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Latvian Academy of Agricultural and Forestry Sciences

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14:40	TF093	PRECISION AIR SEEDER FOR HEMP - CONTROL SYSTEM SIMULATION **Waldemar Samociuk, Pawel Staczek** *University of Life Sciences in Lublin, Poland; Lublin University of Technology, Poland*
15:00	TF058	PRELIMINARY STUDY OF THE STARTING SYSTEM THROUGH THE ELECTRICAL PARAMETERS OF THE START-UP PROCESS OF THE DIESEL ENGINE **Jacek Caban, Jaroslaw Senko, Tomasz Slowik, Szymon Dowkontt** *Lublin University of Technology, Poland; Warsaw University of Technology, Poland; University of Life Sciences in Lublin, Poland*
15:20	TF025	METHODOLOGY FOR THE FORMATION OF THE COMPANY'S LOGISTICS SERVICE SYSTEM **Oleg Zagurskiy, Liliya Savchenko, Alona Ohiienko, Svetlana Zagurska, Oleksandr Domin** *National University of Life and Environmental Sciences of Ukraine, Ukraine; National Aviation University, Ukraine; Kyiv Regional In-Service Teacher Training Institute, Ukraine*
15:40	TF099	INVESTIGATION OF WIDE SPAN VEHICLE TECHNOLOGICAL PART MOVEMENT STABILITY **Volodymyr Bulgakov, Aivars Aboltins, Valerii Adamchuk, Volodymyr Kuvachov, Simone Pascuzzi, Volodymyr Kyurchev, Adolfs Rucins, Victor Nesvidomin** *National University of Life and Environmental Sciences of Ukraine, Ukraine; Latvia University of Life Sciences and Technologies, Latvia; Institute of Mechanics and Automation of Agricultural Production of the National Academy of Agrarian Sciences of Ukraine, Ukraine; Dmytro Motornyi Tavria State Agrotechnological University, Ukraine; University of Bari Aldo Moro, Italy*
16:00		*COFFEE BREAK*
16:30	TF098	INVESTIGATION OF WIDE SPAN VEHICLE TECHNOLOGICAL PART SUSPENSION SYSTEM COMPACTING IMPACT ON SOIL **Volodymyr Bulgakov, Aivars Aboltins, Valerii Adamchuk, Volodymyr Kuvachov, Volodymyr Kyurchev, Adolfs Rucins, Oleh Chernysh** *National University of Life and Environmental Sciences of Ukraine, Ukraine; Latvia University of Life Sciences and Technologies, Latvia; Institute of Mechanics and Automation of Agricultural Production of the National Academy of Agrarian Sciences of Ukraine, Ukraine; Dmytro Motornyi Tavria State Agrotechnological University, Ukraine*
16:50	TF135	INVESTIGATION AND SUBSTANTIATION OF MISCANTHUS RHIZOME DIGGER PIN GRID DESIGN PARAMETERS **Valerii Adamchuk, Viktor Prysyazhnyi, Volodymyr Bulgakov, Hryhorij Kaletnik, Viktor Mazur, Oleksandra Trokhanyak, Aivars Aboltins, Adolfs Rucins, Ivan Holovach** *Institute of Mechanics and Automation of Agricultural Production of the National Academy of Agrarian Sciences of Ukraine, Ukraine; National University of Life and Environmental Sciences of Ukraine, Ukraine; Vinnytsia National Agrarian University, Ukraine; Latvia University of Life Sciences and Technologies, Latvia*
17:10	TF132	MATHEMATICAL MODEL OF MOVEMENT AND CLEANING BEETROOTS FROM SOIL LUMPS WITH SPIRAL SEPARATOR **Volodymyr Bulgakov, Ivan Holovach, Volodymyr Martyniuk, Oleksandra Trokhaniak, Aivars Aboltins, Adolfs Rucins, Yevhen Ihnatiev** *National University of Life and Environmental Sciences of Ukraine, Ukraine; Latvia University of Life Sciences and Technologies, Latvia; Dmytro Motornyi Tavria State Agrotechnological University, Ukraine*
17:30	TF137	THEORETICAL STUDY OF FLEXIBLE BLADE MOVEMENT IN CLEANING CARROT ROOT CROP HEADS WITHOUT EXTRACTING THEM FROM SOIL **Volodymyr Bulgakov, Ivan Holovach, Igor Savchenko, Petro Rykhlivskyi, Myroslav Budzanivskyi, Aivars Aboltins, Adolfs Rucins, Juri Olt, Yevhen Ihnatiev** *National University of Life and Environmental Sciences of Ukraine, Ukraine; Institute of Mechanics and Automation of Agricultural Production of the National Academy of Agrarian Sciences of Ukraine, Ukraine; Latvia University of Life Sciences and Technologies, Latvia; Estonian University of Life Sciences, Estonia; Dmytro Motornyi Tavria State Agrotechnological University, Ukraine*
17:50	TF136	INVESTIGATION OF CONTACT STRESSES IN ENGAGEMENT ELEMENTS OF SCREW CONVEYOR SAFETY CLUTCH **Volodymyr Bulgakov, Oleksandra Trokhaniak, Aivars Aboltins, Adolfs Rucins, Mycola Tkachenko, Arlindo Almeida, Volodymyr Kuvachov** *National University of Life and Environmental Sciences of Ukraine, Ukraine; Latvia University of Life Sciences and Technologies, Latvia; National Scientific Center "Institute of Agriculture" of the National Academy of Agrarian Sciences of Ukraine, Ukraine; Polytechnic Institute of Bragança (ESAB/IPB), Mountain Research Center (CIMO), Portugal; Dmytro Motornyi Tavria State Agrotechnological University, Ukraine*

