Two-tier plough equipped with an additional loosening device

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ABSTRACT

Analyzed are the conditions and specific features of primary soil tillage under irrigated farming systems of Uzbekistan, taking into account soil and climatic characteristics and agrotechnical requirements. Investigated is the structural design of a two-tier plow intended for double-depth plowing, including existing technical solutions applied in agricultural practice. Revealed is the influence of insufficient soil loosening and increased energy consumption on the operational efficiency of conventional two-tier plows. Studied is the interaction between the upper and lower plow bodies and additional loosening devices of various designs during the soil tillage process. Determined is an experimental comparison of three types of loosening tools-chisel-type, sweep-type, and an inclined-shank loosener of the paraplow type-based on soil clod fragmentation and draft resistance indicators. Established is the quantitative effect of the loosener design on the degree of soil loosening and the draft resistance of the implement. Substantiated is the application of an inclined-shank loosener as a rational component of the two-tier plow design that ensures the required soil treatment quality while reducing energy consumption. Presented is a description of the experimental setup and research methodology based on the principles of experimental design theory and standard testing procedures.

Keywords: device, mechanism, subsoil, par plow, agro technical requirements, parameters

1. INTRODUCTION

In recent years, considerable attention has been paid to improving the energy efficiency and quality indicators of soil tillage machinery and implements in agriculture [1-4]. In particular, the use of additional loosening elements (subsoil, tine) in plow designs has been widely studied in foreign research as a means of reducing soil resistance and positively influencing tillage quality.

M. Askari and co-authors [5] conducted comprehensive studies on the effect of different loosening implements (subsoil, bent leg, par plow) on draft force. Their experiments, carried out under clay loam soil conditions, evaluated the influence of forward speed, tillage depth, and the installation of wings on the loosening shank. The results indicated that while increasing forward speed had relatively little effect on draft, tillage depth and the geometry of the loosening element were the primary factors determining draft requirements. Notably, the addition of wings to the loosening shank expanded the soil–tool interaction area, leading to a significant increase in draft force. At the same time, bent leg loosening elements were found to require less energy compared to other types [5].

Research by M. Ahmed and R. Godwin focused on the positioning of wings on loosening elements and their mechanism of soil interaction. The authors emphasized that attaching wings to the shank increases the degree of soil fragmentation, thereby improving loosening quality. However, as noted in their studies, winged loosening elements substantially increase draft requirements [6].

S. Aday and co-authors [7] investigated the effects of different types of loosening elements on draft force and soil disruption. Their experiments in salty clay soils showed that when the working depth of loosening elements was varied between 25-35 cm, draft requirements increased sharply. The results also revealed that the installation of wings facilitated active disruption of deeper soil layers, but this was accompanied by increased energy consumption. Based on these findings, the authors stressed the importance of selecting loosening element parameters in accordance with the design of the plow or combined tillage implement [7].

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Recent studies have explored the potential of reducing draft requirements by designing loosening elements with bio-inspired (bionic) shapes. One such study demonstrated that bionic-shaped loosening elements required 12–22% less draft compared to conventional straight and curved shanks. These findings highlight the significant potential of optimizing the shape and geometry of loosening elements in improving the design of two-tier plows equipped with additional loosening devices [8-10].

Research conducted by I. Ergashev [11] focused on substantiating the parameters of paraplow-type loosening elements with inclined shanks.

