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Rationale for the combined cultivator design for cultivating soil littered with plant remains of rough-stemmed crops

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Abstract. **After harvesting corn, an important question is to cultivate the soil and prepare the field for sowing another crop, because after harvesting there are root and leaf residues that need to be destroyed in time and quality, earning them in the soil. Based on the analysis of the state of the field after harvesting corn, an assessment of quantitative and qualitative indicators of surface contamination and distribution of plant residues in rows and between rows was given. This allowed us to draw conclusions about the effective method of tillage contaminated with crop residues of coarse-stemmed crops. Taking into account the biological, physico-mechanical and morphological features of corn residues (fibrousness, elasticity, stiffness), it was concluded that for grinding post-harvest corn residues it is necessary to use active working bodies with L-shaped knives that will cultivate the soil to a depth of 6-8 cm. grind stems and root parts, ensure a sufficient degree of grinding, good wrapping and mixing with the soil. However, the high energy costs of milling the soil make us look for solutions for the strip use of cutters, while ensuring continuous tillage to a given depth. According to the conclusions of these studies, a combined cultivator is proposed, which provides passive cultivation of the row spacing with folding of plant residues that are on the surface in the row zone, milling this area with cutters 20-25 cm wide. This combination will allow to qualitatively prepare the field with grinding of all plant residues with minimization of energy costs and traction performance of the tractor. The proposed design of the cultivator-shredder is protected by a patent of Ukraine.**

Keywords: field littering, leaf and root residues, maize, pre-sowing tillage, combined unit, cultivator-shredder.

I. INTRODUCTION

As a row crop, corn is a good and most common precursor for spring cereals, and when harvested for green fodder and silage - for winter cereals. At the experimental stations, after corn, good harvests of barley, millet, peas, fodder and other crops were obtained. Corn for silage is the main predecessor of winter crops, and in the extreme south of the country, winter crops are also sown after corn for grain and sunflower. Also, many studies do not exclude the possibility of long-term cultivation of corn in one place with the introduction of fertilizers.

However, in-row predecessors are harvested shortly before the optimal time for sowing winter crops, so there is little time left for soil cultivation. In particular, harvesting corn for silage in the phase of milky-wax grain ripeness, when the largest dry matter yield per hectare is formed, and its stems and leaves still contain enough moisture for ensiling the mass, coincides in most regions of Ukraine with the optimal sowing dates of winter wheat. At the same time, the sowing of wheat is often delayed by the harvesting of corn and the subsequent preparation of the soil. In this regard, they switch to earlier harvesting of corn for silage, when the plants contain even more than 80 % of moisture (at the same time, the collection of fodder units in the silage mass is reduced by 42.7...43.3 % of the milk-wax maturity collected at the end).

In order to reduce this negative factor, there is a need to free the field from the previous crop as soon as possible and

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to prepare the soil in a short period of time. However, the situation is complicated by the fact that after harvesting corn, root and leaf stalk residues remain on the field, which must be destroyed in a timely and qualitative manner, having worked them into the soil. This is an important condition for high-quality soil cultivation and preparation of the field for planting another crop.

In agriculture, high-quality cultivation of fields littered with coarse plant residues after harvesting still remains a problem. And there are a lot of such fields in Ukraine, because:

1) crops of rough-stemmed crops, in particular sunflower, increased significantly;

2) recently, corn is grown mainly for grain without shredding the stalks during harvesting;

3) during harvesting of grain crops, tall stubble (more than 20 cm) remains on the field;

4) there were a lot of neglected and abandoned fields, weedy or untimely processed, which are simply impossible to process without shredding the stems [5], [6].

An important role in soil cultivation after harvesting coarse-stemmed crops is played by the quality of shredding and plowing of root and crop residues, which contributes to their rapid decomposition and the entry of organic and mineral substances into the soil. Of course, the problem of clogging the field with coarse crop residues has been known for a long time, but traditional ways of solving and some new ones do not fully provide and give the desired result.

Scientific studies are devoted to soil cultivation problems [7]-[11]. They proposed a mechanized technology, the essence of which consists in multi-track discing in different directions with heavy disc tools. Long-term data of scientific research institutions and production experience indicate that in the Ukrainian steppe zone, after the row-row predecessors, as a rule, shallow soil cultivation of 8-10 cm is more effective. For such cultivation, disk harrows are most often used. In the future, the field is cultivated with simultaneous harrowing for soil development and weed destruction [12], [13]. In the forest-steppe zone of Ukraine, after corn for silage, when there are at least 20 days left before sowing, with sufficient soil moisture practice husking with disc tools to a depth of 5-6 cm followed by plowing to a depth of 20-22 cm with simultaneous rolling. Immediately after that, the soil is cultivated with disk cultivators, ring-spur rollers, and cultivators with harrows [14].

