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Research Article

The Influence of the Soil Screen Opening Angle on the Quality of Tillage and Fertilizer Distribution

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Abstract

This study investigates the effect of the soil deflector's opening angle on the quality of soil processing and uniform fertilizer distribution in agricultural activities, particularly in orchards and vineyards. The soil deflector temporarily blocks soil movement, facilitating the penetration of fertilizers into the soil, improving their integration with the soil environment. The dynamics of normal forces acting on soil particles are analyzed to understand their influence on the deflector's operational effectiveness. Results indicate that an opening angle between 54° and 66° significantly improves soil processing efficiency, achieving both uniform fertilizer application and optimal energy usage. The experiments explored variations in the soil deflector's opening angle from 50° to 80° at speeds of 6 km/h and 8 km/h. Findings demonstrate that within the optimal angle range, the depth and width of fertilizer application improve markedly, ensuring better soil and nutrient management. The study further highlights that the resistance faced by the deflector decreases at smaller angles, whereas larger angles increase energy consumption and reduce fertilizer distribution efficiency. The research concludes that optimizing the soil deflector's opening angle is crucial for enhancing soil processing performance, improving fertilizer application uniformity, and minimizing energy expenditure. These results provide practical guidelines for the development of agricultural machinery that meets the needs of modern, resource-efficient farming practices, particularly in specialized environments like orchards and vineyards.

Keywords

Soil Screen, Normal Force, Traction Resistance, Fertilizer Distribution, Agricultural Activities, Soil Processing Efficiency

1. Introduction

Effective soil processing is crucial for the optimal development of crops in orchards and vineyards. Soil preparation and the application of fertilizers are essential for improving soil fertility and creating favorable conditions for root development. When performed effectively, these practices directly contribute to increasing yield and ensuring sustainable agricultural practices. One of the key elements in soil processing is the use of advanced technologies capable of performing various functions, such as soil cultivation, fertilizer application, and soil conditioning [1, 2].

The main issue in fertilizing grapevine rows [3] is that during the regeneration process, the vine's roots can receive either too much or too little fertilizer, which causes damage to the absorbing roots, leading to a decrease in the grapevine's productivity [4].

These technologies must ensure maximum efficiency while minimizing energy consumption [5]. One such innovative device is the SS: Soil Screen, which temporarily blocks the

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soil, allowing fertilizers to enter the soil and mix well with it. The design and operation of this mechanism, particularly its opening angle, have a significant impact on the uniformity of fertilizer distribution and soil structure preservation.

This SS is used in a combined machine designed to process between vineyard rows, and it plays a crucial role in ensuring the fertilizer reaches the roots of the vines [6]. Previous studies have highlighted issues related to uniform fertilizer distribution and minimizing energy losses during soil processing [7]. However, research on optimizing the parameters of the SS, particularly its opening angle, is still limited. This study aims to analyze the dynamics of soil particle movement in response to changes in the opening angle: OA of the SS. The research investigates the relationship between the screen's opening angle, traction resistance, and uniform fertilizer distribution.

Objective of the research is the goal of the research is to establish the exact optimal angle for placing the SS in the fertilization process between grapevine rows to ensure uniform distribution of fertilizer. By determining the optimal angle range, the study provides valuable recommendations to improve the efficiency of agricultural machinery, reduce energy consumption, and enhance soil processing effectiveness. The research is focused on justifying the design and parameters of the SS that ensures fertilizer is applied at the specified depth and width in the area where the vine root system develops [8].

In recent years, in the world viticulture, great attention has been paid to the application of mineral and organic fertilizers to the root system in order to achieve high yields [9]. In particular, [10-13] and others have developed technologies and technical means for applying mineral and organic fertilizers to fruit trees, based on the parameters of their working bodies. The authors [9, 10] has compiled a classification of technical means for applying fertilizers to the soil. According to the analysis of the technical means given in the classification, in recent years, tools for applying fertilizers along with soil cultivation are considered the most promising.

2. Materials and Methods

Experimental research on determining the performance of a combined machine's deep loosening tool for cutting vine roots and applying fertilizer was conducted using a laboratory-field device developed by the Scientific-Research Institute of Agricultural Mechanization. Before carrying out the experiments, the moisture, hardness, and density of the soil layers at 0-10, 10-20, 20-30, 30-40, and 40-45 cm depths were determined. In the experiments, the width and depth of fertilizer application, as well as the traction resistance of the working body, were determined according to GOST 28718-2016 "Machines for applying solid organic fertilizers. Testing methods" and O'zDST 3193:2017 "Testing agricultural machinery. Method for energy evaluation of machines". The depth and width of fertilizer application were determined by measuring the distance at which the fertilizer fell after passing through the working body.