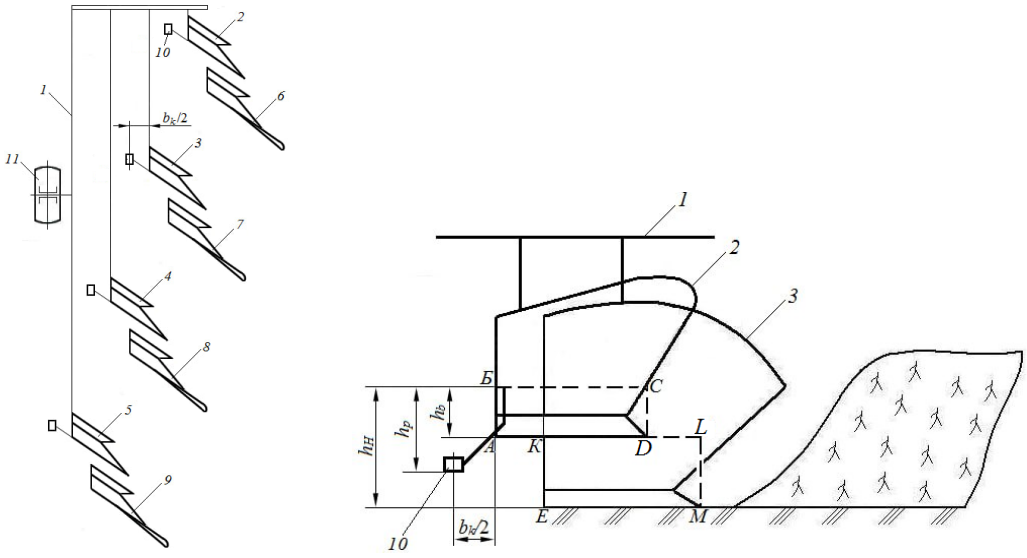
2. MATERIALS AND METHODS

Based on the analytical study of patents, scientific-technical information, and previously conducted research works related to single- and double-tier plowing technologies and the plows implementing them [2, 17, 19], as well as the preliminary investigations carried out by us, the design of a double-tier plow equipped with loosening devices has been developed.

In improving the working process of the double-tier plow with loosening devices, the following factors were taken into account: the relief of the fields; the row spacing of tilled crops; the heterogeneity of the physical-mechanical properties of the soil in terms of depth and width; the fact that existing double-tier plow designs have not fully considered the above-mentioned specific features; and that current double-tier plows tend to produce large clods during operation and fail to meet the established agrotechnical requirements.

Considering these aspects, in the proposed double-tier plow with loosening devices, inclined-post “paraplow”-type loosening elements are mounted on each side of the upper bodies, with their shank blades positioned between the subsequent upper bodies. In this arrangement, the inclined-post “paraplow”-type loosening elements loosen the soil in front of both the upper and lower bodies.

The double-tier plow with loosening devices consists of the frame (1), upper bodies (2, 3, 4, and 5), lower bodies (6, 7, 8, and 9), inclined-post “paraplow”-type loosening elements (10), and the supporting wheel (11) (Figure 1). The inclined-post “paraplow”-type loosening elements (10) are mounted on the sides of the upper bodies using special brackets.



a) b)

Figure 1. Structural design of the double-tier plow with loosening devices and the schematic arrangement of the loosening elements and bodies: a – top view of the plow; b – relative positioning of the loosening element, upper and lower bodies.

In this configuration, the blade of each loosening element shank (10) is installed within the coverage width of the upper bodies (2, 3, 4, and 5), and in terms of depth hp, it is positioned between the cutting edges of the lower body share and the upper body share, i.e. $h_b<h_p<h_H$, here: h_b – installation depth of the upper body share blade; h_p – installation depth of the loosening element shank blade; h_H – installation depth of the lower body share blade.

The technological working process of the double-tier plow with loosening devices is carried out as follows (Figure 2).

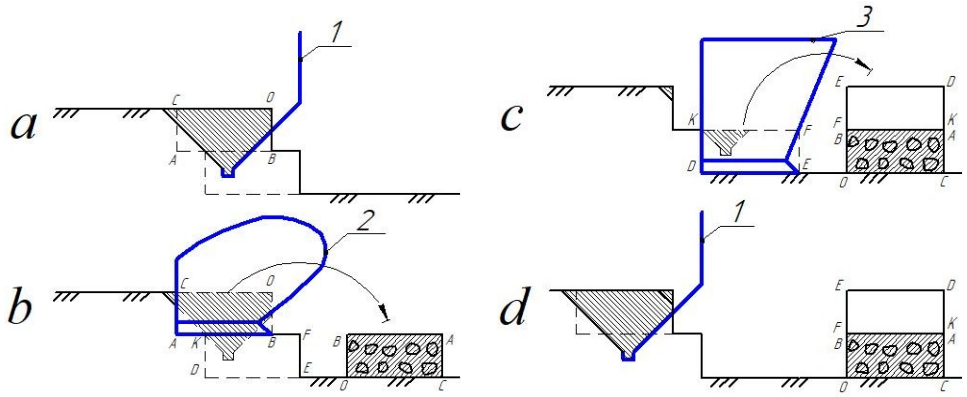


Figure 2. Technological working process of the double-tier plow with loosening devices: a – cross-section of the soil clod loosened under the action of the loosening element; b – overturning of the loosened upper-tier clod by the upper body; c – overturning of the lower-tier clod by the lower body; d – loosening of the subsequent clod under the action of the loosening element.

