

SUBSTANTIATION OF STRIP TILLAGE AFTER CORN HARVESTING BASED ON POST-HARVEST RESIDUE CHARACTERISTICS

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Abstract. Post-harvest corn fields are characterized by a high amount of coarse stemmed plant residues, which significantly complicate soil tillage and seedbed preparation. Due to the fibrous structure and high mechanical strength of corn residues, conventional strip tillage systems often fail to ensure their effective fragmentation, while full-width rotary tillage results in excessive energy consumption. The quantitative assessment was based on 110 sampling plots measuring 1.4 × 2.0 m, and the spatial non-uniformity of residue distribution was evaluated using the coefficient K_z calculated as the ratio of residue density in the crop row to that in the inter-row zone. This study aims to substantiate the application of strip tillage after corn harvesting through the analysis of quantitative and qualitative characteristics of plant residues and the development of a combined cultivator design. Field investigations were conducted to assess the spatial distribution, dimensional parameters and orientation of corn residues in the crop row zone and inter-row space. The coefficient of spatial non-uniformity of residue distribution was determined as 6.3, indicating a significantly higher concentration of plant residues in the crop row zone compared to the inter-row space. The results showed that the main mass of mechanically resistant residues is concentrated in the upper soil layer and predominantly oriented along the crop rows. Based on these findings, the optimal parameters of localized active tillage were substantiated, including a working strip width of 20–25 cm. The scientific novelty of the study lies in the consideration of the spatial variability of post-harvest corn residue distribution as a basis for substantiating the parameters of strip tillage. In contrast to existing approaches, the study provides a quantitative assessment of residue heterogeneity and justifies the localization of intensive tillage within the crop row zone, which enables a more rational distribution of energy consumption across the working width.

Keywords: strip tillage, corn residues, soil tillage, traction resistance, energy consumption, energy saving.

Introduction

After corn harvesting for grain, a significant amount of post-harvest plant residues remains on the field surface. These residues are characterized by high mechanical strength, large geometric dimensions, and a complex spatial structure. Their presence considerably complicates subsequent soil tillage, affects the energy consumption of technological operations, and reduces the efficiency of agricultural machinery use [1-3].

This problem becomes particularly relevant under conditions of intensive corn cultivation and its use in crop rotations with a high share or in monoculture, which leads to the accumulation of large volumes of plant residues [4-6]. In such conditions, post-harvest residues are characterized not only by their quantity but also by complex physical and mechanical properties, including rigidity, fibrous structure, and resistance to destruction. In monoculture systems, the accumulation of plant residues results in deterioration of soil tillage conditions and a decrease in the effectiveness of agrotechnical measures [5].

In modern agriculture, technologies of minimum and strip tillage (strip-till) are increasingly used to address this problem, as they allow combining residue preservation with localized soil treatment [7-9]. The application of these technologies contributes to reducing energy consumption and improving resource efficiency. At the same time, their effectiveness largely depends on the physical and mechanical properties of the plant residues and the nature of their distribution on the field surface.

A review of the literature shows that most studies focus either on the impact of plant residues on soil properties or on the design parameters of tillage machinery [7-12]. However, the issue of quantitative assessment of residue distribution non-uniformity and its consideration in substantiating soil tillage parameters remains insufficiently studied.

The present research was conducted on the basis of the educational and scientific laboratory “DAK GPS” of the higher educational institution Podillia State University [13-15]. Previous studies have shown [9] that in the cultivation of energy corn, an increased concentration of plant residues is observed in the crop row zone, forming local areas with different levels of residue accumulation. This indicates

the necessity of a differentiated approach to soil tillage. At the same time, the efficiency of strip-till largely depends on the characteristics of plant residues and their interaction with tillage tools. In previous studies, the authors substantiated approaches to the design of combined cultivators for soil tillage under conditions of contamination with coarse-stem crop residues [9]. However, these studies mainly focused on the structural aspects of technical means, while the heterogeneous nature of residue distribution has remained insufficiently investigated [16-18].

Despite the considerable number of studies in this field, the issue of substantiating strip tillage parameters based on the actual distribution of corn post-harvest residues across the field remains insufficiently explored. This is especially true for determining rational treatment zones (row vs inter-row) and their technological load. Considering the differences between these zones is essential, as they form different conditions for interaction between tillage tools and plant residues. Ignoring this heterogeneity leads to inefficient energy use and overloading of individual elements of tillage units.

