A Symmetrical Diamond-Shaped Blade Surface for the Working Body of the Plough for Smooth Plowing

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ABSTRACT

The present study focuses on the improvement of plough design to ensure smooth ploughing with minimum energy consumption. Mathematical energy consumption models are obtained through mechanical methods regarding the reservoir turnover process by various dump surfaces. The results indicate that the work per revolution of a diamond-shaped configuration is smaller than that of the rectangular one. This is attributed to the absence of an additional impact of the blade wing on the diamond-shaped formation. Furthermore, the theoretical conditions were verified through a series of experiments that revealed a 10% decrease in the traction resistance of the diamond-shaped plough in comparison to the serial plough and increased productivity by 5.4%, allowing the creation of a symmetrical diamond-shaped shortened blade of a rotary plough with two-mode operation. Different angles of the working surface of the chest and blade wing to the furrow wall are examined.

Keywords-cultivated and diamond-shaped dumps; rectangular and diamond-shaped soil layer; symmetrical diamond-shaped shortened blade; unit performance; traction resistance of the plough; Box–Behnken design

I. INTRODUCTION

Crop yields and the physical properties of the soil depend on the utilized methods of soil cultivation and irrigation [1]. Increasing plough operating speeds leads to a sharp increase in the traction resistance of the plough and a decrease in ploughing quality, whereas overspending on fuel and lubricants increases the cost of crop production [2-4]. Additional shifts through a progressive shuttle method of movement can increase the productivity of arable units. This ensures smooth ploughing without collapsing or piled furrows, or untreated wedges [5-7]. The reduction of traction resistance can improve the quality of tillage and increase the productivity of tillage machines [8-12]. Ploughing aims to improve the crumbling and turning over of the soil layer. Tillage quality has a direct impact on the yield of the cultivated crops. Depending on the specific conditions, various forms of dumps are utilized: cylindrical, cultured, semi-screw, and screw. These shapes are designed for speeds between 4 and 5 km/h [13]. To increase the unit's performance, an increase in speed from 5 to 9 km/h can be utilized. This increase does not require a change in the geometric shapes of the plough hulls and the acquired 10% increase in resistance is offset by an increase in the yield. The additional increase in speed causes lateral formation displacement, preventing the formation of a cohesive surface of the ploughed field, and damages the sealing of plant residues, leading to a sharp increase in traction resistance. However, a further increase in operating speed between 9 and 15 km/h is not possible, because that would require lengthening the blade wing, causing an increase in material consumption and the contact area of the soil with the ploughshare surface, increasing traction resistance.

A new type of high-speed housing was proposed in [14]. The working surface of the housing is a combination of the surfaces of two cones and a cylinder. The results revealed that the body with a combined surface has the lowest resistivity with satisfactory ploughing quality at speeds between 9 and 12 km/h. Authors in [6, 15] created a type of enclosure that allows the adjustment of the working surface parameters depending on the working conditions. However, the structural complexity of manufacturing and adjustment prevents their widespread use. Authors in [16] studied the interaction of the plough working part body with the soil at increased speeds. It was shown that increasing speed leads to higher degrees of soil crumbling. The layer crumbles and instead of rotating relative to the second rib, it shifts by the blade wing. This method is impractical due to the high energy consumption for soil movement. A housing was developed to improve the turnover of the soil. The configuration of the field edge, which is tilted at some angle towards the unploughed field, separates the soil layer with an oblique cross-section. Therefore, the traction resistance of the plough decreased by 10-15% and the embedding depth of the plant residues increased by 3-5 cm. Adjusting the rotation pattern allowed for shortening the blade wing by 150-200 mm and reducing the twisting moment on the rack. Additionally, the lateral component of the resistance force was also reduced, leading to a smaller, in length, field board.

Authors in [17] developed a plough body that separates a layer of parallelogram-shaped soil with a slope of the furrow wall towards the ploughed field. Simultaneously, the layer was effectively arranged in the furrow, its turnover, and the sealing of crop and plant residues. To avoid pinching, a modification in the shape of the layer requires it to be moved for a distance prior to the rotation phase. Such a modification should have an enlarged blade wing. The second stage of reservoir turnover was the most energy-intensive. A plough with multiple configurations of rhomboid-shaped working parts allows for the removal of soil layers in various cross-sectional shapes with an inclined furrow wall [18]. Compared with conventional ploughs, cutting and wrapping a rectangular section had several advantages [19-22]:

- Traction resistance decreased by 16% during deep ploughing up to 31 cm.
- The surface of the ploughed field was less ridged.
- Unit consumption decreased by 29.5% and stalled by 13.6%.

