UDC 631.363.3:632.362.2
DOI: 10.37128/2520-6168-2025-3-12

INFLUENCE OF DISC OPENER PARAMETERS ON CUTTING EFFICIENCY OF CROP RESIDUES IN NO-TILL FARMING SYSTEMS

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The implementation of seeding technologies with minimum or zero tillage offers a wide range of economic and environmental advantages. Among the most significant benefits are the improvement of soil structure and fertility, reduction of erosion and degradation processes, preservation of soil moisture, and substantial savings in fuel consumption and labor. These advantages make no-till and minimum-till systems increasingly relevant for modern sustainable agriculture, particularly under conditions of climate change and soil exhaustion.

However, successful operation in no-till systems poses new engineering challenges, especially related to the performance of disc openers when cutting through dense crop residues. Residue cover remaining on the soil surface after harvest (e.g., wheat straw, maize stalks) creates resistance to the movement of sowing equipment, which can negatively affect seed placement accuracy, depth uniformity, and overall field emergence.

Theoretical studies have shown that the diameter of the disc opener influences key parameters such as the depth of soil penetration, thickness of residue layers to be cut, and the compression angle required for effective slicing. Larger discs can penetrate deeper, but they may also face increased rolling resistance and interact differently with moist or compacted residues.

Experimental research conducted in this study revealed that disc openers with a diameter of 380 mm–regardless of specific shape–demonstrated the best performance in cutting winter wheat straw under two moisture conditions:natural straw moisture (W = 10.1%)Field moisture (W = 22.3%)

It was observed that active disc rotation at increased forward speeds (characterized by a speed ratio $\lambda > 1.37$ and $\lambda = 1.58$) led to a higher degree of residue fragmentation, in contrast to passive rotation where the disc rolls freely in contact with the soil surface ($\lambda = 1.0$). This suggests that excessive forward speed can negatively affect residue handling by increasing mechanical disruption rather than clean cutting.

Furthermore, serrated disc openers were found to be more effective at cutting straw than smooth-edged discs, owing to their improved grip and cutting action. However, their performance was still strongly influenced by the moisture content of the straw, with drier residues being easier to cut cleanly, while higher moisture levels increased resistance and often led to clogging or smearing.

These findings underscore the importance of optimizing disc opener parameters–such as diameter, edge design, and operating speed–for effective operation in conservation tillage systems. The results can assist in improving the design of seeding machinery for no-till applications and in enhancing overall seeding performance under high-residue field conditions.

***Key words**: water level, mathematical modeling, hydraulic pressure tank, pump, transient response, stability, proportional-integral controller.*

Fig. 2. Ref. 17.

1. Problem formulation

One of the key challenges currently faced by farmers using No-till, Strip-till, or Mini-till technologies is maintaining the accurate seed placement depth with the openers of seeding machines [1]. This parameter is one of the most critical factors affecting crop yield.

Several factors must be considered when setting the correct seeding depth. The first factor is soil moisture and seed size. Larger seeds can generally be placed deeper because they contain more internal nutrient

Article received 24.10.2025. Article accepted 08.12.2025. Article published 25.12.2025.

reserves, which support seedling emergence even from greater depths, and require less external moisture compared to smaller seeds.

The second factor is the agronomic timing of seeding. When sowing occurs early in the season, a shallower depth is generally preferred, while later sowing may require deeper placement to ensure contact with sufficient soil moisture [2].

However, an additional and increasingly relevant problem in conservation tillage systems is the uneven distribution of crop residues–such as straw and plant stems–left on the soil surface after harvest. These residues can interfere with the performance of seed openers by creating physical resistance, making it difficult to consistently reach the target seeding depth across the field.

Thus, choosing the correct seeding depth is not the only challenge. Farmers must also overcome a range of multifactorial issues, with one of the most significant being the obstruction caused by crop residues, which act as a barrier to the penetration of disc openers.

Therefore, the optimization and justification of disc opener parameters is a highly relevant task when implementing seeding technologies under no-till conditions [4, 5].

2. Analysis of recent research and publications

Studies have shown that the number of cereal and other crop plantings, as well as cultivated lands, is rapidly increasing across Europe and Ukraine [1, 2, 3]. Compared to conventional tillage and seeding practices, No-till and minimum tillage technologies require less labor time and fuel consumption [6, 7, 8, 17].