The scientific novelty of this study lies in considering the spatial variability of post-harvest corn residue distribution as a basis for substantiating strip tillage parameters without linking them to specific technical designs. It was hypothesized that the pronounced spatial non-uniformity of corn residue distribution significantly affects tillage energy consumption and should be considered when determining the rational width of strip tillage. The aim of the study is to substantiate the feasibility of strip tillage after corn harvesting based on the quantitative and qualitative characteristics of plant residues and their spatial distribution.

Materials and methods

The research was carried out under field conditions after corn harvesting for grain. The object of the study was a field with a significant amount of post-harvest plant residues formed as a result of mechanized harvesting (Fig. 1a). The field experiments were conducted in the autumn 2024 at the experimental field of the higher educational institution Podillia State University in Kamianets-Podilskyi, Ukraine. The measurements were carried out 3-5 days after harvesting under post-harvest field conditions. At the time of data collection, the weather was dry, and the soil surface was in a dry state, which ensured stable conditions for identification and measurement of the characteristics of post-harvest residues.

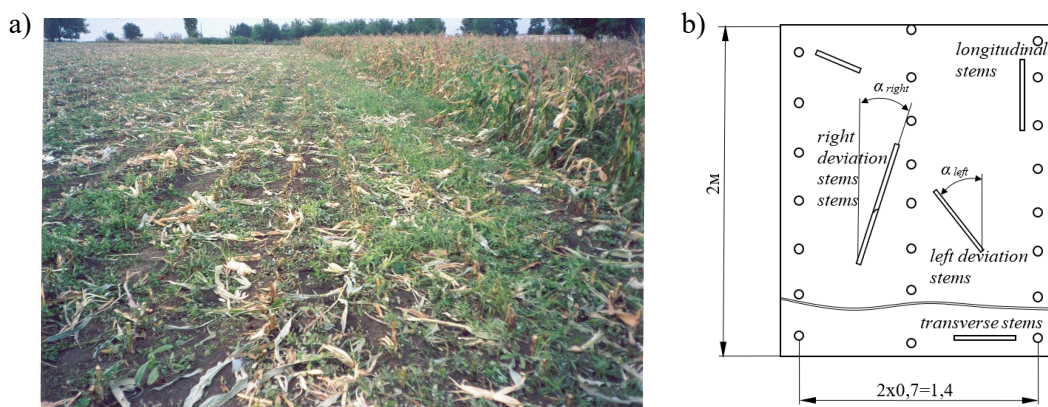


Fig. 1. **Field conditions after corn harvesting:** a – general view;
b – scheme of plant residue distribution within the sampling plot

The plant density of corn averaged about 70 thousand plants per hectare (≈ 7 plants/m²), with a row spacing of 0.7 m. After harvesting, root residues remained on the field surface, along with chopped and partially scattered stem fragments. Root residues were identified as the basal stem parts remaining fixed in the soil after harvesting and directly associated with the original plant standing position. These elements were distinguished from crushed and scattered stem fragments by their fixed vertical or slightly inclined position and direct attachment to the root crown zone.

The methodological approach was based on a combination of field measurements of quantitative indicators of plant residues and the analysis of their geometric and spatial characteristics, which is consistent with approaches used in previous studies [4; 5; 10].

To assess the quantitative and spatial characteristics of plant residues, 110 sampling plots of rectangular shape with dimensions of 1.4×2.0 m (area 2.8 m^2) were used. The plots were arranged along the diagonal of the field. The width of each plot covered two inter-rows and two crop rows, which made it possible to simultaneously account for residue distribution in different field zones (row and inter-row). The layout of the sampling plot is shown in Fig. 1b. Within each plot, the following zones were distinguished as crop row zone and inter-row zone. The number of plant residues was determined by direct counting of their units within sampling plots of a defined area. The accounting was carried out separately for each zone (row and inter-row), which made it possible to determine the residue density.

Residue density was calculated as:

$$N = \frac{n}{S}, \quad (1)$$

where N – number of plant residues per unit area, $\text{pcs} \cdot \text{m}^{-2}$;
 n – number of residues within the sampling plot, pcs;
 S – area of the sampling plot, m^2 .

