

## EFFECT OF UPPER-TIER BODY WORKING DEPTH ON THE AGRO-TECHNICAL AND ENERGY PERFORMANCE OF A TWO-TIER DISC PLOUGH

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**Abstract:** This study investigates the influence of the upper-tier body working depth on the agro-technical and energy performance indicators of a two-tier disc plough. The experiments were conducted at operating angles of 40° relative to the direction of movement and 20° relative to the vertical, with a longitudinal spacing of 70 cm between the upper and lower bodies. The research analyzed how variations in the working depth of the upper-tier plough body—from 10 to 20 cm—affect soil pulverization quality, the completeness and depth of crop residue incorporation, field surface roughness, and draft resistance. The results showed that as the upper-tier working depth increased to 15 cm, the quality of soil crumbling improved; however, further deepening caused a slight decline due to the excessive volume of overturned soil clods. The draft resistance increased from 3.31 to 5.13 kN when the working depth rose from 10 to 20 cm at a speed of 6 km/h, and from 3.52 to 5.47 kN at 9 km/h. The best combination of low draft resistance, high soil pulverization, and effective residue incorporation was observed at a depth range of 15–17.5 cm. Empirical models describing these dependencies were derived using the least squares method, achieving coefficients of determination  $R^2$  above 0.97, confirming the accuracy of the established relationships. The findings suggest that maintaining the upper-tier body working depth within 15–17.5 cm ensures optimal energy efficiency and soil tillage quality for two-tier disc ploughs under similar field conditions.

**Keywords:** two-tier disc plough, upper-tier body depth, soil pulverization, draft resistance, agro-technical performance, energy efficiency

### Introduction

The efficiency of soil tillage plays a crucial role in increasing crop productivity and ensuring sustainable agricultural practices. Among modern tillage implements, the two-tier disc plough has attracted significant attention due to its ability to loosen soil layers at different depths, enhance residue incorporation, and improve soil structure formation. However, the performance of such ploughs largely depends on the working depth of the upper-tier body, which influences soil pulverization quality, residue burial, and draft resistance [1, 2]. An inappropriate working depth can either increase energy consumption or reduce the quality of soil tillage.

Despite the growing number of studies on plough optimization, the specific effect of the upper-tier body working depth on the agro-technical and energy indicators of two-tier disc ploughs remains insufficiently explored. This research aims to experimentally determine the optimal working depth that ensures efficient soil

crumbling, proper residue incorporation, and minimal traction resistance [3, 4]. The results contribute to improving the energy efficiency and overall performance of two-tier disc ploughs under field conditions.

### Methods

Field experiments were conducted using New Holland TD 5.110 and Belarus 1221 tractors to evaluate the effect of the upper-tier plough body working depth on the performance of a two-tier disc plough. The working parts were installed at a 40° angle to the direction of motion and 20° to the vertical, with a longitudinal spacing of 70 cm between the upper and lower bodies [5]. The total tillage depth was fixed at 30 cm, while the upper-tier body depth was varied from 10 to 20 cm. Tests were carried out at operating speeds of 6 and 9 km/h, and measurements included soil pulverization quality, residue incorporation, surface roughness, and draft resistance. Experimental data were processed using the least squares method to derive empirical equations with coefficients of determination above 0.97, ensuring high reliability of the obtained relationships.

### Results and discussion

The experimental results demonstrated that increasing the working depth of the upper-tier plough body from 10 to 15 cm improved soil pulverization and residue incorporation, while further deepening up to 20 cm caused a slight decline in soil crumbling quality due to the excessive volume of overturned soil clods. The completeness and depth of residue burial increased proportionally with the working depth, reaching optimal values at 15–17.5 cm. At the same time, the draft resistance of the plough increased from 3.31 to 5.13 kN at a speed of 6 km/h, and from 3.52 to 5.47 kN at 9 km/h, indicating a direct relationship between depth and traction demand. The surface roughness also increased notably with deeper operation, mainly due to incomplete overlap between the soil layers turned by the upper and lower bodies. Empirical models derived by the least squares method showed high determination coefficients ( $R^2 > 0.97$ ), confirming the accuracy of the established dependencies. Overall, the results indicate that maintaining the upper-tier working depth within 15–17.5 cm ensures optimal soil pulverization, efficient residue incorporation, and reduced energy consumption for two-tier disc ploughs.