The disadvantage of traditional disk tools when performing soil cultivation is the low efficiency of shredding plant residues in one pass and, as a result, a low degree of mixing them with the soil, which is important in the further use of the field. The remains of plant stems have the ability to resist deformation, so they are not grind to some extent, but crumpled, part of them passes between the disks.

At the current stage of development of agricultural production, the problem of maximum loading of energy-rich high-speed wheeled tractors comes to the fore. It is recommended to use active working bodies to implement unused engine power through the tractor's power take-off shaft. In this way, continuous milling tillage of the soil comes to the fore, which is considered more effective from the point of view of shredding the crop residues and mixing them with the soil [12], [16]. Thus, scientists of the National Research Center "Institute of Mechanization and Electrification of Agriculture" (Ukraine) suggest pre-shredding the surface leaf-stem mass with the drums of a forager [17].

It should be noted that when using such means, the accompanying rotation of the active working body is accompanied by the emergence of a pushing force, the direction of which coincides with the direction of movement of the tractor. Taking into account that active rotary means of mechanization perform a technological process with large energy costs, it is worth while conducting theoretical studies to determine the parameters that ensure the minimum energy consumption of soil cultivation.

Taking into account the indicated shortcomings, for effective use in pre-sowing soil cultivation, combined aggregates were developed. Scientists have proven that the scope of use of combined aggregates in agriculture is determined by both the natural and climatic conditions and the physical and mechanical properties of the cultivated soils. The farming system, agrotechnical requirements for soil and crop processing, and energy equipment are very important components for achieving the desired result.

Scientists claim that in order to obtain the desired result from the use of combined aggregates, the following basic requirements must be observed [6]:

1) the technological process performed by the combined unit must be more energy-efficient than the total energy consumption when it is performed by single-operation machines;

2) the productivity of combined machines should not be lower than a set of replaceable single-operation machines;

3) good adaptation to work in adverse weather and soil conditions;

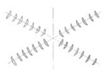
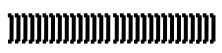
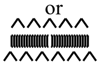
4) assistance in increasing the yield of crops, preservation of soil fertility, provision of a reliable working system-new technologies, etc.

Original solutions in combining active and passive working bodies are offered, in particular, by Schulte, Bomford, Kuhn, Lemken and others, producing shredders of plant residues in a wide range of standard sizes. In these technical means, two types of shredding bodies are used - with a vertical and horizontal axis of rotation of the rotor, on which the knives are installed.

In addition to the traditional method, the search for more rational ways of solving the tasks of freeing the field from plant residues is underway. Among the developments, the combined machine of the Southern Department of UNDIMESG, which includes active and passive working bodies, is well-known. The main working body is a milling drum with a two-tiered arrangement of knives. The milling drum consists of a shaft on which disks are mounted, to which L-shaped knives are attached. Milling working bodies grind the post-harvest residues and soil to a depth of 1-2 cm - the first layer and 6-7 cm - the second. Then the flat-cutting paws move, which grind the layer in the third tier to a depth of 12-14 cm. The needle harrow, which moves behind, additionally loosens the soil, levels the surface and compacts the upper layer [16], [18].

The most common options for soil preparation technologies after harvesting rough-stemmed crops are presented in Table 1.

TABLE 1 THE MOST COMMON TECHNOLOGIES FOR PROCESSING THE FIELD SURFACE AFTER HARVESTING ROUGH-STEMMED CROPS IN UKRAINE

Sufficient moisture (classic technology)	**Insufficient hydration (South of Ukraine)**	**Low clogging with crop residues**	**High clogging with coarse harvest residues**	**Processing with combined units**
1.Disc tillage in two tracks  skim plow with disc working bodies	1.Disking.  Disc harrows with disc working bodies	1.Cultivation  Cultivator of continuous cultivation with arrow legss	1. Milling  Milling cultivator with active working bodies	1. Combined cultivation  or  Combination machine
2. Plowing or shallow cultivation				
3. Pre-sowing treatment I. To a depth of 8...10 cm. II. To the depth of seed wrapping				
4. Sowing				

There is no single, rational, recommended mechanized technology for shredding leaf-stem and root mass before soil cultivation in Ukraine. Therefore, there is an acute production problem that needs a scientific and applied solution.

In solving this problem, we see a classic scheme, namely:

- study of the object of processing;
- analysis of existing machines that are used for similar types of work;
- development of a special design of the shredder.