Authors in [23] examined the scheme of joint rotation of two adjacent parallelogram-type formations. It was highlighted that their simultaneous rotation is possible under specific ratios of the geometric parameters of the layer. This configuration reduced the distance between the hulls and decreased the plough length by 40%. Comparative tests conducted in [24] on clay soil with a humidity of 25% demonstrated the superiority of the rhomboid-shaped plough over the conventional one. The findings revealed decreased traction resistance, lower fuel consumption, decreased tractor skidding, and higher productivity. In addition, the effective formation of the furrow was observed with minor differences in crumbling, sealing of plant residues, and the angle of inclination of the fallen layer. The following parameters of a rhomboid–shaped working part are proposed: the deviation angle of the furrow wall from the vertical should be between 35 and 45°, its vertical section height should be 50 mm, the type of working surface of the body should be cylindrical, and the blade wing should be shorter than that of a conventional body by 10-15 cm [22, 25].

Forming the soil layer in a rhombus shape leads to an improved turnover process. While the energy cost of lifting the reservoir increases, the traction resistance of the working part is reduced. However, the traction resistance reduction or the way the vertical section of the furrow wall influences soil turnover and energy use are not explained. In addition, the results are insufficient to optimize the shape or parameters of rhomboid-shaped working bodies under varying conditions. The current study aims to identify novel configurations of housing working surfaces for rotary ploughs to increase the efficiency of tillage machines.

II. MATERIALS AND METHODS

The developed experimental dump plough configuration is depicted in Figure 1.

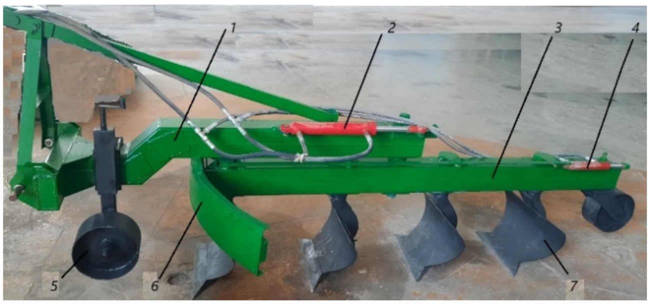


Fig. 1. (1) Dump plough configuration consisting of the main frame, (2) hydraulic cylinder for frame rotation, (3) rotating frame, (4) hydraulic cylinder for working parts' rotation, (5) support wheel, (6) guide arc, and (7) diamond-shaped plough.

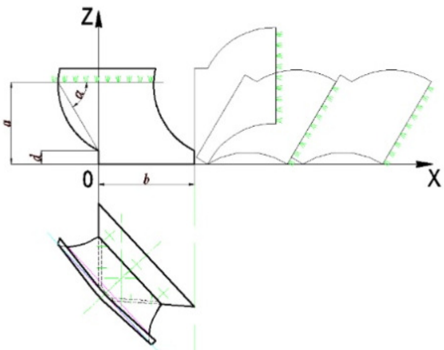


Fig. 2. Main structural parameters of the diamond-shaped plough.

The experiments were performed with the central composite rotatable second-order planning program. According to [26], the effects of structural and operational parameters on agrotechnical and energy performance indicators of the working body are investigated. As a result, a second-degree polynomial was produced describing the optimum operation region. Figure 2 illustrates some parameters that influence the operation of the plough, including ploughing depth (a), height of the vertical section of the furrow wall (*d*), width of the plough body (*b*), and angle of the working body (*a*). Design of Experiments (DOE) was utilized in the Statistica 10 program to determine the parameter's values and desirability functions [27]. The Box–Behnken surface response method, is used to obtain dependence graphs and the most optimal values of the under-study parameters.

III. RESULTS

Different configurations in the shape and size of the cut formation lead to different effects on the trajectory of its movement in the ZOX plane [28]. The layer movement during ploughing is determined by factors such as the type of working equipment, the size of the formation, the speed of movement of the arable unit, and the connectivity and moisture content of the soil. The movement of the formation of various shapes along the ploughshare-dump surface determines the energy consumption of the turnover layer, as illustrated in Figure 3. The work spent on reservoir turnover can be determined by:

$$A_t = \frac{1}{2} \cdot m \cdot \Delta V_x^2 + \frac{1}{2} \cdot I_x \cdot \omega^2 + m \cdot g \cdot \Delta h \quad (1)$$

where m is the mass of the layer (kg), ΔV_x is the projection of the velocity increment center of mass (c.m.) on the X-axis (m/s), I_x is the moment of inertia of the layer relative to the axis passing through the core perpendicular to the plane of rotation (kg·m²), ω is the angular velocity of the layer rotation (c^{-1}), g is the acceleration of gravity (m/s²), and Δh is the increment of the c.m. coordinate in height (m).

