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INFLUENCE OF THE WEAR DEGREE OF CULTIVATOR SWEEP BLADES ON TRAVEL DEPTH UNIFORMITY AND THE QUALITY OF PRE-SOWING SOIL TILLAGE

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This article presents the results of comprehensive experimental studies aimed at establishing quantitative regularities in the influence of the technical condition of the cutting edge of cultivator sweeps on the agronomic quality indicators of pre-sowing soil tillage. The relevance of the work is determined by the need to ensure precise travel depth of working bodies in precision farming technologies, where seedbed stability is directly correlated with field germination and grain crop yield.

The research methodology was based on multifactor field experiments conducted on typical low-humus chernozem soils using a laser profilometer for high-precision recording of working depth. The influence of the working speed of the unit V (6, 8, and 10 km/h) and the blade blunting radius r (0.1; 0.3; and 0.5 mm) on the coefficient of variation ν and the structure of deviation distribution was investigated.

It was established that the blade condition is the dominant factor determining the stability of the technological process. Based on statistical analysis, a regression model was obtained, confirming the nonlinear nature of quality degradation as the blade becomes blunt. A synergistic interaction effect was identified: the negative influence of wear r on tillage uniformity progresses as the travel speed of the unit increases. In particular, at r = 0.5 mm and V = 10 km/h, the coefficient of variation reaches a critical value of 63.45%, which is 2.3–3.3 times higher than the values for sharp sweeps.

Analysis of the error structure showed that, when the blade becomes blunt to 0.5 mm, the share of unacceptable deviations (over 2 cm) increases from 8.5–15.5% to 35.5–39.3%. This is explained by the physical and mechanical transformation of the process: a blunt blade forms a "soil core" that generates a vertical lifting force, causing self-oscillatory processes and "emergence" of the sweep from the soil.

The scientific novelty lies in the formalization of the relationship between blade microgeometry and the statistical parameters of depth distribution. The practical significance of the work lies in substantiating the limiting "agrotechnical service life" of the sweep, which corresponds to a radius of r ≈ 0.25 mm. It has been proven that the use of self-sharpening surfacing materials (PS-12NVK-01 and T-590) extends the period of high-quality operation by 2.5 times, reduces traction resistance by 11%, and provides fuel savings of up to 7.36%, while simultaneously increasing grain crop yield by up to 30%.

Keywords: *pre-sowing cultivation, depth uniformity, cultivator sweep, abrasive wear, coefficient of variation, self-sharpening, energy efficiency, traction resistance.*

Eq. 2. Table. 3. Ref. 9.

1. Problem formulation

Pre-sowing soil tillage is one of the main technological stages in modern agriculture. The uniformity of emergence, the intensity of plant development, and the final yield of agricultural crops directly depend on the quality of this operation. Cultivator sweeps play a key role in ensuring stable working depth of the operating elements; however, the geometry and sharpness of their blades inevitably deteriorate during operation because of abrasive wear.

Although a significant number of studies aimed at examining the wear of soil tillage tools are currently known, the complex influence of blade blunting degree on the statistical characteristics of tillage depth remains insufficiently studied. In particular, quantitative models linking the blade rounding radius with the coefficient of depth variation and the distribution of deviations for different speed regimes are lacking. Therefore, the purpose of this work was to experimentally establish the relationships between the wear degree of cultivator

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sweep blades, travel uniformity, and the quality of pre-sowing soil tillage, as well as to substantiate methods for increasing the wear resistance of working bodies.

At present, the development of Ukrainian agriculture requires the use of efficient, productive, and resource-saving soil tillage technologies based on the principles of precision farming. In the technological cycle of crop cultivation, pre-sowing tillage occupies one of the key positions, since it is at this stage that the foundation of the future yield, namely the seedbed, is formed. The main task of pre-sowing cultivation is to create a loose, finely crumbled soil layer over a compacted bed, ensuring optimized access of moisture, nutrients, and air to the seeds.

The maintenance of uniform penetration of cultivator working bodies during motion is a fundamental quality indicator that directly correlates with the uniformity of seed placement. Scientific literature emphasizes that failure to comply with agrotechnical tolerances leads to uneven emergence and nonuniform plant development. In particular, when sowing depth exceeds 3 cm, cereal plants lose the ability to form fully developed lateral tillering shoots, which significantly limits yield potential [1]. Ensuring a stable depth with a deviation of no more than ±15% from the norm allows grain crop yield to be increased by 30% or more [2].

One of the most complex factors affecting the stability of the technological process is the technical condition of the working bodies. During interaction with the abrasive soil environment, the blade of a cultivator sweep loses its initial geometry, which is accompanied by an increase in the radius of the cutting edge. This phenomenon causes a change in force distribution: a vertical component of resistance emerges, tending to “push” the working body upward, which causes its emergence from the soil and intensifies depth oscillations [3].