It is planned to carry out the following works in the experimental research program in order to optimize the parameters of the working bodies of the combined machine that cuts the roots of the vine, applies fertilizers and works between the rows, and studies the effect of the operating mode and aggregate operating speed on its agrotechnical and energetic indicators:

- to study the effect of the compression coefficient of the base of the cone-shaped harrow, the angle between the base and the base, and the walking height on the width of the fertilization and its unevenness;

- justification of optimal values of the parameters of the conical scatterer using the method of mathematical planning of experiments;

- studying the influence of the opening angle, length, height, and unit speed of the fertilizing working body on the quality of fertilizing and the traction resistance of the working body.

Based on the results of the theoretical study, experiments were conducted by varying the length of the soil barrier from 20 cm to 26 cm in 2 cm intervals. The OA of the soil barrier was set at 60 °, the height at 8 cm, and the movement speed at 6 km/h and 8 km/h.

Accordingly, we study the interaction process of soil particles with the SS in the horizontal plane (Figure 1a). In the horizontal plane, the soil particles are affected by the normal force N_y and the frictional force $T_y=N_y tg_\varphi$, both of which are generated by the working surface of the SS.

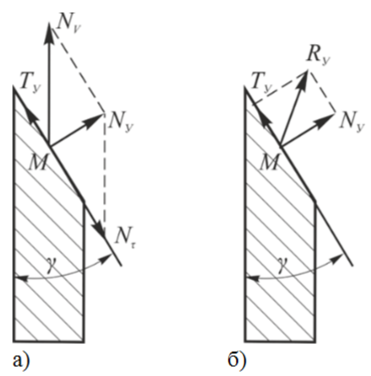


Figure 1. *Diagram for Determining the SS OA.*

The normal force N_y is divided into components: the force N_v, directed along the direction of motion, and the force N_τ directed along the working surface of the SS.

According to the diagram presented in Figure 1a.

$$N_V = N_y / \sin\gamma \tag{1}$$

and

$$N_\tau = N_y ctg\gamma , \tag{2}$$

Here, γ is half of the SS opening angle, in degrees (°).

It is known from literary sources that in order to prevent soil from sticking and accumulating on the front of the soil curtain, the following condition must be observed [9].

$$N_\tau > T_y \quad (3)$$

Substituting the values of N_τ and T_y provided above into this expression, we obtain the following:

$$N_y ctg\gamma > N_y tg\phi_1 \quad (4)$$

or

$$\gamma < 90 - \phi_1. \quad (5)$$

When this condition is met, the soil particles move with acceleration along the direction of the force R_y, which is the resultant force of N_y and T_y, with acceleration V_a (Figure 1b).

$$V_a = V_M \frac{\sin\gamma}{\cos\phi_1}, \quad (6)$$

According to the diagram presented in Figure 2.

Here, φ_1 -is the angle of friction between the soil and the screen, in degrees (°).

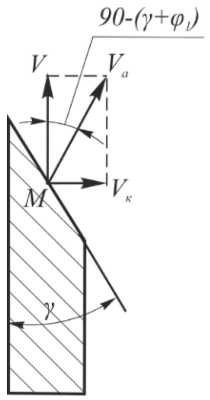


***Figure 2.** Diagram for Determining the Velocity of Soil Particles Under the Influence of the Working Element of the Grabbing Mechanism.*

Let us define the velocity component V_a, perpendicular to the direction of motion.

$$V_k = V_M \frac{\sin\gamma}{\cos\phi_1}\cos(\gamma + \phi_1) \quad (7)$$

In order for the soil particles to not adhere to the working surface of the SS and not clump in front of it, the velocity V_k must reach its maximum value. Based on this, using expression (2), the values V_M =2 m/s and φ_1=25, 30 to 35 °were used to plot the graphs of V_k as a function of the angle γ (Figure 3). From these graphs, it is evident that for all values of φ_1 the velocity V_k changes with respect to the angle γ in the form of a convex parabola, and for certain values of γ, the velocity V_k reaches its maximum. It can be stated with complete confidence that for the values of the angle γ that ensure the maximum velocity V_k the probability of soil adhering to the working surface of the SS and clumping in front of the screen is minimized, and, consequently, the resistance to soil adhesion will also be minimized [10].