For the crop row zone, the number of root residues was determined based on plant density. To evaluate the non-uniformity of plant residue distribution across the field, the ratio of their quantity in the row and inter-row zones was determined:

$$K_z = \frac{N_{\text{row}}}{N_{\text{interrow}}}, \quad (2)$$

where N_{row} – residue density in the crop row zone;
 N_{interrow} – residue density in the inter-row zone.

The orientation of plant residues was determined relative to the crop row direction. The following categories were distinguished: longitudinal; transverse; inclined at angles ($10\text{-}20^\circ$, $30\text{-}40^\circ$, $50\text{-}60^\circ$, $70\text{-}80^\circ$). The number of residues of each type was counted, followed by the determination of their proportion.

The arithmetic mean was determined as:

$$M = \frac{\sum x_i}{n},$$

where x_i – measured value;
 n – number of observations.

The standard deviation was calculated as:

$$\sigma = \sqrt{\frac{\sum (x_i - M)^2}{n}}.$$

The coefficient of variation was determined as:

$$CV = \frac{\sigma}{M} \cdot 100\%.$$

Results and discussion

Quantitative characteristics and spatial distribution of plant residues

As a result of the conducted field studies, it was established that after corn harvesting for grain, a significant amount of post-harvest plant residues remains on the field surface, characterized by pronounced spatial non-uniformity [1-3]. The main feature is their concentration in the crop row zone and a significantly lower amount in the inter-row space.

According to the methodology (Eq. 1), the density of plant residues in the row and inter-row zones was determined. The obtained results indicate a substantial difference between these zones.

The field measurements showed the following quantitative characteristics of residue distribution within the sampling plots (Table 1, Fig. 2a).

Table 1

Variation series of the total number of plant residues within sampling plots

Number of residues, x (pcs)	0-1	2-3	4-5	6-7	8-9	10-11
Number of plots, m	35	36	19	10	6	4

Data processing showed that the average number of residues per sampling plot is $M = 3.2$ pcs, with a standard deviation of $\sigma = 2.5$ pcs.

The coefficient of variation is:

$$CV = \frac{\sigma}{M} 100\% = \frac{2.5}{3.2} 100\% \approx 78\% . \quad (3)$$

The high value of the coefficient of variation ($\approx 78\%$) indicates a significant heterogeneity in the distribution of plant residues on the field surface.

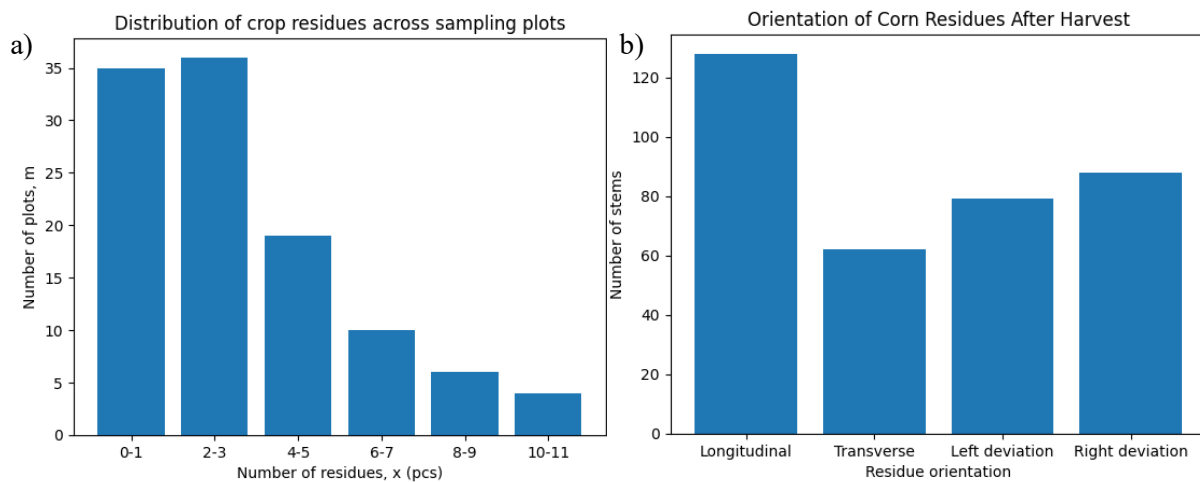


Fig. 2. **Experimental data processing results:** a – number of residues per sampling plot; b – orientation of corn stalk residues after harvesting

According to the statistical analysis, the average number of plant residues in the inter-row zone is 3.2 pcs per sampling plot. Considering that the area of the sampling plot is 2.8 m^2 , this corresponds to a density of $N_{interrow} = 1.14 \text{ pcs} \cdot \text{m}^{-2}$.