The results obtained from the experimental studies are summarized in Table 1, which presents the influence of the upper-tier plough body working depth on the agro-technical and energy indicators of the two-tier disc plough. As shown in the table, when the working depth of the upper-tier body increased from 10 to 15 cm, the proportion of soil particles smaller than 50 mm increased from 75.4% to 81.5% at a forward speed of 6 km/h, and from 76.2% to 81.9% at 9 km/h, indicating improved soil pulverization. However, with a further increase in depth to 20 cm, the amount of finely crumbled soil slightly decreased, which can be attributed to the formation of larger clods due to the higher soil turnover volume. The completeness and depth of residue incorporation increased steadily up to a working depth of

17.5 cm, while the height of surface irregularities rose from 3.6 cm to 6.7 cm,

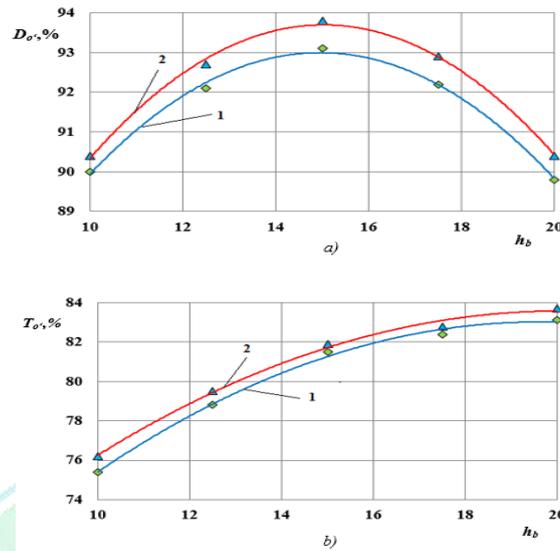
showing that deeper operation enhances residue coverage but deteriorates surface smoothness.

**Table 1 Influence of the Working Depth of the Upper-Tier Plough Body on the Performance Indicators of a Two-Tier Disc Plough**

Working Depth of the Upper-Tier Plough Body, cm	Soil particle size distribution, Do', %			Plant residue coverage quality		Surface unevenness height, sm	Plough draft resistance, kN
	Particle size, mm			Burial completeness, To', %	Burial depth, Ho', sm		
	>100	100-50	<50				
V=6 km/h							
10,0	3,7	6,3	90,0	75,4	5,2	3,6	3,31
12,5	3,4	5,5	92,1	78,8	5,6	4,7	3,60
15,0	2,5	3,4	93,1	81,5	8,1	5,2	4,10
17,5	4,2	4,6	92,2	82,4	9,5	5,8	4,61
20,0	4,8	5,4	89,8	83,1	11,3	6,7	5,13
V=9 km/h							
10,0	3,5	6,1	90,4	76,2	5,4	3,4	3,52
12,5	3,1	5,2	92,7	79,5	5,8	4,3	3,67
15,0	2,1	3,1	93,8	81,9	8,4	4,8	4,25
17,5	3,8	4,3	92,9	82,8	9,9	5,3	4,82
20,0	4,3	5,3	90,4	83,7	11,7	6,4	5,47

The draft resistance of the plough also exhibited a proportional increase with the working depth. At 6 km/h, the traction force grew from

3.31 kN at 10 cm to 5.13 kN at 20 cm, while at 9 km/h, it increased from 3.52 kN to 5.47 kN. This behavior is explained by the greater soil mass engaged in tillage and the higher frictional resistance at deeper penetration. Statistical processing of the experimental data using the least squares method produced reliable empirical models with high coefficients of determination ( $R^2 > 0.97$ ). These results confirm that the most favorable working range for the upper-tier body lies between 15 and 17.5 cm, where soil pulverization quality, residue incorporation, and traction efficiency are optimally balanced, ensuring both high agro-technical performance and reduced energy consumption.