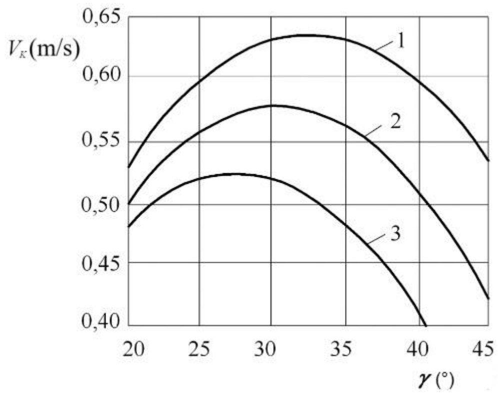


***Figure 3.** Graphs of the change in velocity V_k as a function of the angle γ for different values of the angle φ_1.*

Thus, it is reasonable to determine the SS OA based on the condition where the velocity V_k reaches its maximum value.

To determine the value of the SS OA at which the velocity V_k will be maximum, we examine expression (6) with respect to the angle γ to find the extremum. For this, we take the first derivative of expression (6) with respect to the angle γ and set the result equal to zero [11, 12].

$$\frac{dV_k}{d\gamma} = V_M = \cos\phi_1\left[\cos\gamma\cos(\gamma+\phi_1) - \sin\gamma\sin(\gamma+\phi_1)\right] = 0 \quad (8)$$

From this, we obtain:

$$\cos(2\gamma + \phi_1) = 0 \quad (9)$$

Solving expression (9) for γ, we obtain the following result:

$$\gamma = \gamma_y = \frac{\pi}{4} - \frac{\varphi_1}{2}. \quad (10)$$

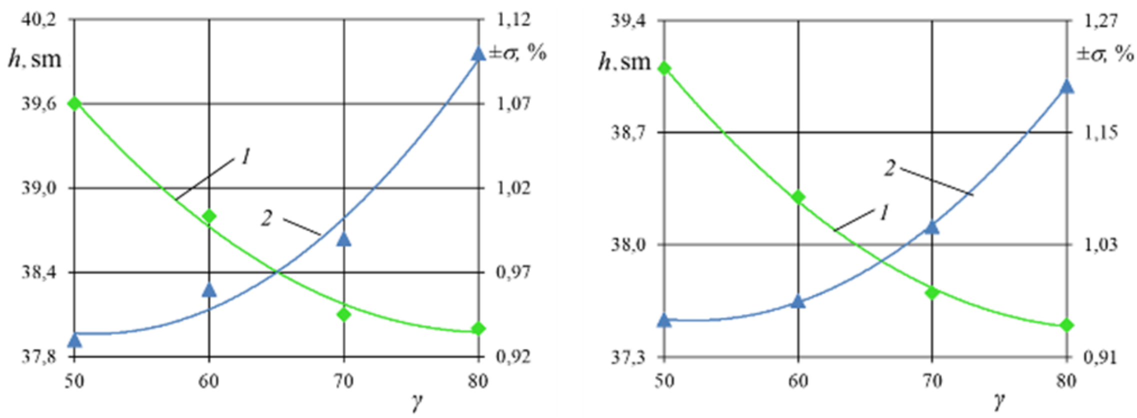
3. Results and Discussion

Substituting the known values of φ_1 (25 °–35 °) into the obtained expression [13], we find that the angle γ(gamma) should be in the range from 27 °to 33 °. Therefore, the SS OA should be between 54 °and 66 °.

Based on the conducted theoretical studies, experiments were carried out by changing the SS OA within the range from 50 °to 80 °with a 10 °interval. The length of the SS was 24 cm, the height was 8 cm, and the movement speed was 6 km/h and 8 km/h.

The results of the conducted experiments are shown in Figures 4 and 5. From the data presented, it is evident that as the SS OA changes from 50 ° to 80 °, the depth of fertilizer application decreased at both movement speeds. At a speed of 6 km/h, the depth of fertilizer application decreased from 39.6 cm to 38.0 cm, while at 8 km/h, it decreased from 39.1 cm to 37.5 cm.

As the SS OA increased, the unevenness of the fertilizer application depth also increased. When considering these indicators for each degree of the opening angle, the depth of fertilizer application and its unevenness initially changed sharply, but then the changes became less significant. In other words, for the OA range of 50 °to 70 °, the changes were more pronounced. Specifically, at a speed of 6 km/h, the corresponding indicators changed by 4.8% and 17.27%, and at 8 km/h, by 5.23% and 17.5%. When the angle increased from 70 °to 80 °, these indicators changed by 0.51% and 1.09%, and 0.52% and 1.01%, respectively. These changes can be explained by the variation in the working element's depth of motion.