INVESTIGATION AND SUBSTANTIATION OF MISCANTHUS RHIZOME DIGGER PIN GRID DESIGN PARAMETERS

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Abstract. In the global energy sector there is an increasing need to replace the traditional energy resources with appropriate analogues of the plant origin, which will significantly reduce the consumption of traditional fuels. Ukraine has significant energy potential for the development of the bioenergy industry, in particular, the use of such an effective bioenergy crop as miscanthus. The technology for growing miscanthus involves the use of the planting material in the form of rhizomes which must be in a significantly crushed form. The goal of increasing the efficiency of the process of collecting the miscanthus planting material is to substantiate the machine parameters for mechanized digging of the miscanthus rhizomes. To do this, based on an analysis of various technological processes for digging up other root crops and devices for soil separation, we have developed a new machine for mechanized collection of miscanthus rhizomes with their simultaneous disintegration into parts, and rhizomes that are treated by a drum and a pin grid, located above. According to the results of the study it was established that the number of miscanthus, separated by rhizomes, is 62%, the amount of damage to the planting material is 2.5%. On industrial plantations the use of the developed machine ensures division of miscanthus rhizomes into parts, and the undivided rhizomes account for only 18.5%; the degree of soil separation is 82.7% with an absolute humidity of 22.6%. The ratio of the miscanthus rhizomes divided into parts and the rhizomes is 39:61, which indicates that for every hundred crushed parts of miscanthus there are almost 40 pieces, already fully suitable as the planting material. The obtained results allow us to recommend the machine for digging up miscanthus rhizomes with certain optimal design parameters for mass (serial) production.

Keywords: collection (gathering) of miscanthus, division (disintegration), sifting of soil, drum, pins.

Introduction

The production and use of the plant biomass for energy helps reduce Ukraine’s dependence on imported oil and natural gas. Currently in Ukraine the number of boilers operating on the basis of renewable energy sources is growing, that is, they are used primarily as solid fuel boilers. For such boilers the main fuel is hard biomass of a forest origin, i.e. firewood and woodworking waste. But as a result of the high price of the wood raw materials, and in some cases due to its absence on the sales market, it is necessary to look for a substitute of the solid biomass. An efficient way to solve the problems with the long-term supply of such raw materials is the use of energy crops.

As researchers claim, in the world the structure of the renewable energy sources accounts for more than 50% of the energy, obtained from biomass of the plant origin [1; 2]. The plant biomass plays the most important role in the thermal energy sector. About 15% of the total volume in EU countries is made from such biomass [3].

The leading European countries by their land area used for the energy crop plantations are: Italy – 57 thousand hectares (the largest area in Europe), Poland – 13 thousand hectares, Sweden – 12 thousand hectares, Germany – 11 thousand hectares, Denmark – 10 thousand hectares, Finland – 8 thousand hectares. In Finland, the share of biomass in the final energy consumption is 28%, in Latvia – more than 27%, in Sweden and Estonia – about 26% [4].

The alternative energy sector in Ukraine is at the stage of development and accounts for about 2% of the total energy consumption, and the age of the industry companies does not exceed 10 years [5]. Although Ukraine has not yet made full use of the existing natural potential, there are favourable climatic conditions and large areas of land that are unsuitable for agriculture which could be better used for growing energy crops, including miscanthus. The total area of land, used for growing energy crops in Ukraine, is about 4000 hectares, the total area of miscanthus cultivation does not exceed 1 thousand hectares. According to the research results [6], miscanthus is a promising crop for obtaining raw materials for energy production; it has advantages over other energy crops in terms of the dry biomass yield, efficiency of the solar energy accumulation and environmental friendliness of the cultivation technology. It is not very demanding for the quality of soil and does not deplete it; it can grow even on low-quality, poor soils; according to estimates by the Bioenergy Association of Ukraine (BAU), there are 3-4 million hectares in Ukraine [7]. Under the climatic conditions of Ukraine, the plant does not produce seeds, so its propagation occurs in a vegetative way. It has been established that miscanthus can be harvested for more than 20 years [8; 9]. Due to this, farmers will be able to make a profit from the use of such land and not occupy the area for growing agricultural crops. It has also been established that an additional advantage of the miscanthus grass is its fertilizer requirements: it needs less nitrogen, compared to other annual and perennial grasses [10].

Carbon dioxide, released when burning miscanthus biomass, does not exceed the amount previously absorbed by the plants during photosynthesis, and therefore does not create a greenhouse effect (a closed cycle is formed). In [11] the authors came to a conclusion that miscanthus requires processing costs only in the first two years after planting, and then does not require care. Low operating costs for cultivation make it possible to widely use this crop. The harvest is gathered using conventional forage harvesters, and the resulting mass can be used directly to generate heat or processed into fuel briquettes or pellets. In addition, the ash content of the miscanthus fuel pellets is lower than that of environmentally hazardous slag from hard coal (ash content up to 20%) or brown coal (ash content up to 40%). It has been established that ash from the miscanthus stems is a valuable potassium fertilizer [12]. Important characteristics of fuel pellets are environmental friendliness and energy safety, minimal carbon emissions into the atmosphere during combustion and the absence of an unpleasant odour. Unlike firewood or coal, they emit significantly less smoke, soot, carbon monoxide and other harmful substances. Compared to other energy crops, miscanthus has a positive energy balance and a positive humus balance, since after 4 years of cultivation it accumulates 15-20 tons of underground biomass per hectare.