The number of root residues in the crop row zone was determined based on plant density. At an average density of 7 plants/ m^2 , the number of residues per sampling plot is about 20 pcs, corresponding to a density of $N_{row} = 7.14 \text{ pcs} \cdot \text{m}^{-2}$.

The obtained results are summarized in Table 2.

Table 2

Density of plant residues in different field zones

Field zone	Number, pcs	Area, m^2	Density, $\text{pcs} \cdot \text{m}^{-2}$
Row	20	2.8	7.14
Inter-row	3.2	2.8	1.14

Based on the obtained data, the coefficient of spatial non-uniformity of plant residue distribution was determined:

$$K_z = \frac{N_{row}}{N_{interrow}} = \frac{7.14}{1.147} = 6.3.$$

The obtained value of $K_z = 6.3$ indicates a significant non-uniformity of residue distribution, manifested in their high concentration within the crop row zone. This pattern is explained by the presence of root residues in this zone, which are practically not displaced during harvesting, whereas the inter-row space contains mainly partially chopped and scattered stem fragments. Such pronounced localization of residues may be considered typical for post-harvest corn fields with high plant density

and mechanical harvesting. Similar trends have been reported in previous studies [4; 5; 10], indicating that root residues concentrated at plant positions are the primary contributors to spatial heterogeneity of residue distribution. At the same time, unlike previous studies, this research provides a quantitative assessment of the degree of spatial heterogeneity, enabling a more substantiated selection of soil tillage parameters.

The obtained results also correlate well with literature data [1-3; 7-9], according to which post-harvest corn residues are characterized by pronounced spatial variability due to both biological features of plant formation and harvesting technology.

Orientation and structure of plant residues

As shown in Fig. 1, after corn harvesting, plant residues are represented by different morphological types, including root parts, longitudinally and transversely oriented stems, as well as elements inclined at various angles. Such diversity of orientation creates complex conditions for their mechanical fragmentation and incorporation into the soil [2; 5; 9; 11].

It was established that the spatial distribution of residues differs significantly depending on the field zone. In the crop row zone, root and vertically oriented elements dominate, whereas in the inter-row space, chopped and randomly distributed fragments prevail. This results in different interaction conditions between tillage tools, plant residues, and soil.

The results of the analysis of the heterogeneous distribution of plant residues in the inter-row space are presented in Table 3.

Table 3

Spatial orientation of plant residues in the inter-row space

Stem orientation type		Number, pcs	Share, %
Longitudinal		128	36.6
Inclined left	10-20°	18	5.1
	30-40°	32	9.1
	50-60°	18	5.1
	70-80°	11	3.1
Transverse		62	17.7
Inclined right	70-80°	16	4.6
	50-60°	19	5.4
	30-40°	37	10.6
	10-20°	16	4.6
Total		350	100

It was established that the largest share corresponds to longitudinally oriented stems (36.6%), while transversely arranged stems account for 17.7%. At the same time, a significant portion of plant residues is oriented at various angles, with a total share exceeding 45%. The visualization of the results is shown in Fig. 2b.

Such a distribution indicates a pronounced randomness of residue placement in the inter-row space and the formation of complex conditions for their interaction with tillage tools.

Based on the obtained results, it was established that the application of uniform technological operations across the entire working width of the aggregate is ineffective. The crop row zone is characterized by high residue density, the presence of root elements, and increased resistance to tillage, whereas the inter-row space contains mainly fragmented residues and requires less intensive treatment. This confirms the feasibility of a differentiated approach to soil tillage, particularly through strip-till technologies.

Influence of residue structure on energy consumption and traction resistance

The obtained results indicate that plant residues after corn harvesting are characterized not only by spatial variability but also by a complex orientation structure.