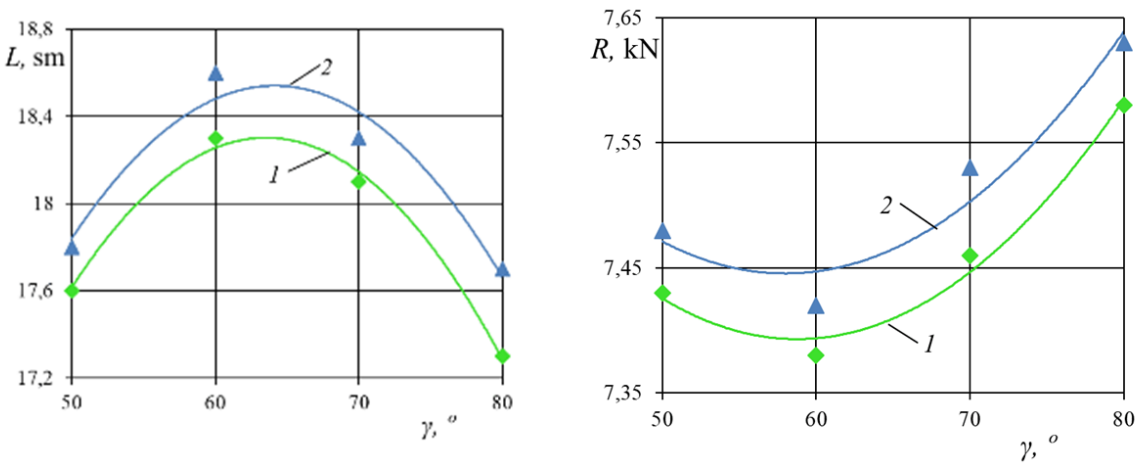
6 km/h 8 km/h

Figure 4. *The OA of the SS and its effect on the fertilizer application depth and its standard deviation.*

In here: h-fertilizer application depth, σ-standard deviation and γ- OA of the SS.

The width of fertilizer application changed according to the law of the concave parabola as the SS OA increased. That is, for the OA range from 50 ° to 60 °, the width increased. Specifically, at a movement speed of 6 km/h, it changed from 17.6 cm to 18.3 cm, and at 8 km/h, from 17.8 cm to 18.6 cm.

In the angle range from 60 ° to 80 °, the width decreased. Specifically, at 6 km/h, it decreased from 18.3 cm to 17.3 cm, and at 8 km/h, from 18.6 cm to 17.7 cm.



а) б)

Figure 5. *The change in fertilizer application width (a) and traction resistance (b) with respect to the OA of the SS.*

In here: L-fertilizer application width, R-Traction resistance.

This can be explained as follows: at an OA of 50°, the fertilizers, exiting the cone planter, stick to the SS and return back, whereas at an angle of 60°, the fertilizers, exiting the cone planter, freely fall to the ground, forming a wide strip. At angles greater than 60°, the screen length does not change, so the distance at which the soil is captured decreases, which accelerates the fall of the fertilizers and reduces their width [14, 15].

Analysis of the conducted research shows that the soil moisture in the 0-30 cm layer, where the working organs of the combined machine for processing grapevine rows operate, ranges from 12.92% to 20.46% depending on the season, soil hardness ranges from 1.08 MPa to 1.51 MPa, and soil density ranges from 0.95 g/cm ^{3} to 1.56 g/cm ^{3}. To process grapevine rows with minimal energy consumption while meeting agrotechnical requirements, the working angle should range from 54° to 66°. Further theoretical and experimental research will be focused on justifying the parameters of the machine.

4. Conclusions

The adhesion resistance of the working element followed the law of a convex parabola as the SS OA increased. Specifically, in the range from 50° to 60°, it decreased, and in the range from 60° to 80°, it increased. When the SS OA changed from 50° to 60°, at a speed of 6 km/h, the adhesion resistance decreased from 7.43 kN to 7.38 kN, and at 8 km/h, from 7.48 kN to 7.42 kN. As the angle increased from 60° to 80°, the adhesion resistance increased from 7.38 kN to 7.58 kN at 6 km/h, and from 7.42 kN to 7.63 kN at 8 km/h.

Abbreviations

SS	Soil Screen
OA	Opening Angle

Conflicts of Interest

The authors declare no conflicts of interest.

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Biography

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