Considering the high cellulose content – 64–71%, miscanthus is a valuable raw material for the production of building materials (material for plaster, screed, roof insulation, roofing material), it is used in the pulp and paper industry (paper, cardboard, packaging material), horticulture and vegetable growing (peat substitute, mulch, pots for seedlings and flowers), livestock farming (litter) [13].

After conducting a number of investigations [14], it was found that for reproduction of miscanthus the method of splitting rhizomes is most often used, the components of which are digging out, preparation for planting, and planting. Rhizomes are obtained from one- or two-year-old miscanthus plants. Digging of uterine rhizomes is usually carried out in spring, immediately before planting (the 3rd decade of March – and the 1st decade of April); in addition, the above-ground biomass is first collected. A complicated step in growing miscanthus is preparation of the planting material.

To dig up 1–2-year-old miscanthus rhizomes, potato diggers are used, which lay undivided bushes of rhizomes on the surface of the field (Fig. 1). The selection of rhizomes is carried out manually, and the division into rhizomes is usually done by cutting them into pieces (Fig. 2).

Fig. 1. **View of the field with dug up miscanthus rhizomes**

Fig. 2. **Process of manual separation of miscanthus rhizomes**

Miscanthus rhizomes are planted to a depth of 8...10 cm with a density of 14...20 thousand rhizomes per ha, with a row spacing of 70 cm and a planting step of 102...70 cm [15; 16]. We have established in our investigations that the soil compaction around the planted rhizomes reduces the field germination and prolongs the period of the emergence of seedlings. The optimal soil hardness for rhizome germination should be within 0.3...0.5 MPa.

Considering this, an urgent task is to develop technical means for mechanized harvesting of miscanthus rhizomes with their simultaneous splitting into parts and rhizomes, that is, direct preparation of the planting material at once. Therefore, the purpose of this study was to improve the technological process of dividing miscanthus rhizomes into parts and rhizomes by substantiating the parameters of the concavity of the grinding apparatus of the machine for their mechanized digging. Therefore, the purpose of this research was to improve the technological process of splitting the miscanthus rhizomes into parts and rhizomes by substantiating the parameters of the pin grid of the grinding apparatus of the machine for their mechanized digging.

Materials and methods

The Institute of Mechanics and Automation of Agro-Industrial Production of the National Academy of Agricultural Sciences and scientists of the National University of Bioresources and Nature Management of Ukraine, together with the specialists from the Slovak University of Life Sciences, and Ulbroka Research Centre of the Latvia University of Life Sciences and Technologies, have developed a new trailed machine for mechanized harvesting of miscanthus rhizomes, which simultaneously splits the miscanthus rhizomes into parts and rhizomes, that is, prepares the planting material for further planting of this crop.

Experimental studies of the technological process of digging out miscanthus rhizomes from the soil and separating them into parts and rhizomes, using the developed machine, were conducted in the field under various design parameters and operating modes, and using general methods for testing samples of agricultural machinery [17]. The results of the experimental study were processed using Microsoft Excel and Mathlab applications.

The design diagram of this machine is presented in Fig. 3 [7].

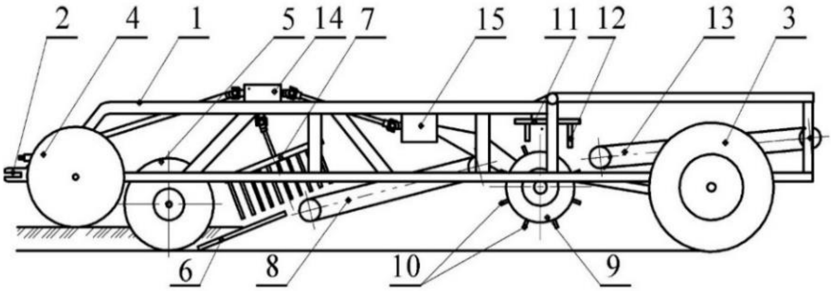


Fig. 3. **Design and technological diagram of a machine for digging up miscanthus rhizomes:**
1 – main frame; 2 – device for connecting to the aggregating tractor; 3 – running wheels; 4 – copying wheels; 5 – flat disks; 6 – three ploughshares; 7 – bar spreader drums; 8, 13 – rod conveyors; 9 – grinding drum; 10 – drum teeth; 11 – overdrum pin grid; 12 – overdrum pins; 14, 15 – reducers

The design of this machine is such that the main frame 1 in the front part has an attachment to a wheeled aggregating tractor of class 1.4. Further, the main frame 1 has vertical flat disks 5, installed in front, cutting the soil with the miscanthus rhizomes into separate strips in the longitudinal direction. Behind the disks 5 there are passive flat shares 6, above the rear parts of which two bar spreader drums 7 are installed, having long bars, directed orthogonal to the plane of the shares 6 and having small gaps. Next there are sequentially located rod conveyors 8 and 13, between the installed chopper of miscanthus rhizomes into parts and rhizomes, which is made in the form of a grinding cylindrical drum 9 with teeth 10 and an overdrum pin grid 11, located above it with two rows of replaceable pins 12. The machine is in a rotational motion, using two reducers 14 and 15, as well as cardan transmissions from the rear power take-off shaft of the aggregating tractor.