The work per unit of time is determined by its geometric parameters. The energy consumption for the turnover of a rectangular reservoir ABCE, as depicted in Figure 3(a), is provided by:

$$N = 0.5 \cdot V_e \cdot a \cdot b \cdot \gamma_п [V_e^2 \cdot tg^2\gamma \cdot \left(cos^2\delta + \frac{1}{3}\right) + g \cdot \left(cos\delta \cdot \sqrt{a^2 + b^2} - a\right)] \quad (2)$$

where V_e refers to portable speed or gun speed, γ denotes the goal of setting the furrow forming the wall and hail, and is assumed to be constant. Additionally, δ is the angle of inclination of the diagonal of the layer, γ_n *is the* volume weight of the soil, a and b are the layer dimensions, and α is the angle of inclination of the furrow wall.

The work of the parallelogram layer when rotated, as illustrated in Figure 3(b), following the trajectory of the relative motion of the center is an arc of a circle, and is expressed by:

$$A_{об} = \frac{1}{2} \cdot I_E \cdot \omega^2 + m \cdot g \cdot \Delta h \quad (3)$$

where I_E indicates the moment of inertia of the section shape relative to the axis passing through the point (pole of rotation) E perpendicular to the plane of rotation, as determined by the Huygens theorem:

$$N = 0.5 \cdot V_e \cdot a \cdot b \cdot \gamma_п [\frac{4}{3} \cdot V_e^2 \cdot tg^2\gamma + g \cdot (b \cdot sin\,\alpha - a)] \quad (4)$$

The equation of the trajectory of a rhomboid-shaped reservoir, as shown in Figure 3(c), is expressed in polar coordinates, providing the power allocated to its rotation:

$$N = \frac{1}{2} \cdot V_e \cdot a \cdot b \cdot \gamma_П \cdot [V_e{}^2 \cdot tg^2\gamma \left(\frac{3 \cdot Q^2 + C}{3 \cdot B}\right) + g \cdot \frac{a \cdot b \cdot sin\alpha + d^2 \cdot cos\alpha - a^2}{a}] \quad (5)$$

where Q, B, and C are provided by:

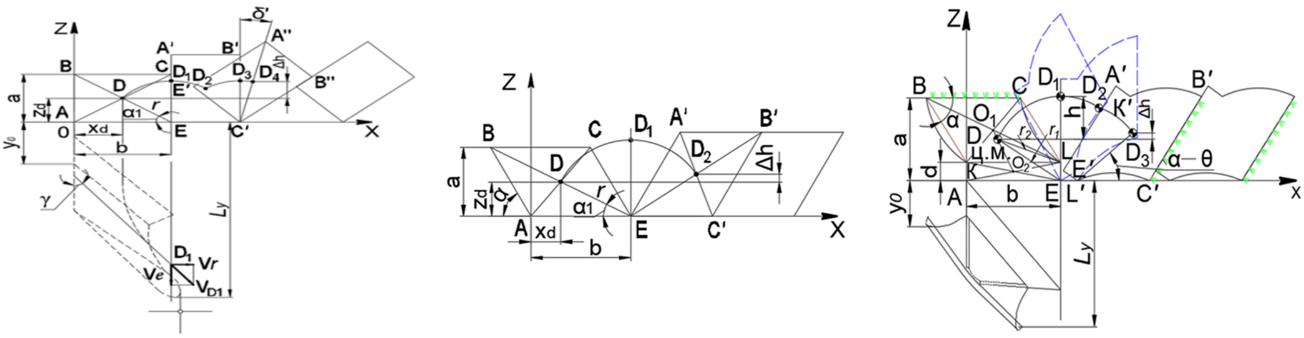
$$Q = sin\alpha[a \cdot b \cdot sin\alpha + (a-d)^2 \cdot cos\alpha] + a(a-2d) \cdot sin\alpha \cdot cos\alpha \quad (6)$$

$$B = [a \cdot b \cdot sin\alpha + (a-d)^2 \cdot cos\alpha]^2 + a^2(a-2d)^2 \cdot sin^2\alpha \quad (7)$$

$$C = (a-d)^2 \cdot \{b^2 \cdot sin^2 a + b(a-d) \cdot sin2a + (a-d)^2 + d \cdot [a^2 \cdot sin^2 a + b(a-d)^2 \times cos^2 a]\, a^2 \times d \times sin^2 a[b^2 + (a-d)^2]\} \quad (8)$$

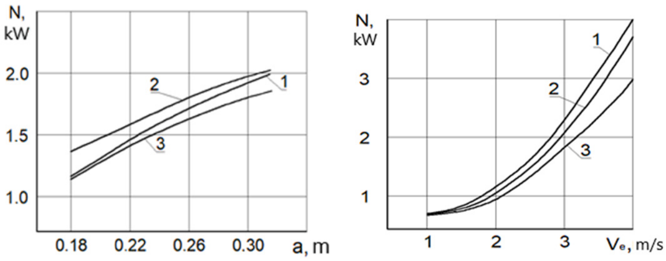
where θ is the angle between the horizontal and the line connecting the center to the second pole of rotation, and d is the size of the vertical section of the furrow.

