70,000	1,180000	5,190000
Effect	**72,52**	28,57	0,00	71,29
Humustim	4,390000	60,000	1,560000	2,770000
Effect	**76,54**	0,00	60,26	90,25
Control ($N_{22}P_{16}K_{20}$)	4,670000	70,000	0,190000	4,410000
Effect	**77,94**	0,00	0,00	93,37

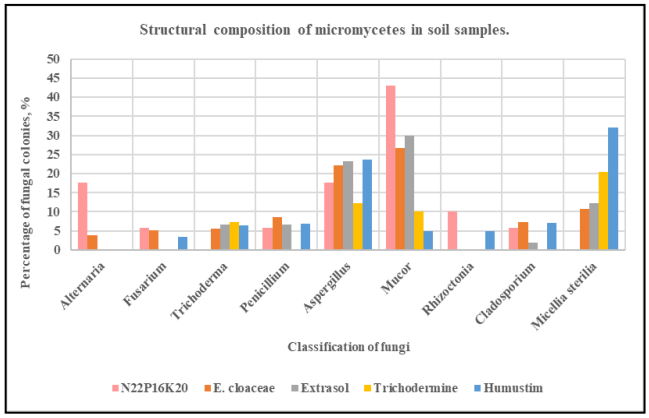


Figure 1. *Structural composition of the micromycetes in the soil samples, taken from the variants with introduction of the biological products "Trichodermin", "Extrasol" and a bacterial preparation based on Enterobacter cloacea*

Table 2. *Structural composition of the Micromycete fungi in the soil samples*

Variant	Percentage of fungal colonies in Petri dishes by variants, %					
	1	2	3	4	5	6
Alternaria	17,7	3,8	0,0	0,0	0,0	5,5
Fusarium	5,9	5,3	0,0	0,0	3,5	0,0
Trichoderma	0	5,5	6,7	7,25	6,5	5,5
Penicillium	5,9	8,5	6,7	0,0	7,0	2,3
Aspergillus	17,7	22,3	23,3	12,3	23,8	21,8
Mucor	43,0	26,8	30,0	10,0	5,0	6,3
Rhizoctonia	10,0	7,3	0,0	0,0	5,0	12,8
Cladosporium	5,9	2,0	2,0	0,0	7,2	5,3
Mycelia sterilia	0,0	10,8	12,3	20,5	32,2	10,8

Variants: 1 - $N_{22}P_{16}K_{20}$, 2 - Enterobacter cloaceae, 3 - Bacillus subtilis, 4 -

Trichoderma viride, 5 – Humic acids, 6 - Control

3.2. Study of the influence of biological preparations on the agrochemical efficiency of the investigated system for mineral fertilizers

In the study of the influence of biological preparations on the agrochemical efficiency of imported mineral fertilizers, the following results were obtained (Table 3).

Table 3. *Agrochemical analysis of the soil samples in the experiment with Pirouette F1 pepper variety one month after planting the plants in a permanent place.*

Variant	pH	EC	N (Total)	P_2O_5	K_2O	Ca^{2+}	Mg^{2+}
		mS/cm	ppm				
Control (before starting the experiment)	7,03	0,23	50,0	8,70	16,60	12,00	7,20
Without preparations	7.09	0.08	25,0	2.00	8.30	8.0	14.40
Percentage to control, %			-50,0	-68,96	-50,0	-33,33	-50,0
Background ($N_{22}P_{16}K_{20}$)	6.63	0.59	100,0	12,40	28.20	16.00	28.80
Percentage to control, %			+50,0	+29,84	+41,13	+25,00	+75,00
Background ($N_{22}P_{16}K_{20}$) + "Trichodermine"	7,00	0,49	100,0	14,60	58,10	20,00	14,40
Percentage to control, %			+50,0	+40,41	+71,42	+40,00	+50,00
Background Фон ($N_{22}P_{16}K_{20}$) +Humustim	6,89	0,60	100,0	9,00	26,56	24,00	14,40
Percentage to control, %			+50,0	+3,33	+37,50	+50,00	+50,00
Background ($N_{22}P_{16}K_{20}$) + "Extrasol"	6,97	0,42	100,0	12,45	10,79	20,00	7,20
Percentage to control, %			+50,0	+30,12	-35,00	+40,00	0,00
Background ($N_{22}P_{16}K_{20}$) +*Enterobacter cloaceae*	6,67	0,30	100,0	12,00	41,50	12,00	7,20
Percentage to control, %			+50,0	+27,50	+60,00	0,00	0,00