A general view of the grinding apparatus for splitting miscanthus rhizomes into parts and rhizomes is presented in Fig. 4.

Fig. 4. **Grinding apparatus of the machine for separating miscanthus rhizomes into parts and rhizomes**

The technological process of digging up the miscanthus rhizomes and splitting them into parts and rhizomes occurs as follows. Moving across the field in which green miscanthus stems have been previously cut, the machine, with its flat discs 5, pre-cuts the soil with miscanthus rhizomes, located at the appropriate depth in a vertical plane, into longitudinal strips. Next, the passive ploughshares 6 cut the soil layer in a horizontal plane to the depth of the miscanthus rhizomes and lift them up. The bar spreader drums 7, rotating towards each other, with their long bars destroy the structure of the rhizomes, partially separating soil impurities, and direct them to the first separating rod conveyor 8. The conveyor 8 delivers the miscanthus rhizomes, extracted from the soil, into a driving cylindrical drum by the short teeth 10, which grab the rhizomes and throw them with acceleration onto the pins 12 of the drum 11, which are located on top in a checkerboard pattern. Hitting the pins 12, the overdrummed rhizomes of miscanthus are destroyed and split into parts and rhizomes and in a crushed form are fed to the rod conveyor 13, which, in turn, separates a significant part of the soil from them, transports and places them on the field surface behind the machine.

Thus digging of the root miscanthus from the soil takes place by the flat ploughshares 6, preliminary separation of the soil occurs on the bar spreader drums 7, the rod conveyor 8 delivers the rhizomes to the grinding apparatus, consisting of a drum 9 and overdrum pin grid 11, and the rod conveyor 13, that is, the ready-made planting material lays behind the machine onto the soil surface.

To improve the quality of the technological process of digging out the miscanthus rhizomes from the soil and splitting them into rhizomes, depending on the harvesting conditions (taking into account the different sizes of the miscanthus rhizomes, the soil moisture, etc.), it is possible to change the speed of the chopping drum and correspondingly adjust the distance between the overdrum pins. So replaceable sets of the overdrum pins were designed with the following lengths: 160 mm, 200 mm and 230 mm.

In addition, the following parameters could be varied during the field experimental studies: the distance between the pins of the overdrum pin grid, their number and length. The length of the first row of pins of the overdrum pin grid was 160 mm (options 1-3) and 120 mm (options 4-5), the second row – 200 mm (options 1-2) and 230 mm (options 3-5). The distance between the pins of the first row was 150 mm (option 1), a combination of 150 mm at the edges and 200 mm in the middle (options 2-4) and 200 mm (option 5). The distance between the pins of the second row of pins was always constant and amounted to 150 mm. Diagrams of options for the location of the pins of the overdrum pin grid are shown in Fig. 5.