When the aggregate moves forward, the inclined-post "paraplow"-type loosening elements (1) loosen the clod in front of the subsequent upper and lower bodies (2 and 3) at a certain depth. The following upper body (2) cuts the loosened upper-tier soil (ACOB) and turns it into the open furrow to the side. Then, the lower body (3), moving behind, cuts the semi-loosened lower-tier soil and overturns it onto the clod previously turned by the upper body. This process is repeated under the combined action of each subsequent loosening element (1), upper body (2), and lower body (3). As a result, the degree of soil loosening in the field treated by the plow is significantly improved, especially in fields with insufficient moisture.

It is known [9, 10, 16] that in the working process of a vertical-post loosening element (Figure 3a), the element moves within the middle of the deformed clod, i.e., in a fully compact medium. This increases the load on the loosening element post and, correspondingly, the draft resistance of the loosening element.

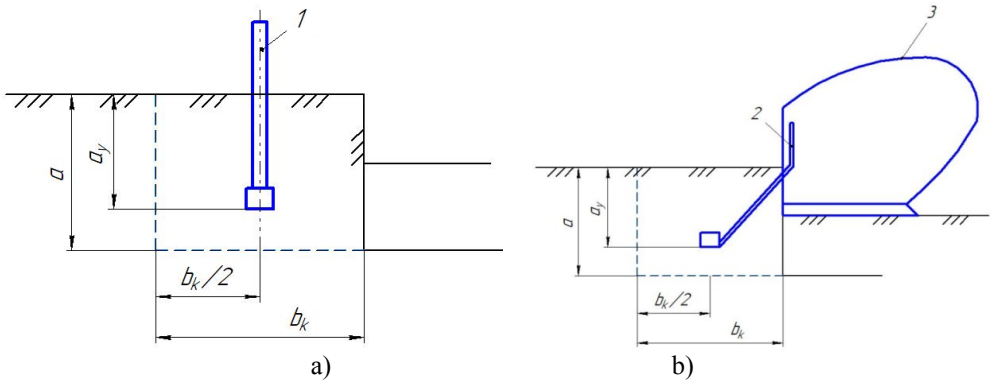


Figure 3. Types of loosening elements: a – vertical-post type; b – inclined-post type.

In contrast, during the working process of the inclined-post “paraplow”-type loosening element (Figure 3b), the clod breaks under the action of its shank at an angle ψ. In this case, the post of the loosening element moves within the crack formed. Consequently, its draft resistance is reduced by up to 30% compared to that of the vertical-post loosening element. Therefore, it was considered advisable to install inclined-post “paraplow”-type loosening elements in the double-tier plow.

In the inclined-post “paraplow”-type loosening element, it was considered advisable to install a chisel-type shank. Such loosening elements, compared to other types-for example, those with wing-shaped shanks-have a simpler construction and lower energy consumption capacity.

In the loosening element, shanks with blades perpendicular to the direction of movement (Figure 4), share-nose type shanks installed at a certain angle to the direction of movement (Figure 4), and wing-shaped shanks (Figure 4) may be used.

The draft resistance of shanks with blades perpendicular to the direction of movement is higher than that of the others, since their blades cut the soil normally, without sliding. Shanks installed at a certain angle to the direction of movement are less reliable, because during operation their noses wear out quickly and may deform. Considering the above, the loosening element was equipped with a wing-shaped shank blade (Figure 4).