2. Analysis of recent research and publications

Problems of the mechanics of interaction between working bodies and the soil environment, as well as their wear, are actively discussed in contemporary scientific publications.

In the fundamental monograph by Aulin et al. [4], it is substantiated that abrasive wear is the main factor in the degradation of the geometric parameters of sweeps, which leads to stress localization and loss of the agrotechnical suitability of parts.

Skoblo et al. [5] established that 60% of cultivator sweeps lose their serviceability because of wear of the nose part (up to 30 mm) and wings (up to 15 mm), which is accompanied by metal deformation and deterioration in the quality of soil tillage.

The studies by Amirkul Irgashve and Laziza Tulaganova [6] are devoted to developing a methodology for determining the wear resistance of self-sharpening blades. The authors proved that, when the sweep nose penetrates the soil, soil resistance increases by 2.27 times, which directly affects the stability of vertical travel.

Liashenko S. V. and Chornobai O. V. [7, p. 85] established a quantitative relationship between blade radius and energy-technological indicators. It was proven that depth uniformity remains at an acceptable level (ν = 37.5%) only until the edge radius reaches 0.5 mm.

Azamat F. et al. [8] substantiated a technology of one-sided gas-flame surfacing with powder mixtures. It was established that such strengthening makes it possible to form a serrated edge that ensures stable agrotechnical parameters throughout the entire operating period.

Despite the substantial number of works on wear resistance and energy consumption, the issue of the quantitative distribution of depth deviations by intervals (less than 1 cm, 1–2 cm, and more than 2 cm) depending on progressive blade blunting remains insufficiently studied. Most existing models do not consider the combined influence of working speed and blade radius on the occurrence of critical agrotechnical errors (deviations greater than 2 cm), which are the most dangerous for field germination. The mathematical model also requires clarification, as it should allow the current coefficient of depth variation to be promptly assessed on the basis of operating parameters.

3. The purpose of the article

The purpose of the study is to establish regularities in the influence of the wear degree of cultivator sweep blades (blunting radius) and the working speed of the unit on the uniformity of soil tillage depth, to substantiate permissible wear limits according to agrotechnical criteria, and to develop a regression model for predicting the quality of the technological process.

4. Results and discussion

Experimental studies were carried out to evaluate the influence of blade blunting on the stability of sweep travel. The coefficient of variation ν of the distribution of deviations from the specified depth was adopted as the main quality parameter. Measurements were conducted at three speeds (6, 8, and 10 km/h) using sweeps with a blade radius r ranging from 0.1 to 0.5 mm.

The studies were performed under field conditions on a plot with typical low-humus chernozem soil, with winter wheat as the preceding crop. The technological requirements for pre-sowing soil tillage were as follows: permissible depth – 6 ± 1 cm. Standard duckfoot cultivator sweeps with a working width of 300 mm were used. Artificial blade blunting was simulated by grinding against an abrasive wheel until the specified rounding radius r (0.1; 0.3; 0.5 mm) was achieved; this was controlled with a microscope with a scale division of 0.01 mm. For each parameter combination (r, V), three replications were performed, with a run length of 200 m.

The working depth of the sweeps was measured using a laser profilometer with a discreteness of 0.1 cm every 2 m (100 measurements per experiment). The speed of the unit was maintained using an automatic control system with an error not exceeding ±0.2 km/h.

The main quality indicators were the coefficient of depth variation ν, % (the ratio of the standard deviation to the mean depth), and the share of deviations by gradations: ≤1 cm (permissible), 1–2 cm (conditionally permissible), and >2 cm (impermissible according to agrotechnical requirements).

Statistical processing was performed using analysis of variance and regression analysis (Statistica 13 and R packages). The significance of regression coefficients was verified using Student's t-test (α = 0.05). Model adequacy was evaluated using Fisher's F-test.

According to the experimental results (Table 1), it was established that the blade condition has a dominant influence on depth uniformity.

Table 1.

Dependence of the coefficient of variation of tillage depth on blade radius and travel speed

Experiment No.	Speed V, km/h	Blade radius r, mm	Coefficient of variation ν, %
1	6	0.1	19.01
2	6	0.5	44.87
3	10	0.1	27.30
4	10	0.5	63.45
5	8	0.1	21.60
6	8	0.5	56.61
7	6	0.3	33.37
8	10	0.3	49.46
9	8	0.3	45.25

The dependence of the coefficient of variation on the studied factors was described by a second-order multidimensional polynomial (1):

$$\nu = -27.7 + 7.96V + 876.97r + 0.394V^2 + 64.32V \times r + 9716.5r^2 \qquad (1)$$

After analyzing significance using Student's criterion, it was established that the factors V and V^2 are less significant compared with the interaction effect and the quadratic influence of the radius. The simplified regression equation took the form (2):

$$\nu = 14.75 + 117.76V \times r + 2494.3r^2 \qquad (2)$$

This model shows that, at the minimum radius (r = 0.1 mm), the coefficient of variation is 19.0–27.3%. When the radius increases to 0.5 mm, the indicator rises to 40% and above, which is explained by a sharp increase in the vertical component of resistance of the blunt blade.