Seeding efficiency in untilled soils is enhanced due to the structural stability of the soil, an increase in soil fauna, improved moisture retention, and reduced compaction (Linke, 1998) [10, 17]. Furthermore, soil resistance to wind and water erosion improves significantly (Chen et al., 2004; Van Oost et al., 2009) [11, 12]. Rainfall, wind, and the soil tillage method have the strongest impact on soil erosion (Tiessen et al., 2010) [14].

Researchers have noted that mechanized intensive tillage can lead to soil erosion levels 3 to 10 times higher than those observed under non-mechanized soil management systems [11]. According to scientific literature, average annual soil erosion in Ukraine affects approximately 10,000 hectares, with total erosion losses estimated at 300–400 to 500–600 million tons of soil per year.

Although minimum or zero-tillage systems, along with plant residues left on the soil surface, provide effective protection against soil erosion and degradation, they also complicate the seeding process. The quality of seed placement depends heavily on the amount, degree of shredding, length, and uniform distribution of crop residues across the field surface.

Authors such as Linke (1998) and Doan et al. (2005) [12, 17] studied the interaction between tillage speed and straw length in the soil, and concluded that longer straw residues are more difficult to incorporate into the soil compared to shorter ones, even at the same operating speeds.

In direct seeding equipment, disc openers typically have diameters ranging from 300 to 500 mm. However, research has been conducted on disc openers with diameters ranging from 360 to 762 mm to evaluate their interaction with crop residues and soil.

Kushwaha et al. (1986) [13] investigated the cutting of plant residues by smooth disc openers with diameters of 360, 460, and 600 mm under No-till soil conditions. Hemmat et al. (2008) [14] used a 762 mm disc opener to study mechanical resistance of the soil in both tilled and untilled areas. Fallahi and Raoufat (2008) [15] focused on the interaction between plant residues, soil, and a 470 mm disc opener. Karayel (2009) [16] used experimental disc openers of 400 and 450 mm to study corn and soybean seeding in no-till fields.

3. The purpose of the article

Considering that the sowing process without prior field surface preparation and incorporation of crop residues is random in nature, depending on the selected working depth for seed placement which is not the only issue a number of complex, multi-factorial challenges must also be addressed. One of the main factors is the presence of residues that hinder the penetration of coulters to the desired optimal depth. Therefore, establishing the patterns and justification of parameters for disk coulters becomes a highly relevant task when applying them in no-till farming systems.

4. Results and discussion

The cutting of winter wheat straw using active disk coulters was studied under field conditions at the “Starokotelnyanske” agricultural enterprise in the Zhytomyr district. The research was conducted under natural climatic conditions on loamy soils at depths of up to 35 mm. Soil moisture was 12.9±0.4%, and soil hardness was 0.5±0.01 MPa, measured using a WALCOM FM-204TR electronic penetrometer.

Both naturally and artificially moistened winter wheat straw were used for the study. The moisture content was (W = 10.1±0.2%), and the straw was collected from the soil surface immediately before the experimental trials. Some samples of naturally moistened straw were soaked in water for 24 hours. The wet straw was removed from the water one hour before testing and spread over the soil surface for natural drying. During the trials, the moisture content of the winter wheat straw was W = 22.3±0.5%.

Four types of disk coulters with different cutting edge shapes were used in the study. Experimental results showed that four disk coulters with a diameter of 380 mm had the following parameters:

- Smooth edge: number of notches n = 0, notch radius r = 0, notch depth Δr = 0 mm;
- Serrated (12 teeth): n = 12, r = 15 mm, Δr = 15 mm;
- Serrated (18 teeth, deep): n = 18, r = 10 mm, Δr = 20 mm;
- Serrated (18 teeth, shallow): n = 18, r = 10 mm, Δr = 10 mm.

The selection of these parameters allows a comparison of straw cutting results with those of passive single- and double-disk coulters obtained in previous research.

The coulters were sequentially mounted on a seeder based on a research device with an active drive via chain transmission, receiving rotational motion from a ground-driven support wheel (diameter 680 mm). Slippage of the wheel on the soil surface had negligible effect on the rotation speed of the disk coulters. Sprockets with varying tooth counts were used to change the transmission ratio and, accordingly, the speed coefficient λ of the disk coulter.