In the variant without the mineral fertilizers and biological preparations, the content of mobile nitrogen decreases by 50%, phosphorus - by 68.96%, potassium - by 33.33%. Importing the biopreparations "Trichodermine", "Extrasol" and a bacterial preparation based on *Enterobacter cloaceae* increases the content of mineral forms of nitrogen up to 50%, mobile phosphorus - up to 40.41%, mobile potassium - up to 71.42%. In the variant with the introduction of organic fertilizer "Humustim", these indicators are 50%, 3.33% and 37.50%, respectively. It was established that the application of biopreparations did not significantly change the soil $pH_{/H2O/}$ in the experiment. A slight increase in $pH_{/H2O/}$ was reported in the variant with the introduction of the biopreparation "Trichodermine". This shows that the fungus *Trichoderma viride* is able to stabilize the redox conditions of the soil. The results of studies of the influence of the mineral fertilization system and biopreparations on the content of mobile potassium in the soil show the following: in the control, the K_2O content decreased by 55% compared to the indicators in the soil sample taken from the plot before the start of the experiment. In the variant with the studied NPK application system, the K_2O content exceeded the control by 41.0%. For comparison, in the variant with the introduction of "Trichodermine" on a background of NPK, an increase in K_2O compared to the control was 71.42%, *Enterobacter cloaceae* + NPK - 60%. In the variants with the introduction of microbial substances - the fungus *Trichoderma viride*, the bacteria *Bacillus subtilis* and *Enterobacter cloaceae*, the increase in mobile phosphorus and potassium is explained by the active processes of mineralization in the soil.

The following conclusions can be drawn as a result of the conducted research:

The introduction of biological preparations "Trichodermin" (*Trichoderma viride*) and "Extrasol" (*Bacillus subtilis*) on a standard mineral background ($N_{22}P_{16}K_{20}$) in greenhouse pepper enhances the process of biological activity of the soil.

The use of effective microorganisms improves the phytosanitary condition of the crop at the expense of the lower content of toxin-producing fungi in the soil.

Inoculation of the soil with "Trichodermine" during greenhouse pepper cultivation enhances the biological activity of the soil and regulates the structural composition of the soil microbial community. The number of colonies of *Trichoderma* spp. in the soil is the main regulating factor.

Among the biopreparations studied, the most effective in terms of regulating nutritional regime in pepper cultivation is the biopreparation "Trichodermine", which increases the content of mineral forms of nitrogen in the soil up to 50%, of mobile phosphorus - up to 40%, of mobile potassium - up to 71% on the mineral background ($N_{22}P_{16}K_{20}$).

The scientific article confirms the expediency and high agrochemical efficiency of the application of the biopreparations "Trichodermine" and "Extrasol" for regulating the nitrogen-phosphorus-potassium nutritional regime.