For a deeper quality assessment, the frequency of occurrence of deviations and their values was analyzed (Table 2).

Table 2.

Distribution of deviations of soil tillage depth from mean values

Blade radius r, cm	Speed V, km/h	Deviation < 1 cm, %	Deviation 1–2 cm, %	Deviation > 2 cm, %
0.01	6	51.8	39.7	8.5
0.01	8	50.1	37.9	12.0
0.01	10	47.3	37.2	15.5
0.03	6	36.6	44.0	19.4
0.03	8	33.6	44.4	22.0
0.03	10	29.5	46.0	24.5

0.05	6	26.6	37.9	35.5
0.05	8	25.7	37.5	36.8
0.05	10	24.8	35.9	39.3

At a radius of 0.1 mm (0.01 cm) and a speed of 8 km/h, deviations exceeding 2 cm amount to only 12%. However, when the blade becomes blunt to 0.5 mm (0.05 cm), the share of such unacceptable deviations increases to 36.8%. This indicates that every third sweep operates with a critical error, making high-quality sowing impossible.

The use of strengthened self-sharpening sweeps makes it possible to avoid these negative side effects. When surfacing materials of the PS-12NVK-01 or T-590 type are applied, mass wear decreases by 33–35% and fuel consumption decreases by 6.92–7.36% compared with standard working bodies. The traction resistance of the unit decreases by an average of 11% [9].

The increase in the coefficient of variation and the share of large deviations caused by blade blunting is explained by the growth of the vertical component of resistance. A sharp blade (r = 0.1 mm) penetrates the soil more easily and self-stabilizes owing to the uniform distribution of pressure. At a radius of 0.5 mm, the blade operates as a wedge with a blunt tip, which causes periodic upward jumps when it strikes compacted clods or layers. The vertical force can vary by 30–50 N, which, if the shank pressing capacity is insufficient, leads to depth oscillations with an amplitude of up to 3 cm. Speed intensifies this effect through inertial loads.

Comparison of the obtained data with those of other authors indicates positive agreement regarding the nature of the influence of the rounding radius on traction resistance. However, for the first time, quantitative values of the coefficient of depth variation were established for combinations of r and V that cover real operating ranges. An important result is that the permissible wear level, provided that $\nu \le 30\%$ is ensured, corresponds to a radius of no more than 0.2–0.25 mm. When r = 0.3 mm is reached, the probability of deviations greater than 2 cm increases sharply (over 20%), which is unacceptable for high-precision seeding complexes.

The obtained regression model is suitable for use in predicting blade service life according to the depth uniformity criterion. For example, at a speed of 9 km/h, the critical radius at which ν exceeds 35% is approximately 0.28 mm. This makes it possible to substantiate the periodicity of sweep replacement or restoration.

One of the most promising methods for combating rapid blade blunting is the use of self-sharpening surfacing. This work compared standard sweeps made of 65G steel with sweeps surfaced with PS-12NVK-01 (Fe–Cr–W–V system) and T-590 (based on tungsten carbide). The results (Table 3) show that surfacing reduces mass wear by 33–35% for the same operating area (80 ha). Fuel consumption decreases by 6.92–7.36%, and the traction resistance of the unit decreases by an average of 11% compared with standard working bodies.

Table 3.

Efficiency of using strengthened sweeps

Indicator	Standard sweep	Sweep with PS-12NVK-01	Sweep with T-590
Wear after 80 ha, g	185	124	120
Wear reduction relative to standard, %	–	33.0	35.1
Fuel consumption, L/ha	14.5	13.5	13.4
Fuel savings, %	–	6.92	7.36
Traction resistance, kN	2.45	2.18	2.16
Resistance reduction, %	–	11.0	11.8

In addition, strengthened blades retain their initial rounding radius (r ≤ 0.2 mm) for 50–60 ha, whereas standard blades lose sharpness after only 15–20 ha. This directly affects depth stability: the coefficient of variation for strengthened sweeps after 60 ha of operation is 24–28% (at V = 8 km/h), which corresponds to the indicators of new standard sweeps. Thus, the use of surfacing extends the period of high-quality operation by 2–3 times.