Graphs of the dependence of power costs on the depth of ploughing were created according to (2), (4), and (5). Figure 4(a) illustrates the $N = f(a)$ relation and Figure 4(b) portrays the ploughing speed $N = f(V_e)$. The structural and operating parameters of the diamond-shaped plough involved studying the influence of *d*, *a,* a, and the speed of movement (υ) on the degree of soil crumbling (*K*), the working width (*B*), and the specific energy indicators (N_{sp}).



(a) (b) (c)

Fig. 3. Rotation patterns of layers: (a) rectangular, (b) parallelogram, and (c) rhomboid-shaped.



(a) (b)

Fig. 4. Change in capacity per layer turnover depending on the: (a) depth of ploughing and (b) speed of movement of the equipment for three layers. Number 1 refers to the rectangular, number 2 to the parallelogram, and number 3 to the rhomboid-shaped layer.

Based on the experimental results, regression equations were obtained for the influence of the design and operating parameters on the agrotechnical and energy performance of the working body, as displayed in Figures 5 and 6. The regression equations, specific energy consumption equations, are:

$$N_{sp} = 0.007\alpha^2 - 0.84\alpha - 0.40a^2 + 23.95a - 30.53\vartheta^2 + 172.82\vartheta + 0.01\alpha a - 0.14\alpha\vartheta - 1.41a\vartheta - 373.331 \quad (10)$$

$$N_{sp} = 0.178d^2 + 4.579d - 11.294\vartheta^2 + 67.918\vartheta - 2.674d\vartheta - 3.675 \quad (11)$$

The crumbling degree is represented by (12). The adequacy of the obtained regression equations is verified using Fisher's F-test at a significance level of 0.05:

$$K = 0.005\alpha^2 - 1.238\alpha - 0.041a^2 + 0.489a + 0.024\alpha a + 83.162 \quad (12)$$

A field experiment was conducted to verify these results. The arable units employed for the experiment consisted of a T-150K tractor and a PLP-6-35 plough, on which the working bodies were alternated. The test conditions of the experiments are given in Table I. The results of comparative tests on quality and energy consumption are presented in Figures 7, 8, and Table II.

(a) (b)

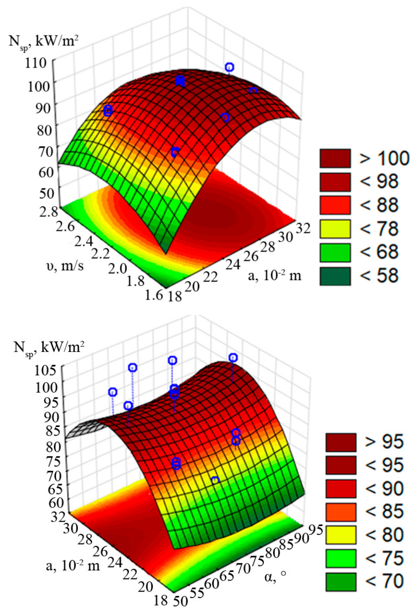


Fig. 5. Dependence of N_{sp} on: (a) a and υ at α=60 ° and (b) a and α at υ=2.60 m/s.

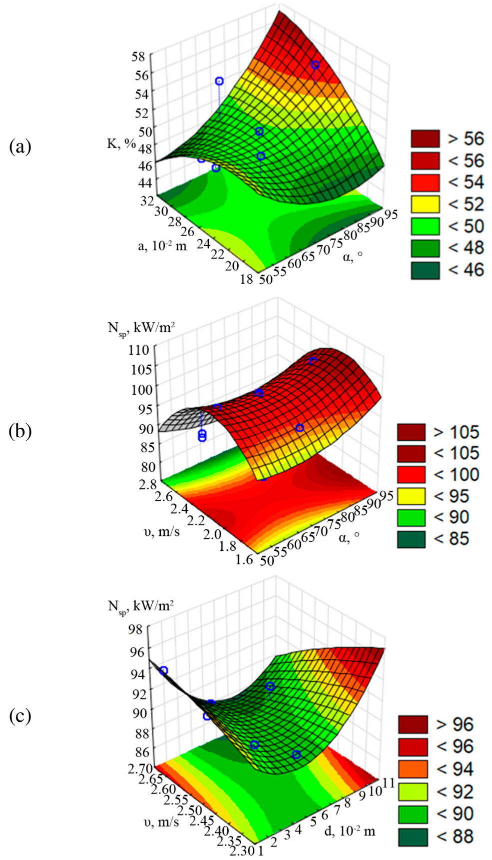


Fig. 6. Dependence of: (a) *K* on a and α, (b) N_{sp} on υ and *a* at a=25.5×10^{-2} m, and (c) N_{sp} on *d*.