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Ternary magneto-biochar-clay composite as efficient adsorbent for aqueous naproxen and carbamazepine from Ishmi river water in Albania

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Abstract: *The quality of surface waters in Albania is an issue particularly as the country aims to join the EU. Organic compounds in water matrix are difficult to remove, and recent Ishmi river monitoring shows that the anti-inflammatory such as naproxen is predominant among other pharmaceuticals. The commonly used antiepileptic such as carbamazepine is also detected. Thus, their removal from effluents is of high environmental relevance. Therefore, ternary magneto-biochar-clay (MBC 1:2:1) adsorbent was prepared from low-cost feldspar (FLC), grape cluster stalk waste (GC) biochar, and iron oxide magnetic nanoparticles (MNP), and was used as an adsorbent. Adsorption experiments tested the effect of solution pH (2.5-10) of naproxen and carbamazepine with simulated contaminated and Ishmi river water, after pH optimization. The results showed that the maximum adsorption was achieved at a pH value of 2.5 for naproxen and carbamazepine in a single compound solution. Interestingly, for naproxen in both cases (single and combined), the maximum adsorption was achieved at pH value of 2.5, while for carbamazepine the maximum adsorption was achieved at pH value of 2.5 for single and no significant adsorption was achieved in combined compound solution. The adsorption of naproxen and carbamazepine at optimized pH of 4.5 in Ishmi water remained stable, with the only difference for carbamazepine in single compound, where the adsorption was lower compared to simulated contaminated water. This study demonstrated that in addition to easy handling, the MBC 1:2:1 adsorbent was efficient for naproxen and carbamazepine removal.*

Keywords*:* FELDSPAR; GRAPE CLUSTER STALK; pH; NAPROXEN; CARBAMAZEPINE; ADSORPTION

1. Introduction

Pharmaceutical active compounds presence in the surface water bodies is becoming a challenge with the increase of world population. It is reported that in a global scale, the presence and concentration of pharmaceuticals is problematic, especially in low- to middle-income countries related with poor wastewater treatment facilities or even without any treatment technology (direct discharge) [1]. Pharmaceuticals reach the water bodies mainly through direct discharge of wastewaters, wastewater treatment plants effluent discharges, pharmaceutical industry, livestock, etc.

The commonly used nonsteroidal anti-inflammatory drugs (NSAIDs) such as naproxen, is frequently detected in surface waters [2]. This, as a result of continuous input due to relatively high consumption and preference compared with other NSAIDs. The relatively high inputs and concentrations in the water environment could negatively impact the water species. Naproxen toxicity is confirmed to *Daphnia magna*, zebrafish embryos, microorganisms (*Bacillus thuringiensis) [3, 4]*. Another frequently globally detected pharmaceutical in the water environment is the commonly used antiepileptic, such as carbamazepine [1]. Carbamazepine toxicity is also reported to *Daphnia magna* [5]. Thus, these compounds need to be removed from water.

Adsorption technique, which is also proposed in this study, stands as a cost-efficient, free by-product formation, easy to operate, and environmentally friendly when bio-waste origin material is used for as an adsorbent. In addition, their combination (bio-waste) with other materials such as minerals (clays), and magnetic nanoparticels surpass some of their disadvantages such as low durability, leaching, and make easier the solid-liquid separation (magnetic properties) [6, 7].

Therefore in this study grape cluster stem waste, feldspar clay, and magnetic nanoparticles were combined in a composite, which was used to remove naproxen and carbamazepine in certain pH conditions and from river water. The solution pH is one of the main factors in the sorption process as directly rules the composite charge and compound's speciation in the water.

As Albania is aiming and preparing to join the European Union (EU), it has to monitor, report and to achieve a good quality status of the water bodies, in accordance with the EU policies (Directive 2000/60/EC).

Ishmi river basin is located in the central north-west part of Albania with more than 30% of the country population living in this area (Census 2023). The area is the most important in the economically aspect with the highest industrial activity, and with no active wastewater treatment plant. A two year (2023-2024) assessment was realized and the study focus compounds were detected with 2.01 and 2.04 µg/L for naproxen, and 0.35 and 0.16 µg/L for carbamazepine, respectively for the two years (Fig. 2). These results are in line and reflect the consumed amounts (only the Albanian state reimbursed amounts) of naproxen with 1879.7 and 1311.8 kg, and carbamazepine with 432.1 and 430.5 kg, respectively for the two years (Fig. 1). The presence in water and the reimbursed consumed amounts of naproxen and carbamazepine represents a potential threat to the water organisms. Therefore, the proposed study aims to test the capacity of the low-cost prepared composite for their removal at different solution pH from Ishmi water.