Purpose and scope of work

The purpose of this publication is to select the optimal cost-effective unit for tilling the field after harvesting rough-stemmed crops in one pass.

The primary task for the realization of this goal is to conduct scientific research on the study of the object of cultivation - a field littered with leaf, stem and root residues as elements that need to be grind and plowed. The list of issues under study includes: systematization of residues by size; mutual arrangement on the area and in depth; determination of size characteristics.

The obtained results will be the basis for further engineering decisions regarding the development of machine designs, the selection of a technological scheme, and the determination of technological parameters, which will allow us to offer our vision of the construction of a plant residue shredder.

II. MATERIALS AND METHODS

The study of the issue of field clogging after harvesting corn and the direct development of the design of the cultivator-shredder of plant residues was carried out as part of the scientific work of the educational and scientific laboratory "DAK GPS" of the Higher Education Institution "Podilskyi State University" [19]-[23].

The first stage of the study is to determine the quantitative and qualitative characteristics of the field after harvesting the corn. Field research was conducted on the experimental fields of the University after harvesting corn for silage.

Analysis of the quantitative characteristics of the field after harvesting corn was carried out by direct counting and measurement of the remaining plant remains.

The field was divided into plots 2 m long and two rows wide (1.4 m). The scheme of dividing the field into diagonal sections was used (Fig. 1).

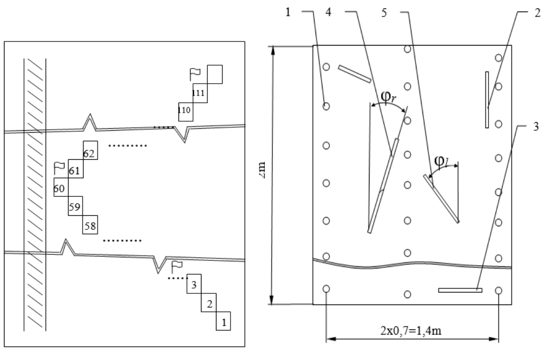


Fig. 1. Division of the field into measurement sites and placement of plant remains on the site: 62 - research sites; - a section of the field where corn was not cut; - sites on which research of rhizomes and above-ground parts was carried out; 1. basal lobes, 2 – longitudinal stems, 3 – transverse stems, 4 – stems deflected to the right, 5 stems deflected to the left, φ – deflection angl

On the site, the number of stems placed along the rows, across, at an angle to the left and right is counted; length of longitudinal (as well as deviated up to 40°) and transverse (50-80°) stems; diameter of plant residues on the site.

The planning of experiments and processing of the obtained results was carried out according to the existing methods of field and engineering experiments [10], [17].

The variability of the measurements of the object under investigation is determined by variation series and variation curves.

In order to construct a variation series or curve, the selected parameter is measured (at least 100 measurements) and the obtained measurements are divided into classes. For this it is necessary:

1. Find the smallest and largest measurement X_{max}, X_{min} ;

2. Find the number of intervals (classes) K:

a) you can use the formula

$$K = 3.2 \cdot \lg n , \quad (1)$$

where n is the number of measurements.

b) Divide into intervals, setting the step Δ

$$K = \frac{X_{max} - X_{min}}{\Delta} \quad (2)$$

3. The lower limit of the 1st class

$$X_1^{low} \le X_{min} \quad (3)$$

upper limit of the 1st class

$$X_1^{up} = X_1 + \Delta \quad (4)$$

Other classes are calculated in the same way.

4. Count the frequency m - the number of measurements in each class. It is evaluated in absolute numbers, as well as percentages.

5. Determine the middle of the intervals

$$X_{ic} = \frac{X_i^{н} + X_i^{в}}{2} \quad (5)$$

Based on the data of the variation series, variation curves are constructed, which are a graph, on the abscissa axis of which the measured values that correspond to the average value of the class boundary are plotted, and on the ordinate axis - the frequency (m or p, %) of measurements within each class.

Variational series and curves can be compared by the arithmetic mean value of M_c and the root mean square deviation σ (dispersion of measurements).

$$M_c = \frac{\sum m_i * x_{ic}}{\sum m_s}, \quad (6)$$

$$\sigma = \sqrt{\frac{\sum (M_c - X_{ci})^2 * m_i}{\sum m_i}}, \quad (7)$$

Size changes in most cases are subject to the law of normal distribution. It is known from the probability theory that with a normal distribution of dimensional characteristics, 99.7% of the amount of material is laid within the limits.

Processing experimental data according to this method, we obtain a number of variation curves, which are used to calculate the above parameters.