TABLE I. FIELD EXPERIMENT TEST CONDITIONS

Indicators		Indicator values
Type of work		Ploughing fallow land
Soil type and name according to mechanical composition		Chernozem, leached, and medium loam
Relief		Flat
Micro-relief		Slightly undulating
Soil moisture	0-10×10^{-2} m	20.4%
	10-20×10^{-2} m	18.2%
	20-30×10^{-2} m	18.0%
	Average value	18.9%
Soil hardness	0-10×10^{-2} m	1.45 MPa
	10-20×10^{-2} m	2.47 MPa
	20-30×10^{-2} m	3.00 MPa
	Average value	2.30 MPa
Soil density	0-10×10^{-2} m	1.40 kg/m^3
	10-20×10^{-2} m	1.45 kg/m^3
	20-30×10^{-2} m	1.54 kg/m^3
	Average value	1.46 kg/m^3
Amount of crop residues	Per 1 m^2	475
	Pieces 1×10^{-3} kg	585
Amount of weeds	Per 1 m^2	35
	Pieces 1×10^{-3} kg	47
Height of weeds		0.20-0.25 m
Height of crop residues		0.20-0.25 m
Botanical composition of weeds		Wild oats
Agro-background		Wheat stubble
Previous treatment		Ploughing of fallow land at 0.25-0.27 m depth, early spring moisture closure, sowing, and harvesting

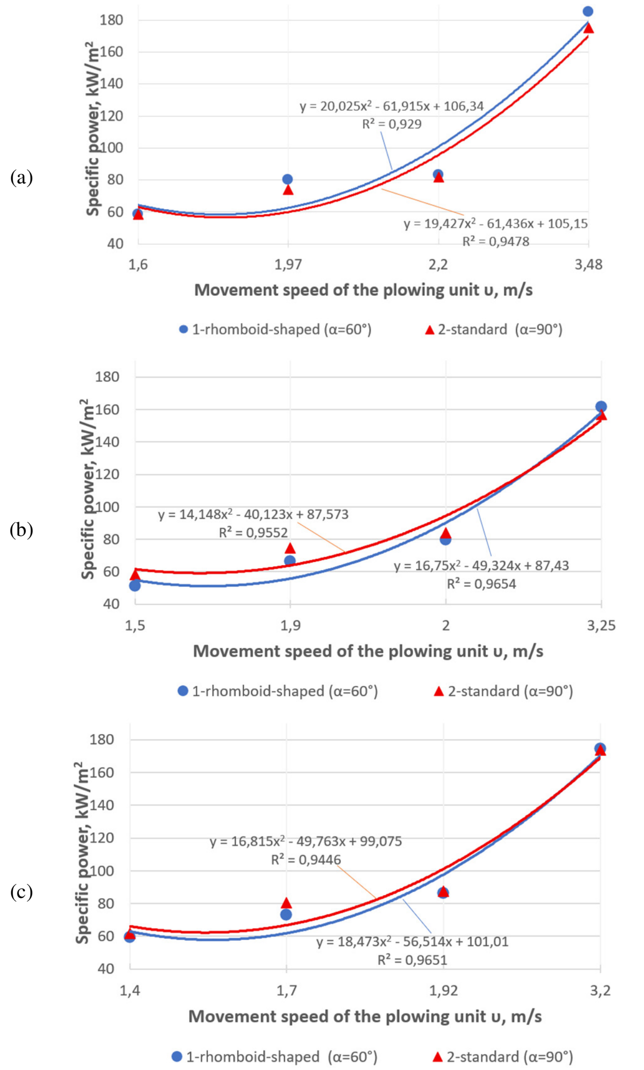


Fig. 7. Dependence of N_{sp} on υ at different depths of soil cultivation at: (a) a=21.4×10^{-2} m, (b) a=26.4×10^{-2} m, and (c) a=30.2×10^{-2} m.

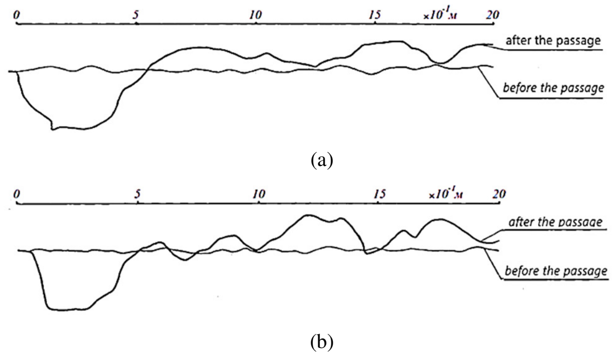


Fig. 8. Cross-section of arable land processed by: (a) diamond-shaped plough and (b) serial plough.