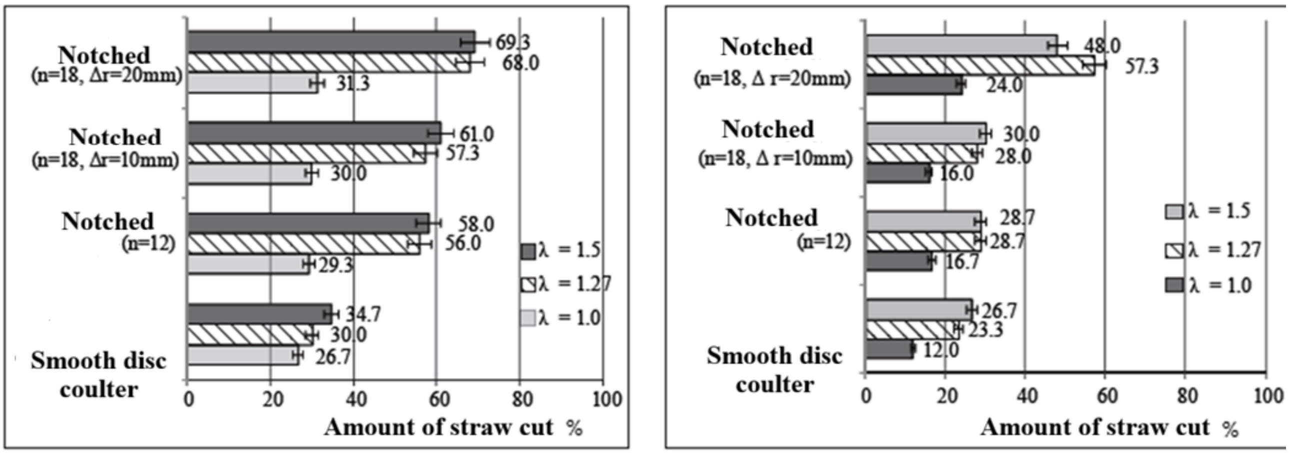
The average lengths of distributed straw for winter wheat and spring barley were 330±10 mm and 353±10 mm, respectively. The straw was laid out in five separate rows, each 0.5 m long, with 100 stalks per row. The average forward speed of the equipment with disk coulters was 7 km/h, and the movement of the coulters was perpendicular to the straw placement. The disk coulter penetration depth into the soil was 35 mm, as this is the typical sowing depth for major cereal crops.

The process of cutting both naturally moistened and artificially moistened straw of both plant types was carried out five times. Similar tests were conducted using different disks and different speed coefficients (λ = 1.0, λ = 1.37, and λ = 1.58). After the active disk coulters passed over the distributed straw (both cut and uncut), the effectiveness of straw cutting was assessed. The active coulters with varying numbers of teeth on the cutting edge were evaluated based on the number of cut straw stalks.

The best straw cutting results using this methodology were achieved with an active single-disk serrated coulter (18 teeth, Δr = 20 mm). The next experimental focus was on the influence of the speed coefficient of the active single-disk serrated coulter (λ) on cutting efficiency. The tested values of the speed coefficient λ were: 1.0, 1.1, 1.27, 1.37, 1.42, 1.5, and 1.58. The seed placement depth for the disk coulter was set at 35 mm.

Research on cutting winter wheat straw using disc coulters has shown that all passive disc coulters, at a movement speed coefficient (λ = 1.0), reduce the natural moisture content of winter wheat straw (W = 10.1%) by approximately 30% (Fig. 1a). No significant differences were observed between disc coulters of different diameters. The amount of straw cut by toothed active disc coulters (transmission numbers λ > 1.37 and λ = 1.58) increases by 26.7% to 38.0% compared to cutting by passive disc coulters. The highest amount of natural moisture is retained by winter wheat straw (69.3 ± 7.6%) cut by an active disc coulter with 18 notches (Δr = 20 mm).