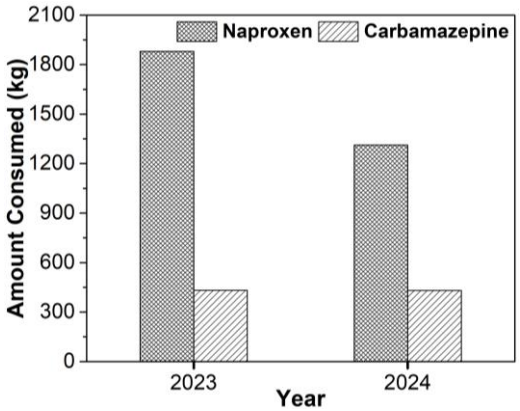


Fig. 1 *Amounts of consumed naproxen and carbamazepine for the years 2023 and 2024 in Albania (only state reimbursed amounts)[8]*

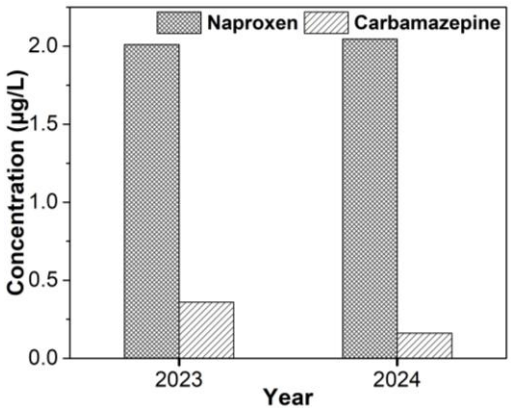


Fig. 2 *Concentrations of naproxen and carbamazepine in Ishmi river basin for the years 2023 and 2024 (data in publication process)*

2. Materials and Methods

Standards of naproxen and carbamazepine, and sodium azide (NaN_3), were purchased from Merck-Sigma-Aldrich GmbH, Germany. HPLC grade acetonitrile and MilliQ water (Purelab, UK) were used throughout the study. Mettler Toledo Scale (ME 204) and pH meter (inoLab® pH 7110) were used for weighing and pH measurements.

For the preparation of the low-cost ternary magneto-biochar-clay (MBC 1:2:1) adsorbent, the adjusted mass of dried biomass of grape cluster stalk (GC), feldspar clay (FLC), and MNP were used. The GC was collected in a vineyard in the central part of Albania. The GC and FLC were cleaned, washed and dried, while the magnetic nanoparticles (MNP) were prepared by chemical co-precipitation [9] of $FeCl_3$ (7.8 g) and $FeSO_4 \cdot 7H_2O$ (3.9 g) in 400 mL water by drop-wise of 2.0 M NaOH addition (until dark colored).

The first step for MBC 1:2:1 preparation, was the MNP preparation as mentioned above, followed by the addition of the calculated mass of GC, and the mixture was shaken for 30 minutes at 200 rpm. After that, the FLC was added and the mixture was shaken for 2 hours at 200 rpm in a horizontal shaker. The mixture was centrifuged for 5 minutes at 2500 rpm, dried overnight at 80 °C, transferred into crucibles, and calcined under limited air for 2 hours at a temperature of 500 °C. The calcined adsorbents were sieved through a 1 mm sieve size, washed several times with Milli-Q, dried at 40 °C over night, and kept in glass bottles for further use.