TABLE II. EXPERIMENTAL AND SERIAL WORKING BODIES' PLOUGH COMPARATIVE TESTS RESULTS

Indicators		**Experienced**	**Serial**
Working bodies		Diamond-shaped	PLZH-31
Processing depth	Mathematical expectation	25.26×10^{-2} m	25.27×10^{-2} m
	Average quadratic expectation	3.48×10^{-2} m	2.30×10^{-2} m
	Average quadratic expectation	2.71×10^{-2} m	1.89×10^{-2} m
Capture width	Mathematical expectation	2.165×10^{-2} m	2.156×10^{-2} m
	Average quadratic expectation	5.9×10^{-2} m	4.0×10^{-2} m
	Coefficient of variation	2.71%	1.89%
Arable land ridge average height		6.4×10^{-2} m	8.1×10^{-2} m
Leveling	Before plough passage	0.83×10^{-2} m	0.84×10^{-2} m
	After plough passage	3.12×10^{-2} m	5.51×10^{-2} m
Plant and crop residue sealing		94.4%	93.9%
Depth of embedding of plant residues		5.44×10^{-2} m	4.88×10^{-2} m
Crumbling quality by weight	Fraction sizes over 200 mm	3.4%	3.6%
	Fraction sizes of 200-100 mm	13.5%	14.4%
	Fraction sizes of 100-50 mm	30.2%	28.6%
	Fraction sizes less than 50 mm	52.9%	53.4%
Actual speed of movement		2.25 m/s	2.13 m/s
Traction resistance		30.08 kN	33.42 kN
Traction power		67.68 kW	71.18 kW
Engine shaft rotation speed		35.14 s^{-1}	34.84 s^{-1}
Hourly productivity		1.75 ha/h	1.66 ha/h
Hourly fuel consumption		31.86 kg/h	33.98 kg/h
Clogging and sticking of working organs		Not observed	

The novelty of this creation is confirmed by a patent [28]. Comparative tests suggested diamond-shaped dumps had advantages compared to traditional ones, as confirmed by [29].

The blade upgrade is followed by the development of a shortened ploughshare surface. This surface has a symmetrical shape relative to the longitudinal axis of the Z-pillar, as depicted in Figure 9. The field and furrow edges alternately change places, depending on the operating side of the tool. The ploughshare-dump surface of the working part consists of different angles of attachment relative to the furrow wall. Furthermore, the dump chest is set at an angle of 40° and the wing at 49°. In the area of the upper part of the field edge, the ploughshare surface is raised by 65 mm, allowing the dump wing to efficiently complete the rotation of the soil layer. To prevent soil from sticking in the place of the "fracture" of the ploughshare surface, their articulation is carried out along a radius of about 1200 mm. The geometry parameters of the ploughshare's surface remain constant due to the symmetry of the working part, indifferent of the direction of the movement. The remaining parameters of the symmetrical working part remain in the form indicated in [29].

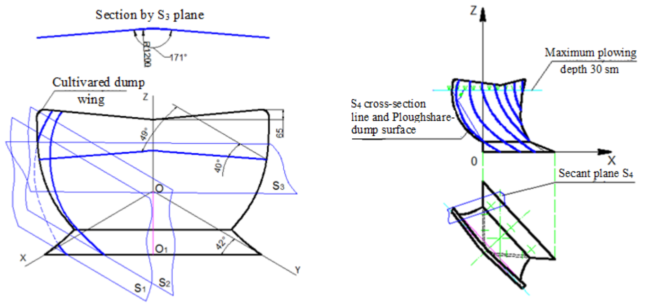


Fig. 9. Shortened symmetrical rhomboid-shaped ploughshare-dump surface.

IV. DISCUSSION

The present study produced a set of observations. A plough working part separating a rhomboid-shaped soil layer leads to a decrease in the traction resistance, with the angles of rotation of the sections of the layers being equal. The transfer distance of the c.m. in a rectangular formation is less than in a rhomboid-shaped one. Furthermore, the elevation height of the center of mass of a rectangular layer is higher. In the most typical state for basic tillage, the destroyed layer is shifted by the blade wing towards the ploughed field, instead of the second stage of layer rotation. Consequently, the traction resistance of the working part is increased. This result is exhibited by the working part that removes the rhomboid-shaped soil layer when α is 40°.

The energy indicators are equal when the height of the furrow wall is 5 cm. Additionally, the same value for the height of the field board is sufficient for smooth plough movement during operation. In contrast, the size of the vertical section has no effect on the ploughing depth and working width. The lowest specific energy consumption is achieved at a rhombic angle of 60 °. Furthermore, a diamond-shaped plough has 10% lower traction resistance than a serial plough. The reduction in traction resistance leads to a decrease in the tractor's slippage, and, therefore, the operating speed is increased from 2.13 to 2.25 m/s. Moreover, an increase in speed allows for a 5.4% increase in its productivity. The power cost of moving a diamond-shaped plough is 4.92% less than that of a serial one. The efficiency of diamond-shaped working bodies is evident in energy indicators at a processing depth from 24 to 28 cm. The lower power costs of ploughing and increased productivity lead to a decreased hourly fuel consumption by 6.24%. In addition, a plough with diamond-shaped crumbling bodies on old arable soil is compared to a conventional one. The soil density after diamond-shaped ploughing is limited to 900-1100 kg/m^3. This range is consistent with the optimal soil density for spring wheat, ranging from 1,100 to 1,200 kg/m^3.