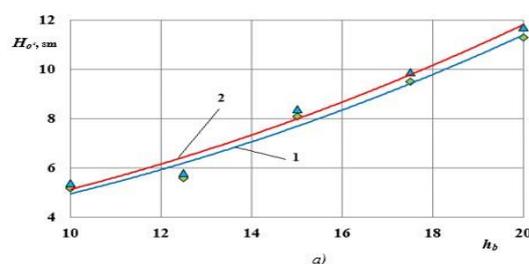


1.  $V=6$  km/h; 2.  $V=9$  km/h  
a)  $Do' = f(h_b)$ ; b)  $To' = f(h_b)$

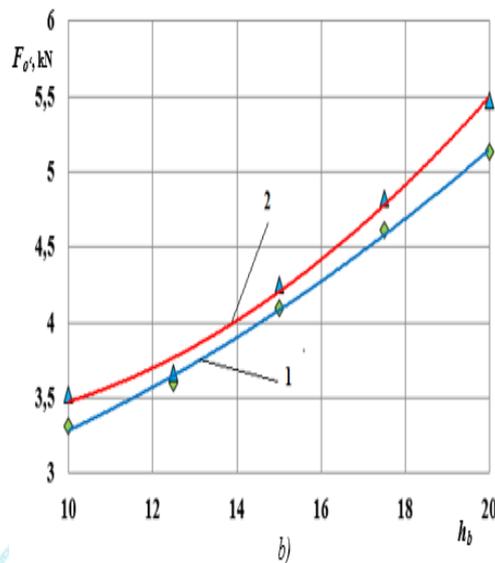
**Figure 1.** Variation of the proportion of soil fractions smaller than 50 mm ( $Do'$ ) and the completeness of residue incorporation ( $To'$ ) depending on the working depth of the upper-tier plough body ( $h_b$ , cm) at operating speeds of 6 and 9 km/h.

Figure 1 illustrates the variation in the proportion of soil fractions smaller than 50 mm ( $Do'$ ) and the completeness of residue incorporation ( $To'$ ) as functions of the working depth of the upper-tier plough body at operating speeds of 6 and 9 km/h. As seen from the graphs, both parameters increase with depth up to approximately 15 cm, indicating improved soil pulverization and residue coverage. This trend suggests that moderate deepening of the upper-tier body enhances the soil mixing effect and ensures better fragmentation of soil aggregates. However, at depths greater than 17.5 cm, both the proportion of fine soil fractions and the completeness of residue incorporation show a slight decrease. This decline is attributed to the excessive turning of large soil clods, which reduces uniform mixing and causes partial disruption of the soil surface structure. These findings confirm that excessive deepening of the upper-tier body does not necessarily improve tillage quality but instead leads to diminishing returns.

Figure 2 presents the variation in the residue incorporation depth ( $Ho'$ ) and the plough's draft resistance ( $Fo'$ ) with respect to the working depth of the upper-tier body. The results demonstrate that as the upper body penetrates deeper into the soil, the



residue burial depth increases due to improved soil inversion, while the plough's draft resistance rises significantly. For instance, at an operating speed of 6 km/h, the draft force increased from 3.31 kN at 10 cm to 5.13 kN at 20 cm, while at 9 km/h, it rose



from 3.52 kN to 5.47 kN. This increase in traction demand reflects the higher soil mass being displaced and the greater frictional resistance between the soil and working surfaces. The relationship between these parameters was mathematically modeled using the least squares method, yielding strong correlation coefficients ( $R^2 > 0.97$ ). The optimal working depth of 15–17.5 cm thus provides a balance between residue incorporation efficiency and energy consumption, ensuring stable operation of the two-tier disc plough with minimal power losses.

1.  $V=6$  km/h da; 2.  $V=9$  km/h da  
a)  $Ho' = f(\square)$ ; b)  $Fo' = f(\square)$

**Figure 2.** Variation of the residue incorporation depth ( $Ho'$ ) and the plough draft resistance ( $Fo'$ , kN) depending on the working depth of the upper-tier plough body ( $h_b$ , cm) at operating speeds of 6 and 9 km/h.

### Conclusion

The conducted experimental research has demonstrated that the working depth of the upper-tier body has a decisive influence on the agro-technical and energy performance of the two-tier disc plough. Increasing the upper-tier depth up to 15–17.5 cm improved soil pulverization, enhanced residue incorporation, and ensured uniform soil inversion. However, further deepening to 20 cm caused a deterioration in soil crumbling quality and an increase in surface roughness due to excessive clod formation.

The plough's draft resistance increased proportionally with the working depth and operating speed, confirming that deeper tillage requires greater traction effort and energy input. The most efficient operating range for the upper-tier plough body was identified as 15–17.5 cm, which provides an optimal balance between soil quality indicators and energy efficiency. These findings can serve as a scientific basis for the

design optimization and field adjustment of two-tier disc ploughs to achieve higher productivity and reduced fuel consumption in modern tillage systems.

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