For the sorption experiments, stock solutions of naproxen and carbamazepine (10000 mg/L) were prepared in acetonotrile:MilliQ (50:50, v:v) and kept at 4 °C. The working solutions were prepared from the stock with 100 mg/L NaN_3, acting as biocide. The acetonitrile percentage was less than 0.1 %, in order to eliminate the co-solvent effect in the adsorption process. The sorption experiments were realized using 5 mg adsorbent mass and 10 mL of 2.5 mg/L naproxen and carbamazepine solution in 20 mL brown glass vials at different solution pH (2.5 – 10). Meanwhile, those with Ishmi river water at pH 4.5 only. The mixture was agitated at 200 rpm for 24 h at room temperature (20 °C). Samples were filtered with 1 µm glass fiber filters and measured using HPLC-UV (naproxen at 230 nm wavelength and carbamazepine at 285 nm wavelength with a mobile phase of acetonitrile:0.2% formic acid in water (60:40, v:v), and a flow rate of 0.3 mL/min) The solution pH was adjusted usig 0.2 M HCl or NaOH.

3. Results and Discussion

The effect of solution pH is one of the most important vital factors in the sorption process due to the impact and the control of the sorbent charge and speciation of the compounds in the solution [10]. Therefore, the solution pH effect for naproxen and carbamazepine was tested over five different pH points (2.5 – 10), and the results are given in Fig. 3 and Fig. 4. The highest sorption capacity of naproxen was achieved at solution pH of 2.5 (Fig. 3). The sorption had a decrease trend up to solution pH of 6.5 and after that remained stable until solution pH of 10. This trend could be as a result of the composite charge and naproxen. As the pHpzc of the composite is around 9, at low pH values, the composite is mainly positively charged, indicating high electrostatic interaction between the positive functional composite groups with the ionic naproxen species in the solution. Naproxen has a pKa of around 4.2 (Pubchem), thus at low solution pH conditions dissociates, while in higher solution pH (> 4.2) mainly exists in the neutral form. Therefore, with the increase of the solution pH the surface of the composite becomes progressively less positively, resulting in a weak electrostatic interaction. Starting from the solution pH of 6.5 up to 10, there is still some adsorption observed from the composite. This behave indicates that not only the electrostatic interaction is involved in the sorption process; also hydrophobic interactions occur between the aromatic composite groups and the benzene structures of naproxen (in these pH conditions naproxen is in its neutral form). In binary solutions (naproxen and carbamazepine), the same trend was achieved, but the sorption capacity resulted lower compared with single solution system, indicating some competition between the two compounds.

Carbamazepine was also tested at five different solution pH same as naproxen in single and binary solution systems, and the results are presented in Fig. 4. The highest adsorption was achieved at pH 2.5, and the lowest at solution pH of 8 and 10. Carbamazepine has two pKa values (2.3 and 13.9), thus at all tested solution pH mainly existed in the neutral form (Pubchem). In these conditions the sorption of carbamazepine was mainly driven by interactions mainly from cationic groups of the composite (pHpzc 9) and the benzene ring of carbamazepine. This is also supported by binary solution results trend, which shows that the competition with naproxen was higher at solution pH of 2.5 and 4.5. After that, the competition reduces and at solution pH of 10 was almost the same sorption capacity. The higher competition at low solution pH (where naproxen is ionized), indicates that both compound compete for the same sorption sites of the composite.

The MBC 1:2:1 composite sorption capacity for naproxen and carbamazepine removal from water was also tested with Ishmi river water and the results are given in Fig. 5 and Fig. 6. It was observed that for naproxen in single system the sorption capacity remained similar, meanwhile in the binary a slight decrease was observed, reflecting the same trend as in the MilliQ (Fig. 5). For carbamazepine, in single system the sorption capacity was slightly lower compared to that of MilliQ, but remained stable in the binary system solution, indicating a relatively low competition with naproxen.