The proposed operational configuration allows a reduction in the spacing between operational units up to 700 mm. This is achieved through maintaining installation angles close to the ground and to the wall of the standard plough furrow, and by featuring a symmetrically diamond-shaped and truncated blade. This modification consequently leads to decreased dimensions and a lower specific metal deterioration for the plough.

V. CONCLUSIONS

The symmetrical diamond-shaped plough with a shortened wing cutting the diamond-shaped layer ensures smooth plowing. The rotary plough operates in a left or right rotation mode, performing a movement in the furrow that enhances the utilization coefficient of the working movement. The diamond-shaped plough allows the distance between the working parts to be reduced to 700 mm. Therefore, the overall dimensions and specific metal content are reduced.

The proposed configuration ensures the highest soil layer quality turnover in a high-speed mode of the arable unit, preventing the formation of wedges, dumps, and ruts. In addition, it minimizes the idling and the overall duration of the ploughing process within a paddock. Furthermore, the unit's traction resistance is reduced along with the slippage of wide-wheeled tractors in the furrow. Consequently, a reduction of specific metal consumption by 1.7 times and a reduction of labor costs by 1.5 times are observed, preparing the soil for sowing. Finally, soil tillage with a reversible plough increased the productivity of the soil-tillage unit by up to 30% and enabled the effective use of wheeled tractors up to a 2.0 kN traction class when ploughing fields of up to 150 ha.

PATENTS

The proposed blade design will be protected by obtaining a Eurasian patent, and it is planned to test the work by conducting field experiments in 2025-2026. A patent application has been filed for the novelty of the development, "Plough share and moldboard surface for a symmetrical working body for a reversible plough" (Registration No. 2024/0437.1, registration date 05/31/2024). A positive decision was received in July 2025. The utility model patent No. 5143 "Working part for a rotary plough for basic tillage" [29].

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REFERENCES

[1] S. J. Oad, H. Maqsood, A. L. Qureshi, S. Ahmed, I. A. Channa, and M. I. Ali, "Farm-based Evaluation of Sustainable Alternative Irrigation Practices," *Engineering, Technology & Applied Science Research*, vol. 9, no. 3, pp. 4310–4314, June 2019, https://doi.org/10.48084/etasr.2810.

[2] T. Espolov, A. Espolov, Z. Suleimenov, I. Seytasanov, G. Tazhigulova, and R. Kultemirov, "Problems of Rational Land Use in Agriculture," *EurAsian Journal of BioSciences*, vol. 12, no. 2, pp. 405–411, 2018.

[3] R. Soucek, "Zu einigen Fragen des technischen Standes der Bodenbearbeitungsgeräte in der DDR und deren Weiterentwicklung," 1974.

[4] A. Celik, M. G. Boydas, and S. Altikat, "A Comparison of an Experimental Plow with a Moldboard and a Disk Plow on the Soil Physical Properties," *Applied Engineering in Agriculture*, vol. 27, no. 2, pp. 185–192, 2011, https://doi.org/10.13031/2013.36485.

[5] A. J. Koolen and H. Kuipers, *Agricultural Soil Mechanics*. Berlin, Germany: Springer-Verlag, 2012.

[6] S. Gebregziabher *et al.*, "Animal drawn tillage, the Ethiopian ard plough, maresha: A review," *Soil and Tillage Research*, vol. 89, no. 2, pp. 129–143, Oct. 2005, https://doi.org/10.1016/j.still.2005.08.010.

[7] S. Moreland, K. Skonieczny, and D. Wettergreen, "Soil Motion Analysis System for Examining Wheel-Soil Shearing," in *Proceedings of 17th International Conference of the International Society for Terrain-Vehicle Systems*, Blacksburg, VA, USA, Sept. 2011.

[8] L. Zhu *et al.*, "Modeling of share/soil interaction of a horizontally reversible plow using computational fluid dynamics," *Journal of Terramechanics*, vol. 72, pp. 1–8, Mar. 2017, https://doi.org/10.1016/j.jterra.2017.02.004.

[9] M. Nagy, C. Cota, N. Cioica, and L. Fechete, "Modeling the Geometric Parameters of the Equipment Explant 500 Active Body for Soil Processing," presented at the International Symposium, Bucharest, Romania, Oct. 2011, pp. 69–72.

[10] A. Ibrahmi, H. Bentaher, E. Hamza, A. Maalej, and A. M. Mouazen, "Advanced Analytical Method of Mouldboard Plough's Design," *The International Journal of Advanced Manufacturing Technology*, vol. 88, no. 1, pp. 781–788, Apr. 2016, https://doi.org/10.1007/s00170-016-8806-y.