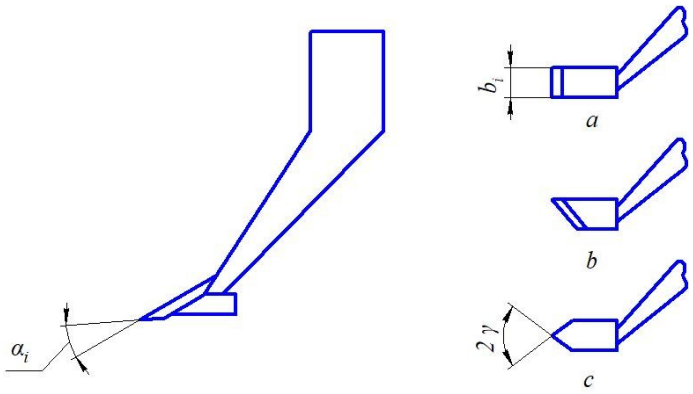


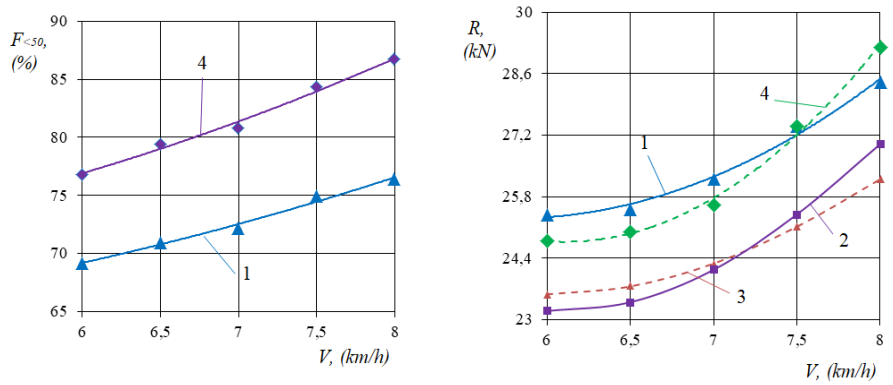
Figure 4. Types of loosening element shanks.

3. RESULTS AND DISCUSSION

Based on the results of theoretical investigations, experiments were conducted to study the performance indicators of the double-tier device with and without loosening elements. In these experiments, the working depth of the upper and lower bodies was set at 15 cm and 20 cm, respectively, while that of the inclined-post loosening element was 25 cm. The longitudinal distance between the lower bodies was 90–105 cm; the lateral displacement of the upper body relative to the lower body toward the field side was 15 cm; the longitudinal distance from the upper body to the blade of the inclined-post loosening element shank was 35 cm; the distance from the field edge of the upper body to the center of the loosening element shank was 22.5 cm; the width of the loosening element shank was 5 cm; and the forward speed of the aggregate was set at 6.0 and 8.0 km/h.

As evaluation criteria for the performance of the device, the degree of soil crumbling and its draft resistance were adopted. The experimental results were compared with the outcomes of theoretical studies. The results of the experiments are presented in Table 1 and Figure 5.

The presented data show that, as the forward speed of the aggregate increases, the soil crumbling degree in both devices (with and without loosening elements) increases according to a concave parabolic law, while the draft resistance also increases following the same law. The installation of loosening elements in the device significantly improves the soil crumbling degree compared to the device without loosening elements, while simultaneously reducing draft resistance. For example, at a speed of 6.5 km/h, the installation of loosening elements improved the soil crumbling degree by 15.56%, and at 8 km/h by 8.7%. At these speeds, draft resistance decreased by 6.4% and 8.17%, respectively.



1 – experimental results (without loosening element); 2 – experimental results (with loosening element); 3 – theoretical calculations (with loosening element); 4 – theoretical calculations (without loosening element)

Figure 5. Graphs of the variation of soil crumbling degree (F<50) and draft resistance (R) depending on the type of double-tier device with and without loosening elements.

From the above, it is evident that the application of loosening elements in the double-tier plow is advisable.

The graphical dependencies presented in Figure 5 can be expressed by the following empirical formulas, determined using the method of least squares:

$$Y_1 = 0.0485714x^2 - 0.8060000x + 4.2037143;\ R^2 = 0.9295255;$$

$$Y_2 = = 2.4x^2 - 28.12x + 151.28;\ R^2 = 0.9934.$$

For draft resistance:

$$Y_1 = 1.2571x^2 - 15.36x + 71.691;\ R^2 = 0.9948;$$

$$Y_2 = 0.6514x^2 - 7.544x + 47.146'\ R^2 = 0.9903.$$

Table 1. Variation of draft resistance and soil crumbling degree depending on the use of loosening elements in the double-tier plow.

Aggregate speed (km/h)	**Soil crumbling degree (*F*<50), %**	**Draft resistance *R* (kN)**	
		Theoretical	**Experimental**
1 – Experimental results (without loosening element)			
6	69.2	25.4	24.8
6.5	69.4	25.52	25
7	72.1	26.2	25.6
7.5	75.8	27.4	27.4
8	79.7	28.4	29.2
2 – Experimental results (with loosening element)			
6	78.5	23.58	23.2
6.5	80.2	23.76	23.4
7	80.5	24.28	24.14
7.5	85.4	25.12	25.4
8	86.7	26.2	27

Based on the results of theoretical investigations, three types of loosening elements were selected for experimental studies: the wing-shaped loosening element, the inclined-post loosening element, and the chisel-type loosening element. As the wing-shaped loosening element, a universal wing with a coverage width of 250 mm was adopted. The inclined-

post loosening element and the chisel-type loosening element had a shank width of 5 cm, with a working depth of 25 cm. The forward speed of the aggregate was set at 6.0 and 8.0 km/h.