III. Results and Discussion

A. Analysis of the state of the field surface after harvesting coarse-stemmed crops

The obtained data are processed by grouping by quantitative indicators and the corresponding calculations, based on which variation series and variation curves are constructed as shown in Figure 2. In order to construct a variation series or curve, the selected parameter is measured (at least 100 measurements) and the obtained measurements are distributed by classes. Based on the data of variation series, variation curves are constructed, which are a graph, on the abscissa axis of which the measured values corresponding to the average value of the class boundary are plotted, and on the ordinate axis - the frequency (m or p, %) of measurements within each class.

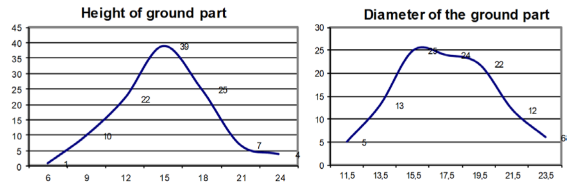


Fig. 2. Sample variation curves

Variational series and curves can be compared by the arithmetic mean value of M_c and the root mean square deviation (dispersion of measurements). As the results showed, size changes in most cases are subject to the law of normal distribution.

Having these data, it is possible to carry out a detailed analysis, the purpose of which is to form the main characteristics of the machine for solving the tasks. The following conclusions can be drawn based on the results of measurements carried out in separate areas for the study of basal remains:

- dispersion, or the root mean square deviation of all measurements is quite significant, that is, a fluctuation of the parameters (within $M_c \pm 3 * \sigma$) is not excluded;
- the arithmetic average deviation of the height of the rhizome and the range of heights indicate that for processing the root system, taking into account the degree of shredding, it is enough to deepen the working body by 8...9 cm;
- the main part of rhizome diameter measurements lies within 12.5...18.5 cm; therefore, the required width of row processing is at least 20 cm;
- the diameter of the ground part varies widely: the main part measures 15...20 cm and reaches a maximum of 24 cm. This must be taken into account when choosing the method of shredding and the working body;
- the average value of the height of the ground part (cut height) is 15.2 cm, which meets the agrotechnical requirements for harvesting corn.

Analysis of the quantitative characteristics of the field surface by measurements in the rows showed:

- After harvesting corn, there remains a fairly significant amount of plant remains on the field, and the values of various parameters vary within fairly wide limits.
- The analysis of the total amount of plant remains shows that only 16.2 % of the plots (with an area of 2.8 m^2) are clean, that is, they do not have plant remains in the rows. The average number of them is 3.2, although in some areas their number reaches 10 or more.
- Whole stems must also be taken into account when choosing a method of freeing the field from plant residues, as they make up about 25% of the total amount of plant residues in the rows;

- The analysis of the location of the plant remains indicates that most (47 %) of the stems are located longitudinally (±10˚), while transverse ones occupy only up to 25 %.

B. Development of the construction of a combined cultivator-shredder of plant residues

Taking into account the results of the study of the condition of the surface of the field, it can be concluded that one of the rational solutions to the problem of freeing the field from plant residues without increasing energy costs for continuous milling of the surface is the use of strip milling (Fig. 3).

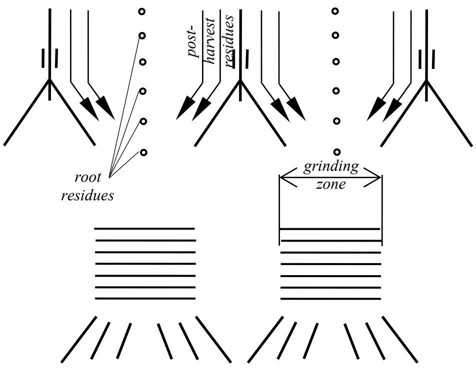


Fig. 3. Scheme of the work process

Therefore, the basis of the development is the task of qualitatively and economically preparing the field for sowing; ensure high-quality shredding and wrapping of plant remains of rough-stemmed crops with efficient use of energy spent on the drive of milling drums, and thereby achieve the possibility of increasing the width of the aggregate and its productivity; leave the field surface leveled and clean of plant remains.

The task is achieved by the fact that in the cultivator - shredder, which contains a frame - a beam, on which milling sections, hillers and flat disk knives are mounted, active working bodies are placed only in certain areas - in the shredding zones (along the sowing row). Shredding of residues along the entire front of the grip width is achieved with the help of hillers, which direct the stems and other plant residues left in the rows into the shredding zone. Flat disc knives are installed in order to prevent clogging of the hillers.

Due to the fact that shredding takes place only in the zone of the row, the energy for milling is used effectively (it is not used for soil cultivation in the rows). The leveling of the field surface is achieved by directing the soil with milling sections to different sides with the help of the guide ribs of the distribution board.