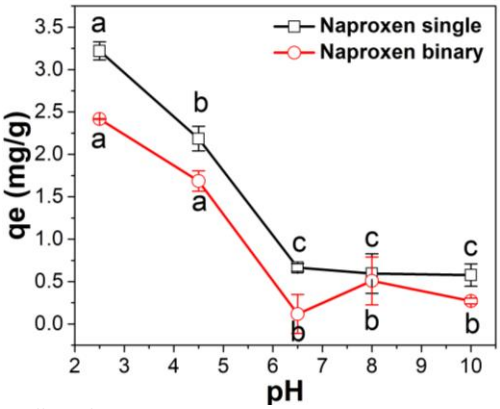


Fig. 3 *The effect of pH on naproxen adsorption onto MBC 1:2:1 composite in simulated contaminated MilliQ water (low capital letters – significance at $p<0.05$)*

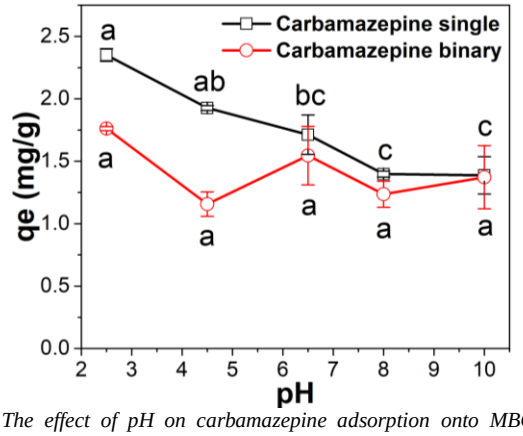


Fig. 4 *The effect of pH on carbamazepine adsorption onto MBC 1:2:1 composite in simulated contaminated MilliQ water*

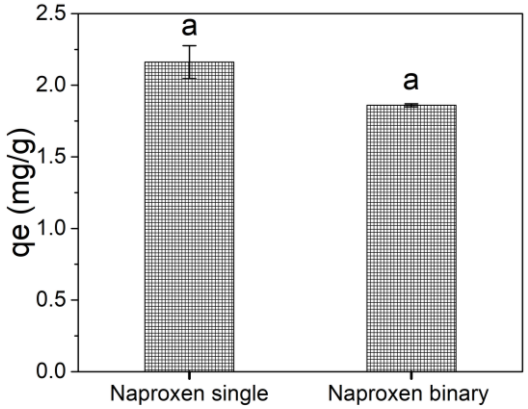


Fig. 5 *The adsorption capacity of the MBC 1:2:1 composite for naproxen at pH 4.5 with Ishmi river water*

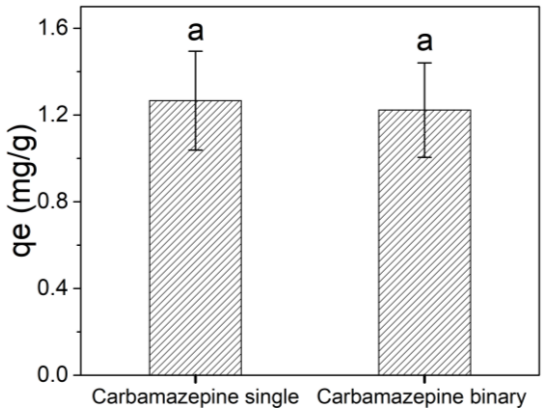


Fig. 6 *The adsorption capacity of the MBC 1:2:1 composite for carbamazepine at pH 4.5 with Ishmi river water*

4. Conclusions

The adsorption of naproxen and carbamazepine was tested over five different solution pH onto the low-cost MBC 1:2:1 composite. The highest adsorption for both compounds was achieved at solution pH of 2.5. The competition resulted to be higher at low pH conditions, mainly at 2.5 and 4.5. The sorption capacity of the composite for both compounds with simulated contaminated Ishmi river water was similar with that of simulated contaminated ultrapure water. These results demonstrate that even in real environment water conditions (river water), the sorption capacity of the prepared MBC 1:2:1 composite is efficient and applicable for naproxen and carbamazepine removal from water.

5. References

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6. Acknowledgements

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