[11] I. A. Nweke, "The Good, the Bad and the Ugly of Tillage in Agricultural Sustainability– A Review," *Greener Journal of Agricultural Sciences*, vol. 8, no. 9, pp. 217–250, 2018, https://doi.org/10.15580/GJAS.2018.9.090618130.

[12] S. Nukeshev *et al.*, "Traction Force, Sowing Quality, and Deformation Characteristics of the Coulter of a Grain–Fertilizer–Grass Seeder," *AgriEngineering*, vol. 6, no. 3, pp. 2326–2351, July 2024, https://doi.org/10.3390/agriengineering6030136.

[13] A. Oluwajobi and C. Xun, "The Effect of the Variation of Tool End Geometry On Material Removal Mechanisms in Nanomachining," in *Proceedings of 13th International Conference on Tools*, Miskolc, Hungary, Mar. 2012, pp. 71–76.

[14] P. N. Burchenko, *Mechanical and Technological Foundations of New Generation Tillage Machines*. Moscow, Russia: All-Russian Scientific Research Institute of Mechanization, 2002.

[15] K. Wegener, "Ploughing," in *CIRP Encyclopedia of Production Engineering*, Berlin, Germany: Springer, 2014.

[16] R. J. Godwin, "A review of the effect of implement geometry on soil failure and implement forces," *Soil and Tillage Research*, vol. 97, no. 2, pp. 331–340, Aug. 2006, https://doi.org/10.1016/j.still.2006.06.010.

[17] L. G. Parayev, S. A. Trostyansky, O. N. Naumova, and Y. V. Kram, *Plough Body*, vol. 292605. 1970, https://patents.su/2-292605-292605.html.

[18] A. Depresh, *Multi-Body Plough*, vol. 358801. 1972, https://patents.su/6-358801-mnogokorpusnyjj-plug.html.

[19] R. Lal, "The Plow and Agricultural Sustainability," *Journal of Sustainable Agriculture*, vol. 33, no. 1, pp. 66–84, Jan. 2009, https://doi.org/10.1080/10440040802548555.

[20] W. Van Muysen, G. Govers, and K. Van Oost, " Identification of Important Factors in the Process of Tillage Erosion: The Case of Mouldboard Tillage," *Soil and Tillage Research*, vol. 65, no. 1, pp. 77–93, Jan. 2022, https://doi.org/10.1016/S0167-1987(01)00282-3.M. Novotny, "Hat der Rautenpflug Zukunft," *Agrartechnick International*, vol. 8, no. 56, pp. 8–9, 1977.

[21] Novotny, M., "Hat der Rautenpflug Zukunft," *Agrartechnick international*, vol. 8, no. 56, pp. 8–9, 1977.

[22] J. K. Kouwenhoven, U. D. Perdok, J. Boer, and G. J. M. Oomen, " Soil Management by Shallow Mouldboard Ploughing in the Netherlands," *Soil and Tillage Research*, vol. 65, no. 2, pp. 125–139, Dec. 2001, https://doi.org/10.1016/S0167-1987(01)00271-9.

[23] G. Qiong, R. E. Pitt, and A. Ruina, " A Model To Predict Soil Forces on the Plough Mouldboard," *Journal of Agricultural Engineering Research*, vol. 35, no. 3, pp. 141–155, Feb. 1986, https://doi.org/10.1016/S0021-8634(86)80053-1.

[24] E. Ruhm, G. Wasseler, H. Wassler, and G. Schätz, "Der Rauten-Pflug Pro Und Kontra," *Agrar übersicht*, vol. 29, no. 11, pp. 708–711, 1978.

[25] H. I. Stübenbock, "Untersuchungen Über Das Pflugen MIT Rautenkörpern," *Grundlage Landtechnick*, vol. 1, no. 21, pp. 1–9, 1981.

[26] M. J. Anderson and P. J. Whitcomb, *RSM Simplified: Optimizing Processes Using Response Surface Methods for Design of Experiments*, New York, NY, USA: Productivity Press, 2016.

[27] S. L. C. Ferreira *et al.*, "Box-Behnken design: An alternative for the optimization of analytical methods," *Analytica Chimica Acta*, vol. 597, no. 2, pp. 179–186, July 2007, https://doi.org/10.1016/j.aca.2007.07.011.

[28] B. Nuralin *et al.*, "The Working Part of a Reversible Plough: Design and Experiments," *Acta Agriculturae Scandinavica, Section B — Soil & Plant Science*, vol. 70, no. 8, pp. 679–685, Oct. 2020, https://doi.org/10.1080/09064710.2020.1833977.

[29] B. N. Nuralin, M. M. Konstantinov, S. V. Oleynikov, M. Galiev, V. S. Kukhta, and A. Z. Nuralin, "Working Part for a Rotary Plough for Basic Tillage," p. 5143, July 2020, https://elib.wkau.kz/lib/document/ PPPP/ F6889 EBD-8ED4-40EE-B7C3-0712B705EF3A/.