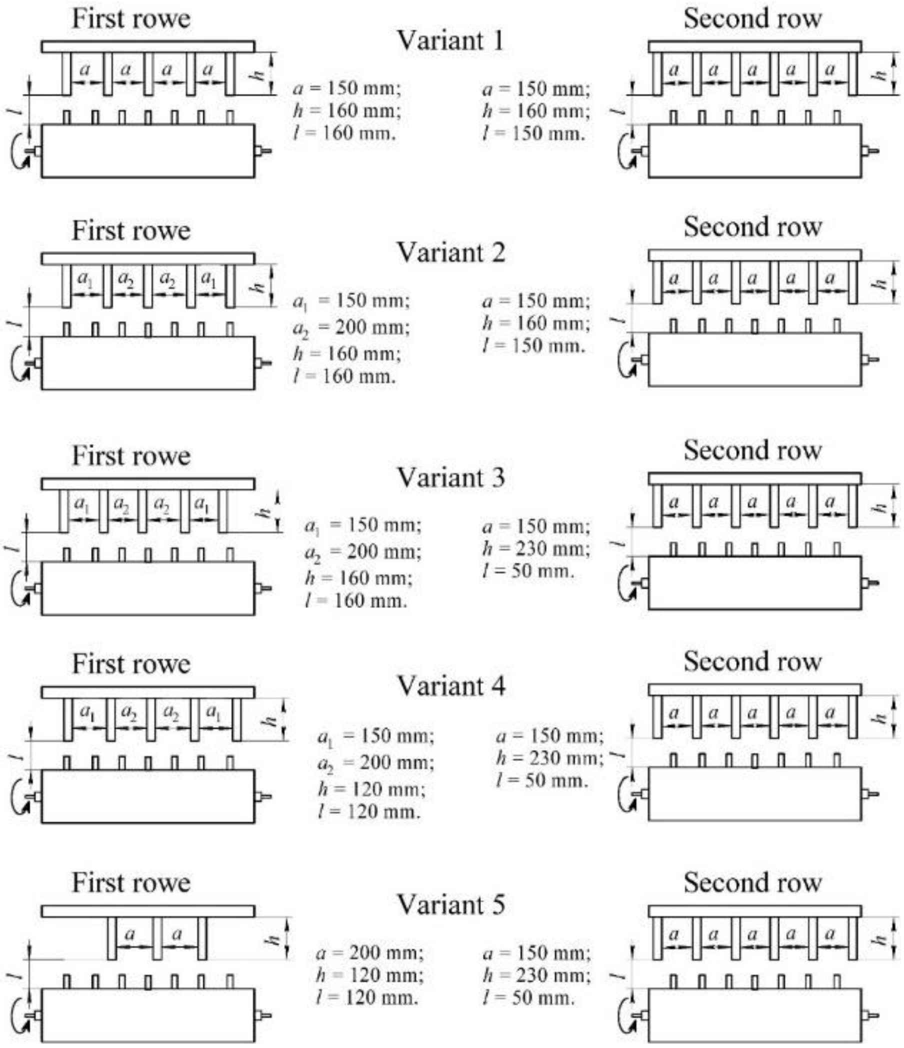


Fig. 5. **Diagrams of the variants for location of the overdrum pin grid**

During the previous field tests of the produced experimental prototype of the machine and its testing in various operating modes and operating conditions, it was immediately established that the overdrum pins should be located in one row, the distance between the pins should be at least 150 cm, the length of the pins should be 200 mm, the drum rotation speed – 5.0 s^{-1}.

Preliminary tests and experimental research of the technological process of mechanized extraction of miscanthus rhizomes from the soil with simultaneous splitting into parts and rhizomes were performed on a pilot plot of the field of the Institute of Mechanics and Automation of Agro-Industrial Production of the National Academy of Agrarian Sciences of Ukraine during 2019-2022. For these studies a machine was designed and made that allows to conduct experimental field research. Its general view is presented in Fig. 6.

Fig. 6. **Machine for digging up miscanthus rhizomes during the field experimental investigations**

Before conducting the experiments, preliminary operations were performed. The green plant part (the miscanthus stems) was removed. After this small stems remained on the soil surface, the average size of which did not exceed 3...5 cm. Each time this preparatory operation was done immediately before conducting the experimental research on digging up the miscanthus rhizomes.

The next preparatory operation was to determine the stripes in the lines of placement of rhizomes, which had the length and width dimensions with the following values: 40×30 cm. The error in measurements of the stripes and markings of each stripe with separate wooden pegs did not exceed 2.0 cm. The depth of travel of flat ploughshares in passive soils, using the copying wheels was set in advance on a flat surface, and it was equal to 15 cm, that is, it corresponded to the depth of the miscanthus rhizomes in the soil. The error upward or downward also did not exceed 2 cm.

The experimental studies of the technological process of digging the miscanthus rhizomes from the soil with their simultaneous division into parts and rhizomes, with the determination of the quality indicators, were performed in the following sequence. For mechanized harvesting of the miscanthus rhizomes the vertical drums were previously removed from the machine. A plastic film was placed under the conveyors of the technical equipment to collect the sifted soil, the parts of rhizomes and the miscanthus rhizomes.

Each strip of the pre-harvested rhizome was weighed on scales and placed in the middle of the first conveyor of the technical means, and the drive of the conveyors and drum was turned on. The first conveyor conveyed the strip of rhizomes to the adapter, which, with its components, divided it into parts and rhizomes while simultaneously separating the soil. The soil was poured onto a plastic film, and parts of the rhizome and the rhizomes went to a second conveyor for further pre-purification.

During the research the harvesting of miscanthus rhizomes occurred immediately before the experiments. In addition, the soil samples were taken to determine its moisture content. The soil samples were taken into aluminium cups from the area where miscanthus rhizomes were located at a distance of 0 – 0.15 m, delivered to the laboratory and weighed on a VLK-500 electric scale with an accuracy to 1 g. The soil samples were dried in an oven at a temperature of + 105°C until water completely evaporated.

To determine the amount of the damaged planting material, received after the passage through the machine, the length of the crop line was first measured on the plot, equal to 5 m of the plot, from which the rhizomes, dug up by the machine, were collected on the plastic film, and their total number was calculated. Next, the damaged rhizomes were isolated from them, and their number was counted. Figure 7 shows the selection and separation of the rhizomes into parts and the rhizomes, dug by the developed machine. The selection and separation of the miscanthus rhizomes was performed manually, the results of the calculations were recorded in a journal.

Fig. 7. **Selected miscanthus planting material, divided into parts and rhizomes**

In addition to this, the rhizomes that were completely deformed (crushed) and those that had less than four points were classified as damaged. The separated parts of rhizomes were collected separately, manually divided into rhizomes, and their number was counted. In this case, rhizomes that were completely deformed (crushed) and those that had less than four points were classified as damaged.

To determine the parameters that influence the process of dividing miscanthus rhizomes into parts and rhizomes, we conducted a full-factorial experiment PFE – 3^3, that is, determination of the dependence of the percentage of uncrushed miscanthus rhizomes *Y* into parts upon changes in three main factors: the drum rotation speed *n*, s^{-1}, distance between fingers *h*, m and the soil moisture *w*, %.

Since during the performed experiments the variable independent factors are heterogeneous and have different units of measurement, and the numbers expressing the value of these factors have different orders, they were brought to a unified calculation system by moving from the actual values to the coded ones, presented in Table 1.