Such a combination of factors directly affects the energy consumption of soil tillage. It is known [6-8; 10] that the resistance to cutting and fragmentation of plant residues depends on their density, geometric characteristics, and orientation relative to the direction of tool movement.

In a first approximation, the specific energy consumption can be expressed as:

$$E = k N (1 + \lambda \sin \alpha), \quad (4)$$

where k – resistance coefficient;
 λ – coefficient of orientation influence;
 N – residue density, pcs·m⁻²;
 α – angle of stem inclination.

This relationship makes it possible to account not only for the quantity but also for the orientation of plant residues.

When stems are oriented longitudinally, the resistance to their processing is minimal, whereas in transverse or inclined positions (especially above 40-60°), the required force for their destruction increases significantly.

Since energy consumption is directly related to the work performed by tillage tools, this relationship also reflects changes in the traction resistance of the aggregate. With increasing residue density and orientation angle, resistance to their destruction increases, leading to higher traction force requirements [11; 12].

Thus, in the crop row zone, where a higher concentration of residues and root elements is observed, a greater traction resistance is expected, while in the inter-row space it is lower but more variable due to the random arrangement of residues.

Field zoning and substantiation of strip tillage parameters

Additional analysis of the spatial distribution of plant residues was carried out based on visual assessment of the field surface after harvesting (Fig. 1).

As shown in Fig. 1, plant residues are distributed unevenly, with their main mass localized in the crop row zone, while the inter-row space contains significantly fewer residues. The distribution in the inter-row space is chaotic, which confirms the results of the quantitative analysis.

Taking into account the established non-uniformity, a differentiated approach to soil tillage is advisable. To substantiate the width of the intensive tillage zone, the following relationship was used:

$$B = b_{row} + 2\Delta, \quad (5)$$

where B – width of the tillage strip, m;
 b_{row} – row width, m;
 Δ – width of the residue concentration zone on both sides of the row, m.

Under conditions of 0.70 m row spacing and experimentally determined concentration zone width, the rational strip width is 0.20-0.25 m.

The energy efficiency of strip tillage was evaluated through the relative treated area:

$$E_{strip} = E_{ful} \frac{B}{L}, \quad (6)$$

where E_{strip} – energy consumption for strip tillage;
 E_{ful} – energy consumption for full-width tillage;
 L – row spacing, m.

At $B = 0.25$ m and $L = 0.70$ m, the relative energy consumption is: $B/L = 0.25/0.70 \approx 0.36$, which corresponds to a reduction in energy consumption by approximately 60-65% compared to continuous cultivation.

Thus, taking into account the spatial zoning of the field allows increasing the efficiency of soil tillage through rational distribution of energy consumption and adaptation of technological parameters to actual field conditions.

The obtained results provide practical engineering recommendations for strip-till implement design. The active working tools should be concentrated within a 0.20-0.25 m treatment band corresponding to the residue accumulation zone, with partial overlap into adjacent areas of residue concentration, while passive tools can be used in the inter-row space where residue density is significantly lower. Such a

differentiated arrangement of working elements reduces unnecessary soil disturbance, decreases tractor draft requirement, and improves the overall energy efficiency of the tillage process. In addition, the increased residue concentration in the row zone necessitates the use of reinforced working bodies and optimized axle placement to reduce traction resistance.

Conclusions

1. It has been established that after corn harvesting, plant residues are distributed unevenly across the field surface, with 60-70% of their total amount concentrated in the crop row zone, while their share in the inter-row space does not exceed 10-15%.
2. The spatial heterogeneity of residue distribution was quantitatively characterized by the coefficient $K_z \approx 6.3$, indicating that the density of residues in the row zone exceeds that in the inter-row space by more than six times.
3. It was found that plant residues are characterized by a complex structure and diverse orientation, which complicates their fragmentation and incorporation into the soil, especially in the row zone where root residues are present.
4. It has been demonstrated that full-width tillage does not ensure a rational distribution of load across the working width of the machinery, resulting in excessive energy consumption.
5. The feasibility of applying strip tillage has been substantiated, where the intensive action of working bodies is localized within the row zone and the adjacent area.
6. The rational strip width of 0.20-0.25 m has been determined, which allows processing approximately 36% of the field area and ensures a 60-65% reduction in energy consumption compared to full-width tillage.

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