The difference between this disc coulter and others used in the study was quite significant. Experimental research on cutting winter wheat straw with moisture content (W = 22.3 ± 0.5%) established that an active disc coulter with 18 teeth (Δr = 20 mm) is optimal for cutting artificially moistened straw. For the active notched disc, the coulter speed coefficient is λ = 1.27, and the discs cut 57.3% of the wet winter wheat straw (Fig. 1b). The other three active smooth and toothed disc coulters cut a smaller amount of winter wheat straw. The amount of wet straw cut by passive disc coulters at a speed coefficient (λ = 1.0), regardless of the number of notches on the cutting edge, is 12–24% lower than that cut by toothed active disc coulters. The smooth disc coulter cuts up to 12% more straw, and the difference between smooth and toothed disc coulters is significant.

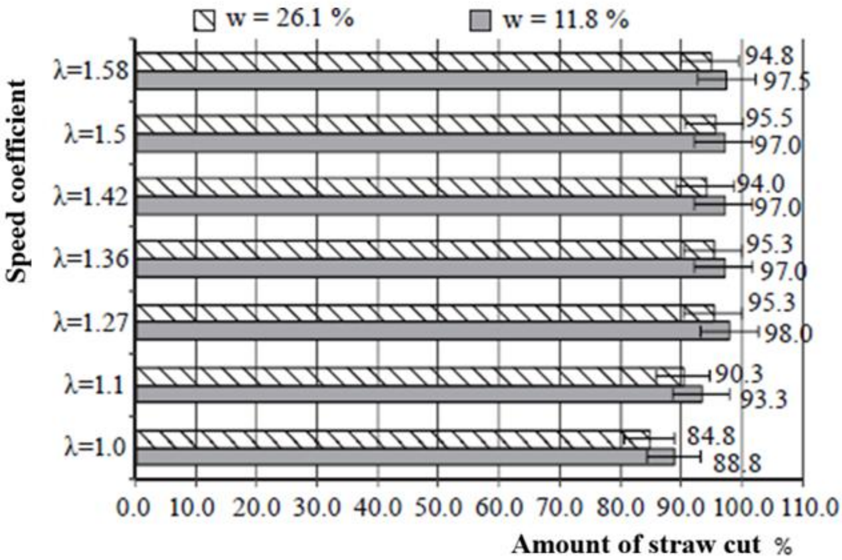


$P_{0,05}$ (λ=1,0)=4,6%; $P_{0.05}$ (λ=1,27)=6,1 %; $P_{0,.05}$ (λ=1.5)=7.5% $P_{0,05}$(λ=1,0)=3,9 %; $P_{0.05}$ (λ=1,27)=7,8%; P0,05(λ=1,5)=8,2 %

Fig. 1. Influence of the shape of the single-disc coulter, the speed coefficient λ, and straw moisture on cutting winter wheat straw:

a) natural moisture content of straw (W = 10.1%); b) wet straw (W = 22.3%)

The passive disc coulter with a transmission ratio of λ = 1.0 cuts the smallest amount of residue (84.8–88.8%) at both natural moisture (W_1 = 11.8%) and wet moisture (W_2 = 26.1%) of winter wheat straw (Fig. 2). The active disc coulter cuts straw with both natural and wet moisture more effectively at speed coefficients of λ = 1.37 and λ = 1.57, respectively. It has been established that changing the rotational speed coefficient of the disc coulter from λ = 1.1 to λ = 1.58 does not significantly affect the cutting of winter wheat straw at natural or wet moisture levels.



$P_{0,05}$ (W_1) = 3,1 %; P0,05 (W_2) = 3,9 %; $P_{0,05}$ (W_1,W_2) = 3,4 %

Fig. 2. Influence of Single-Disc Coulter Parameters (18 teeth, Δr = 20 mm) and speed coefficient λ on cutting winter wheat straw with natural moisture (W_1 = 11.8%) and wet moisture (W_2 = 26.1%)

During further experimental research, a notable increase in the amount of winter wheat straw cut was observed, which was attributed to natural experimental conditions. Specifically, the resistance to coulter penetration into the soil in these trials was roughly twice as high (1.0 ± 0.02 MPa at a depth of 35 mm) compared to earlier studies. According to researchers (Linke, 1998) [17], there is a clear relationship between soil hardness and the resistance encountered when cutting straw, highlighting the need for additional investigations. It was determined that as soil hardness increases, the effectiveness of cutting plant residues also improves. Observations showed that when the disc coulter penetrates the soil up to 35 mm deep, some straw particles remain uncut. To enhance the amount of cut plant residues, it is recommended to increase the penetration depth of the disc coulter by 20–25%.