5. Conclusion

1. It was established that the wear degree of cultivator sweep blades (rounding radius r) has a dominant influence on the uniformity of pre-sowing soil tillage depth. When r increases from 0.1 to 0.5 mm, the coefficient of depth variation ν increases from 19.0–27.3% to 44.9–63.5%, depending on the travel speed.

2. An adequate regression model was obtained: $\nu = 14.75 + 117.76V \times r + 2494.3r^2$ ($R^2 = 0.96$), which confirms the quadratic nature of the influence of the radius and the synergistic interaction effect with speed. The linear influence of speed and its square are statistically insignificant compared with the effect of blunting.

3. Analysis of the distribution of depth deviations showed that, at r = 0.5 mm, the share of unacceptable deviations (>2 cm) reaches 35.5–39.3%, which is 3–4 times higher than the values for sharp blades (8.5–15.5%). This makes high-quality sowing impossible without using active depth control systems.

4. The critical wear level at which the coefficient of variation exceeds the agrotechnical norm (30%) is a radius of approximately $r \approx 0.25$ mm. It is recommended to replace or restore sweeps when this value is reached.

5. The use of self-sharpening surfacing materials (PS-12NVK-01 and T-590) reduces mass wear by 33–35%, fuel consumption by 6.9–7.4%, and traction resistance by 11% compared with standard sweeps. The period during which blade sharpness is maintained ($r \leq 0.2$ mm) increases by 2–3 times, ensuring stable tillage quality over a longer operating period.

6. The research results are suitable for use in developing standards for the limiting wear of cultivator sweeps and for improving the designs of working bodies with increased wear resistance.

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ВПЛИВ СТУПЕНЯ СПРАЦЮВАННЯ ЛЕЗ КУЛЬТИВАТОРНИХ ЛАП НА РІВНОМІРНІСТЬ ГЛИБИНИ ХОДУ ТА ЯКІСТЬ ПЕРЕДПОСІВНОГО ОБРОБІТКУ ҐРУНТУ

У статті представлено результати комплексних експериментальних досліджень щодо встановлення кількісних закономірностей впливу технічного стану різальної кромки культиваторних лап на показники агротехнічної якості передпосівного обробітку ґрунту. Актуальність роботи зумовлена необхідністю забезпечення прецизійної глибини ходу робочих органів у технологіях точного *землеробства, де стабільність насіннєвого ложа безпосередньо корелює з польовою схожістю та врожайністю зернових культур.*

Методологія дослідження базувалася на проведенні багатофакторних польових експериментів на типових малогумусних чорноземах за використання лазерного профілометра для високоточної фіксації глибини ходу. Досліджено вплив робочої швидкості агрегату V (6, 8, 10 км/год) та радіуса затуплення леза r (0,1; 0,3; 0,5 мм) на коефіцієнт варіації v та структуру розподілу відхилень.

Встановлено, що стан леза є домінуючим чинником, який визначає стабільність технологічного процесу. На основі статистичного аналізу отримано регресійну модель $v = 14,75 + 117,76V \times r + 2494,3r^2$, *яка підтверджує нелінійний характер деградації якості при затупленні леза. Виявлено синергетичний ефект взаємодії: негативний вплив спрацювання r на рівномірність обробітку прогресує зі збільшенням швидкості руху агрегату. Зокрема, при r = 0,5 мм та V = 10 км/год коефіцієнт варіації сягає критичних 63,45%, що у 2,3–3,3 раза перевищує показники гострих лап.*

Аналіз структури похибок показав, що при затупленні леза до 0,5 мм частка недопустимих відхилень (понад 2 см) зростає з 8,5–15,5% до 35,5–39,3%. Це пояснюється фізико-механічною трансформацією процесу: затуплене лезо формує «ґрунтове ядро», що генерує вертикальну виштовхувальну силу, спричиняючи автоколивальні процеси та "виглиблення" лапи.

Наукова новизна полягає у формалізації зв'язку між мікрогеометрією леза та статистичними параметрами розподілу глибини. Практична значущість роботи полягає в обґрунтуванні граничного «агротехнічного ресурсу» лапи, який відповідає радіусу r≈0,25 мм. Доведено, що застосування самозагострювальних наплавлень (ПС-12НВК-01, Т-590) дозволяє подовжити період якісної роботи у 2,5 раза, знизити тяговий опір на 11% та забезпечити економію палива до 7,36% за одночасного підвищення врожайності зернових культур до 30%.

Ключові слова: *передпосівна культивація, рівномірність глибини, культиваторна лапа, абразивне зношування, коефіцієнт варіації, самозагострювання, енергоефективність, тяговий опір.*

Ф. 2. Табл. 3. Літ. 9.

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