The investigation of the percentage of the uncrushed miscanthus rhizomes *Y* made it possible to determine the dependence on many factors, characterizing the process of dividing miscanthus rhizomes into parts and rhizomes, namely:

- the drum rotation frequency *n*, s^{-1}, which was coded with the index X_1;
- the distance between fingers *h*, m, coded by index X_2;
- the rotation frequency of the blade working body, *n*, rpm, coded by the index X_3.

Table 1

Results of factor coding and levels of their variation when studying the torque of a conveyor with a bladed working body

Factors	Designation		Interval of variations	Levels of variation natural/coded		
	Coded	Natural				
Drum rotation speed *n*, s^{-1}	X_1	X_1	1.67	3.33/–1	5/0	6.67/ + 1
Distance between the fingers *h*, m	X_2	X_2	40	160/–1	200/0	240/ + 1
Soil moisture *w*, %	X_3	X_3	8	14/–1	22/0	30/ + 1

Processing of the experimentally obtained array data took place using well-known methods and methods of statistical processing by well-known methods of correlation and regression analysis, to ultimately obtain empirical regression equations. To obtain a regression model for the optimization parameter, an appropriate full-factorial experimental design was selected, which was implemented in the following sequence.

The response functions (optimization parameter), that is, the torque $Y = f(n, h, w)$, determined experimentally, are presented in the form of a mathematical model of a complete quadratic polynomial:

$$Y = b_0 + b_1 x_1 + b_2 x_2 + b_3 x_3 + b_{12} x_1 x_2 + b_{13} x_1 x_3 + b_{23} x_2 x_3 + b_{11} x_1^2 + b_{22} x_2^2 + b_{33} x_3^2 , \quad (1)$$

where $b_0, b_1, b_2, b_3, b_{12}, b_{13}, b_{23}, b_{11}, b_{22}, b_{33}$ – coefficients of the corresponding values x_i;
x_1, x_2, x_3 – the relevant factors to be coded.

The regression equation for the determination of the percentage of uncrushed miscanthus rhizomes has the form:

$$Y = 3.02162 - 1.66644 \cdot n \text{-} 0.02601 \cdot h + 0.01156 \cdot w + 0.00054 \cdot h \cdot n - 0.00006 \cdot h \cdot w + 0.0059 \cdot n^2 . \quad (2)$$

The resulting regression equation (2) can be used to determine the percentage of uncrushed miscanthus rhizomes Y depending on the drum rotation speed n, the distance between fingers h and the soil moisture w within the following limits of change in the input factors: $3.33 \leq n \leq 6.67$ (s^{-1}); $160 \leq h \leq 240$ (m); $14 \leq w \leq 30$ (%).

Results and discussion

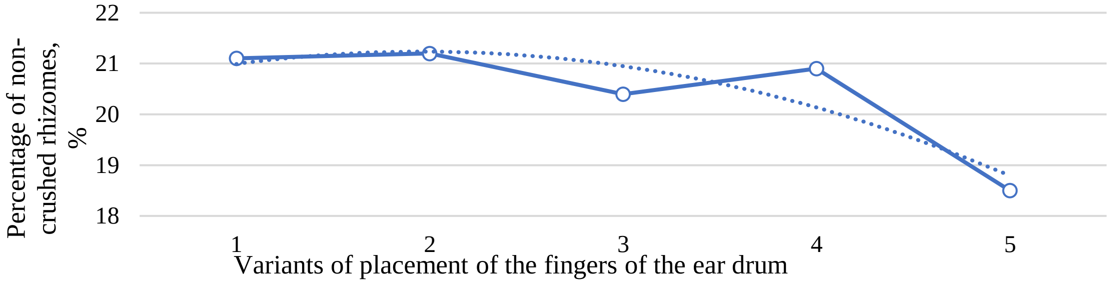
Based on the results of processing the data from the experimental studies, graphical dependencies were constructed, which made it possible to establish the dependencies of the uncrushed parts depending on the use of one or another application of the overdrum pins. Figure 8 shows graphs of the degree of uncrushed parts (not suitable for use as the planting material) and the degree of the soil removal from the crushed parts of the miscanthus. The degree of grinding and extraction of soil from the crushed parts of the white miscanthus is determined as percentage.

As seen from the graphs, shown in Fig. 8, and the percentage of the non-separated miscanthus rhizomes varies from 18.5% to 21.5%. Besides, the smallest value of non-division, which corresponds to the best values, is performed when using the 5th variation of the location of the overdrum pins. The absolute moisture content of the rhizomes was about 83%.

As for the degree of separation of soil from already crushed parts of the miscanthus rhizomes, as follows from the graph in Fig. 8 b, this indicator varies from 76.3% to 82.7%. The most favourable conditions for the highest percentage of soil separation were also achieved when using option 5 of the placement of the overdrum pins. Approximation of the obtained graphical dependencies by analytical curves indicates that they are described by the second-order curves.