Previous experiments conducted in the Zhytomyr region at the farm STOV "Starokotelnianeske" revealed that increasing the disc penetration depth from 20 to 35 mm improves the cutting efficiency of winter wheat straw by 7–18%. Additionally, it was found that passive smooth disc coulters with a diameter of 460 mm moving at 6.4 km/h are capable of cutting 100% of plant residues (2000 kg/ha) when penetrating the soil to a depth of up to 50 mm.

5. Conclusion

When the toothed disc coulter is forcibly rotated (with speed coefficients $\lambda > 1.37$ and $\lambda = 1.58$) in untreated soil (moisture content 12.9 ± 0.4%, hardness 0.5 MPa, and penetration depth up to 35 mm), it cuts between 56.0% and 69.3% of winter wheat straw at natural moisture (W = 10.1%). This is substantially higher than the cutting efficiency observed when the toothed disc coulter moves freely at $\lambda = 1.0$. In the case of forced rotation, the smooth disc coulter also cuts a significantly greater amount of straw compared to its free movement. However, this improvement is less pronounced for toothed disc coulters. Across all scenarios, dry straw is more effectively cut than wet straw. Adjusting the speed coefficient of toothed disc coulters (with n = 18 teeth, Δr = 20 mm) from $\lambda = 1.1$ to $\lambda = 1.58$ does not have a significant impact on cutting performance in untreated soil with varying moisture levels, where soil hardness measures around 1.0 ± 0.02 MPa at 35 mm depth. Nevertheless, when the disc coulter ($\lambda = 1.0$) moves freely, the quantity of cut straw is markedly lower compared to when forced rotation is applied.

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ВПЛИВ ПАРАМЕТРІВ ДИСКОВИХ СОШНИКІВ НА ЗДАТНІСТЬ ПРОРІЗАННЯ РОСЛИННИХ РЕШТОК У СИСТЕМІ NO-TILL

Впровадження технології безобробітного посіву має низку економічних та екологічних переваг, таких як покращення властивостей ґрунту, зменшення ерозії та деградації ґрунту, а також підвищення ефективності використання часу та палива. Однак основним недоліком цих технологій є те, що рослинні рештки на поверхні ґрунту знижують здатність до рівномірного проростання насіння сільськогосподарських культур, що вимагає впровадження додаткового процесу збору або зрізання рослинних решток.

Теоретичні дослідження обґрунтовують залежність діаметра однодискового сошника від робочої глибини проникнення диска, глибини шару рослинних решток та кута стиску. Використовуються активні та пасивні сошники, які зрізають солому ковзанням по робочій поверхні поля.

Експериментальні дослідження встановили, що найкраще зрізаються солома природної вологості (W = 10,1%) та волога солома озимої пшениці (W = 22,3%) за допомогою чотирьох різних форм дискових сошників діаметром 380 мм (гладкі без зубців n=0, глибина канавки Δr=0 мм; зубчасті n=12, Δr=15 мм; зубчасті n=18, Δr=10 мм; зубчасті n=18, Δr=20 мм). Експериментальні дослідження підтвердили обмеження обертання активного дискового сошника на високих швидкостях (коефіцієнт швидкості λ>1,37 та λ=1,58), що призводить до більшої кількості зрізаної соломи порівняно з випадком використання дискового сошника з пасивним обертанням у контакті з ґрунтом (λ=1,0). Зубчасті дискові сошники ефективніше зрізають солому та рослинні рештки, ніж гладкі диски. Дослідження підтверджують залежність здатності зрізання соломи від вологості матеріалу, причому кількість зрізаної соломи зменшується зі збільшенням вологості матеріалу.

Примусове обертання зубчастого дискового сошника (коефіцієнт швидкості λ>1,37 та λ=1,58) у необробленому ґрунті (вологість 12,9±0,4%, твердість 0,5 МПа, глибина проникнення диска до 35 мм) забезпечує 56,0 – 69,3% зрізання соломи озимої пшениці природної вологості (W=10,1%), що суттєво перевищує показники, отримані під час вільного руху зубчастого дискового сошника при λ=1,0.

Ключові слова: *дисковий сошник, коефіцієнт швидкості, рослинні рештки, нульовий обробіток, розподіл соломи, зубчасті диски.*

Рис. 5. Літ. 18.

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