For the research on the selection of loosening element types, different loosening elements were prepared (Figure 6). As evaluation criteria for the performance of the loosening elements, the soil crumbling degree and draft resistance were adopted. The experimental results are presented in Table 2 and Figure 6.

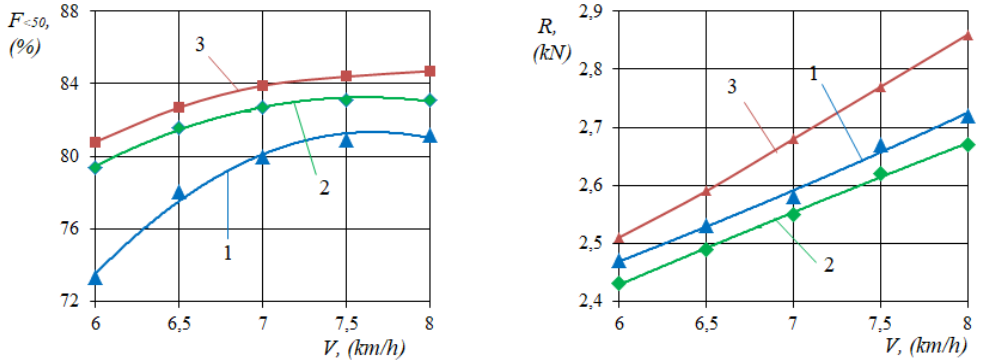
The data show that, with increasing forward speed of the device, the soil crumbling degree under the action of all three loosening elements increased according to a convex parabolic law, while draft resistance increased according to a linear law.

Among them, the wing-shaped loosening element produced the highest soil crumbling degree, whereas the chisel-type loosening element resulted in the lowest values. The soil crumbling degree under the inclined-post loosening element did not differ significantly from that of the wing-shaped loosening element. However, the draft resistance of the wing-shaped loosening element was relatively very high, while that of the inclined-post loosening element was the lowest among the three.

Considering the above, the inclined-post loosening element was adopted as the most suitable type of loosening element.



Figure 6. Different types of loosening elements: a – wing-shaped loosening element; b – inclined-post loosening element; c – chisel-type loosening element.



1 – wing-shaped loosening element; 2 – inclined-post loosening element; 3 – chisel-type loosening element

Figure 7. Graphs of the variation of soil crumbling degree (F<50) and draft resistance (R) depending on the inclined-post loosening element type.

$$Y_1 = 0.0485714x^2 - 0.8060000x + 4.2037143 \quad R^2 = 0.9295255;$$

$$Y_2 = -2.8343x^2 + 49.085x - 131.18 \quad R^2 = 0.9887;$$

$$Y_3 = -2.8343x^2 + 43.416x - 84.931 \quad R^2 = 0.9887.$$

For draft resistance

$$Y_1 = -0.0029x^2 + 0.162x + 1.5594 \quad R^2 = 0.9983;$$

$$Y_2 = 0.0057x^2 + 0.048x + 1.9751 \quad R^2 = 0.992;$$

$$Y_3 = -0.0014636x^2 + 0.1052636x - 0.7390000 \quad R^2 = 0.9998919.$$

Table 2. Variation of loosening element type depending on its draft resistance and soil crumbling degree.

Forward speed of the aggregate (km/h)	Soil crumbling degree ($F_{<50}$), %	Draft resistance (R), kN
Wing-shaped loosening element		
6	80.8	2.51
6.5	82.7	2.59
7	83.9	2.68
7.5	84.4	2.77
8	84.7	2.86
Inclined-post loosening element		
6	79.4	2.43
6.5	81.6	2.49
7	82.7	2.55
7.5	83.1	2.62
8	83.1	2.67
Chisel-type loosening element		
6	73.3	2.47
5	78.02	2.53
7	80	2.58
7.5	80.9	2.67
8	81.2	2.72

4. CONCLUSIONS

According to the conducted theoretical and experimental studies, for the reliable operation of the two-tier plow with minimal energy consumption while fully meeting agro technical requirements, it must be equipped with loosening elements. Based on the results of experimental investigations, in order to ensure the required soil crumbling of the layers processed by the upper and lower bodies with minimal energy expenditure, the two-tier plow should be fitted with an inclined-post loosening element.

The soil crumbling degree of the loosening element with an inclined post is 1.6% lower than that of the wing-shaped loosening element, but 4.19% higher than that of the chisel-type loosening element. The draft resistance of the loosening element with an inclined post is 5.1% lower than that of the wing-shaped loosening element, and 1.56% lower than that of the chisel-type loosening element.

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