The results of the field experimental research indicate that the main working body of the crusher with the overdrum pin grid of the new developed machine for digging and crushing the miscanthus rhizomes into parts and rhizomes ensures a ratio of the miscanthus rhizomes, split into parts, and the rhizomes in the ratio of 39:61 processed material (39 pcs. - this is the planting material that is completely crushed and ready for use, 61 pieces - still require additional grinding). The amount of damage to the miscanthus planting material does not exceed 2.5%.

a)



b)

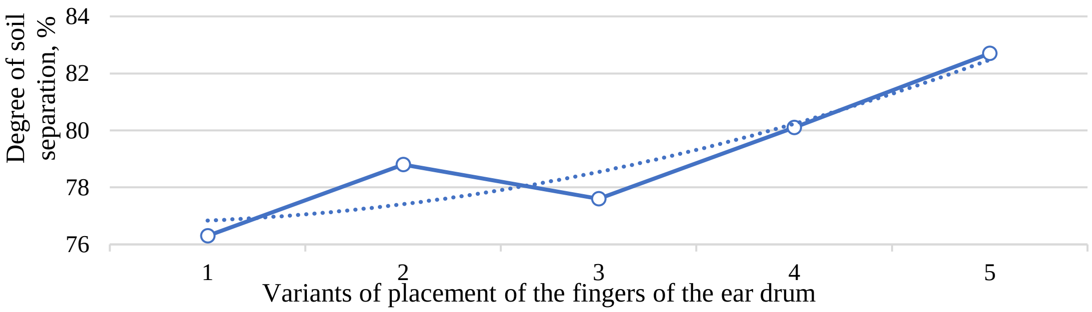


Fig. 8**. Graphs of changes in the percentage of the uncrushed miscanthus rhizomes into parts** (a) **and the degree of soil separation (b) for various design options of location of the overdrum pins:** 1, 2, 3, 4, 5 – variants of location of the overdrum pins

These figures are virtually identical across all overdrum pin placements and lengths, used on this machine.

Based on the results of the experimental investigations of the percentage of uncrushed rhizomes of miscanthus Y, using the application program "STATISTICA 10", we built a graphical reproduction of intermediate general regression models in the form of quadratic responses and their two-dimensional sections of the percentage of uncrushed rhizomes of miscanthus *Y* as a function of two variable factors $x_{i(1,2)}$ at a constant level corresponding third factor $x_{i(3)} = \text{const}$ (Fig. 9).

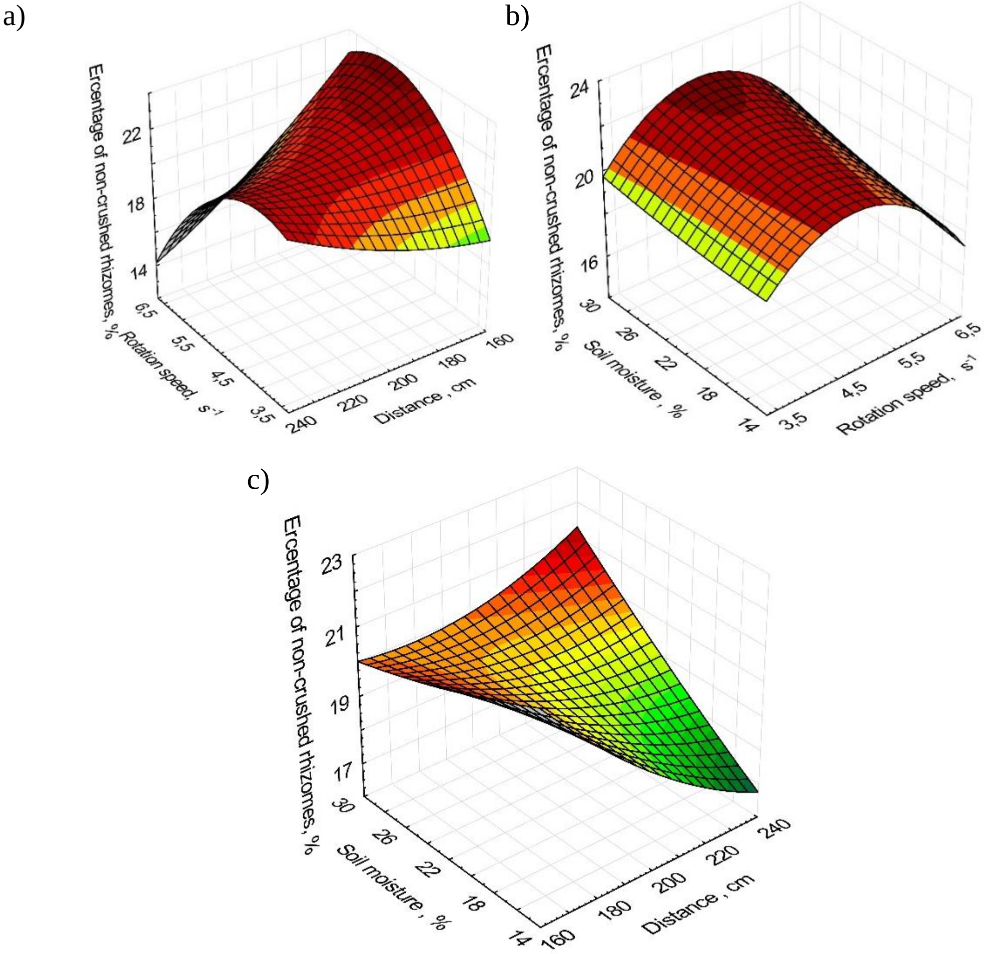


Fig. 9. **Response surfaces of percentage of uncrushed rhizomes of Miscanthus *Y* depending on:** a – $Y = f(n; h)$; b – $Y = f(n; w)$; c – $Y = f(w; h)$

Analysis of the above regression equation shows that the main factors influencing the percentage of uncrushed miscanthus rhizomes *Y* are: the rotation speed of the chopping drum $x_1(n)$ and the distance between the fingers $x_2(h)$. Increasing the value of the factor $x_3(w)$, i.e. soil moisture *w* ,leads to an increase in the percentage of uncrushed rhizomes.