Cultivator - shredder of plant residues is shown in Fig. 4a – side view, during field cultivation after harvesting rough-stemmed crops; Fig. 4b - top view, location of working bodies.

Cultivator - shredder includes frame 2, on which milling sections 5, hillers 3 and flat disc knives are located.

Milling sections 5 include a chain transmission 4, a milling drum with L-shaped knives 6, a casing with a dividing shield 7. The shield 7 is made trapezoidal with guide ribs. Hillers 3 are spreading legs with guide wings, which are located in front of the milling sections in the rows. Flat disk knives 1 are placed along the axis of movement of the hillers. They rotate freely on the axles when rolling across the field.

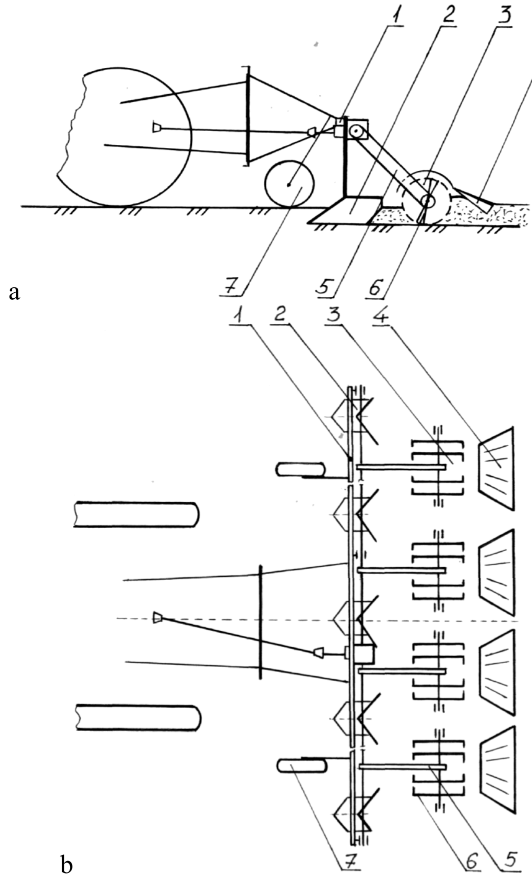


Fig. 4. Milling shredder of root and leaf-stem residues: a-side view; b-view from above.

The cultivator - shredder of plant residues works in this way. When moving the machine along the rows of the field after harvesting coarse-stemmed crops, the hillers 3 move between the rows, loosening the soil and transporting the stalks and other plant remains left after harvesting to the shredding zone (up to the row), where they are grind by the knives 6 of the milling sections 5 and mixed with soil. A flat disc knife 1, which cuts long stems, prevents the hillers from clogging with plant remains. Thanks to this, plant remains fall only on the side walls of the guide “wings” of the hillers, which are used to move freely. The milling drum works in the shredding zone. Soil and plant residues thrown by the knives hit the casing of the milling section and with the help of the guide ribs of the shield 7 are distributed along the front of the unit's movement, leveling the field surface.

This design was developed and tested at the higher education institution "Podilskyi State University", and its design and method of field preparation are protected by patents of Ukraine u200803382.

IV. CONCLUSIONS

1. The presence of a large amount of plant residues both in the row and between the rows greatly complicates soil cultivation and worsens the further use of the field, which requires operations to free the field from coarse harvest residues, in addition, taking into account the fibrous

structure of corn stalks, it can be concluded , that for shredding the post-harvest remains of corn, it is necessary to use working bodies that would cut (and not tear) the stalks, ensure a sufficient degree of shredding, good wrapping and mixing with the soil. Milling working bodies are best suited for this.

2. The arithmetic mean deviation of the root height and the range of heights indicate that for processing the root system, taking into account the degree of shredding, it is enough to deepen the working body by 8...9 cm, i.e., to such a depth, it is necessary to carry out processing with active working bodies in the rows.

3. The main part of rhizome diameter measurements lies within 12.5...18.5 cm; therefore, the required width of row processing is at least 20 cm.

4. The location of the vast majority of plant remains along the row indicates that it is best to use L-shaped knives that chop the stem across or at an angle to the longitudinal axis of the stem.

5. The design of the machine is proposed, which combines active (milling) working bodies (in the row zone) for effective shredding of plant residues and passive ones (paws equipped with hillers) designed to loosen the soil in the inter-row area and send the residues to the row zone for shredding. The use of cutters only in the shredding zone allows you to significantly increase the width of the grip, and therefore the productivity of the unit, while achieving the required quality of shredding.

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