When the drum rotation speed *n* changes within 3.33...6.67 s^{-1}, the percentage of uncrushed miscanthus rhizomes *Y* decreases by 31.7%; when the distance between the fingers *h* changes from 160 cm to 240 cm, the percentage of the uncrushed miscanthus rhizomes *Y* decreases by 30.5%,; and when the soil moisture *w* changes within 14...30%, the percentage of the uncrushed rhizomes of miscanthus *Y* increases by 4.6%.

Miscanthus rhizome planters are composed beside furrow opening devices, by coxering disks and press wheels. It requires certain firmness between the soil and rhizomes because they can germinate the plant to rise and grow. Rhizome coverage is done generally using two metallic disks inclined in the form of spherical calottes. In order to displace the cut soil on the channel by the coulter, it is necessary to have a certain inclination, both towards the forward direction and the surface of the soil. In paper [18, 19] is presented theoretical modelling of the working process of these disks estimating the soil area displaced and moved laterally in order to cover the channel, depending on the angles of inclination of the disks. The work process scheme and mathematical relationships for estimating the volume of soil displaced are presented.

In work [20] an analysis of the designs of the existing machines for harvesting energy willow by the world's leading manufacturers was made. A characteristic peculiarity of these machines is the presence of specialized equipment for harvesting energy crops. This equipment is combined exclusively with special combines and is designed for harvesting energy crops on plantations, laid out according to agrotechnological requirements.

In work [21] there are in-depth studies on mechanized ditch digging and field reclaiming. The ejection mechanism of the soil particles during the digging process was analysed to investigate the effect of the excavation device on the ejection trajectory and the landing point of the soil particles.

The results of the design developments and the field experimental studies allow to formulate such conclusions, based on the processed results of the study.

Conclusions

1. Based on the analysis of modern technological processes and designs of machines for digging up various root crops and devices for soil separation, a new machine has been developed for mechanized harvesting of miscanthus rhizomes with their simultaneous crushing, that is, splitting into parts and rhizomes. The division of the miscanthus rhizomes into parts and rhizomes is ensured by the grinding apparatus, consisting of a drum and an overdrum pin grid, equipped with pins with different relative positions and lengths.
2. Preliminary field tests of the produced prototype of the machine were conducted, and it was tested in various operating modes and operating conditions to determine the design and kinematic parameters. It was established that the overdrum pins should be located in one row, the distance between the pins should be at least 150 mm, the length of the pins should be 200 mm, and the drum rotation speed should be 5.0 s^{-1}.
3. According to the results of the experimental research of various options of location of the overdrum grid pins (5 options), the largest number of miscanthus, separated by the rhizomes, was about 62%. In this case, the amount of damage to the planting material was not more than 2.5%.
4. The machine for mechanized harvesting of miscanthus rhizomes on industrial plantations ensures a sustainable process for separating the miscanthus rhizomes into parts and the rhizomes. The percentage of undivided rhizomes is only 18.5%, the degree of the soil isolation is 82.7% with an absolute moisture content of 22.6%. The ratio of the miscanthus rhizomes, divided into parts and the rhizomes to their undivided quantity, which can be expressed in a quantitative ratio for every hundred collected and evaluated rhizomes obtained during the experimental study, is 39:61. This indicator witnesses that the parts are immediately completely suitable for use as the planting material.
5. Based on the results of the experimental investigations, the corresponding regression equation and response surface were constructed to establish the influence of the controlled factors upon the value of the percentage of the uncrushed miscanthus rhizomes. Analysis of the above regression equation shows that the main factors influencing the percentage of the uncrushed miscanthus rhizomes Y are: the rotation speed of the chopping drum $x_1(n)$ and the distance between the fingers $x_2(h)$. Increasing the value of the factor $x_3(w)$, i.e. soil moisture w, leads to an increase in the percentage of the uncrushed rhizomes.
6. When the drum rotation speed n changes within 3.33...6.67 s^{-1}, the percentage of the uncrushed miscanthus rhizomes Y decreases by 31.7%; when the distance between the fingers h changes from 160 cm to 240 cm, the percentage of the uncrushed miscanthus rhizomes Y decreases by 30.5%; and when changing the soil moisture w within 14...30%, the percentage of the uncrushed miscanthus rhizomes Y increases by 4.6%.
7. The next stage of design work and research is the development of mechanisms that ensure the removal of the undivided parts of miscanthus after passing through the grinding apparatus and their direction for re-grinding. The bottleneck in the use of this machine is also the collection of the crushed parts of miscanthus either into a hopper or direct transportation to a vehicle. This will require further research of the movement stability of the machine and its energy performance.

Author contributions

Conceptualization, V.A., V.B., V.P., and A.R.; methodology, V.A., V.P. and O.T.; software, H.K.; validation, A.A., A.R., I.H., and V.M; formal analysis, V.B and O.T.; investigation, V.B., S.I., V.N. and I.H.; data curation, A.A., V.B. and V.M.; writing – original draft preparation, V.B.; writing – review and editing, A.A. and V.B.; visualization, H.K., V.M.; project administration, V.B.; funding acquisition, A.A., A.R., O.T. and I.H. All authors have read and agreed to the published version of the manuscript.

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