Study on plowing of cotton soil using two-tier plow

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Abstract. The purpose of the study is to substantiate the parameters of a two-tier plow for plowing soil from under cotton. The basic principles and methods of classical mechanics, mathematical analysis and statistics were used in this study. The effects of the cotton field relief on the tillage and traction resistance of a two-tier plow were studied theoretically and experimentally. Analytical expressions are obtained for determining the uniformity of the course, the load of the bodies and the center of resistance of the plow, depending on its main parameters and the roughness of the relief of the cotton field. It is established that serial two-tier plows, due to the discrepancy between their width of the gripper and the width of the row spacing, do not meet the requirements of agricultural technology: the plowing depth is not stable, the coefficient of variation of the plowing depth reaches 16% for a trailed plow, and for a mounted plow - 25.8%; the transverse direction of the plough the bottom of the furrow turns out to be stepped; the value of the traction resistance changes at each pass of the plow. To improve the quality of plowing fields from under cotton, a new plowing method has been developed, carried out by a two-tier plow, the width of which is a multiple of the width of the row spacing of cotton. The width of the plow bodies is equal to half the width of the row spacing.
1. Introduction
A better degree of sealing and a greater angle of rotation are characteristic of cultural plowing with pre-ploughs. However, the depth of embedding of plant residues (7-12 cm) is not sufficient for effective control of perennial weeds. Therefore, this technological process in the cotton-growing zone is used only for processing soils for grain crops. More advanced is the technological process of two-tier plowing, which can provide full (100%) and deep sealing of plant residues. K.M.Mansurov [1], R.I.Baimetov [2], M.M.Muradov [2], O.R.Kenzaev [3], V.I.Kravchenko were engaged in research of ploughs in the cotton-growing zone at different times. [4] and others.
F.M.Mamatov [5-12, 14-20, 22-29], I.T.Ergashev studied the influence of the cotton field relief on the work of plows in order to improve the quality of processing and the stability of the plowing unit [6, 10, 16, 27], B.S.Mirzaev [8-13, 15-25, 27, 32], D.Chuyanov [9, 31], H.Ravshanov [8-10, 24, 29, 30], H.Fayzullaev [9, 29, 33] and others.
Studies have found that before plowing cotton fields have a pronounced uneven terrain, characterized by the presence of ridges and irrigation furrows. In fields with a row spacing of 90 cm, the height of the ridges varies from 7 to 24 cm, and in fields with a row spacing of 60 cm from 6 to 18 cm.
The presence of ridges and irrigation furrows in the fields significantly worsens the quality of work and the dynamic performance of the plow: the coefficient of variation of the depth goes beyond the limits of the agrotechnical tolerance (υа=10%), reached the value of υа=24.9%, the degree of unevenness of the traction resistance to δ=0.4, and the bottom of the furrow is obtained stepwise.
The impact of terrain on the performance of two-tier plows has not been studied. Therefore, the establishment of patterns of changes in the quality of plowing and the energy intensity of two-tier plowing depending on the terrain of the cotton field, the improvement of technologies and, accordingly, two-tier plows are urgent tasks of practical importance.
At present, plowing for cotton sowing is carried out by two-tier plows PYA-3-35 and PD3-35, the width of the bodies of which is 35 cm. Cotton fields are usually plowed along the rows. Due to the fact that the width of the row spacing is not a multiple of the width of the body grip, cotton stalks can fall on the furrow cut or field cut of the upper body when plowing. This leads to clogging of the plow and, accordingly, to a violation of the plowing technology, as well as to a sharp decrease in the productivity of the plowing unit. In addition, when processing fields with uneven terrain for cotton sowing with serial plows, the depth of processing varies greatly, and the bottom of the furrow is obtained by steps, since the relief of the cotton field is characterized by the presence of irrigation furrows and ridges., the height of which in fields with a row spacing of $B_M=90$ cm is from 7 to 24 cm, and in fields with $B_M=60$ cm - from 6 to 18 cm. In fields with a row spacing of $B_M=90$ cm, the unevenness of the processing depth can be ±12 cm, and in fields with $B_M=60$ cm – within ±9 cm, which is
unacceptable. This is due to the fact that when plowing, the field (support) wheel of the plow can roll over various places of the row spacing irregularity due to the non-multiplicity of the plow width to the width of the row spacing. At the same time, the depth of plowing changes at each transition of the plow within large limits. Thus, the existing ploughs for processing the soil from under cotton currently do not take into account the factors that are due to the technology of cotton, thus can not fully provide the required quality of processing. Therefore, in the future, it is advisable to bring the design of tools for the main tillage for cotton into line with the complex of machines for working in a certain row spacing width. The purpose of the study is to substantiate the parameters of a two-tier plow for plowing soil from under cotton.

2. Methods and Results
To determine the influence of the cotton field relief on the plough operation, we make the following assumptions: the soil under the influence of the support wheels does not deform; the irregularities of the cross profile between the row spacing are the same throughout the field; the irregularities of the cotton field in the coordinate plane are described as

\[ Z = \frac{h}{2} \sin A(x - e) \]  

(1)

where \( h \) – is the height of the irregularities of the cotton field, cm; \( A \) – is the coefficient that determines the period of the sinusoid; \( e \) – is the phase shift of the sinusoid, cm

The period of the sinusoid depends on the width of the row spacing, i.e. \( A = \frac{2\pi}{BM} \)

When plowing, the plow is set to a given plowing depth, taking into account the uneven terrain of the field. The following relationship exists between the specified processing depth \( \alpha_3 \) and the roughness of the cotton field

\[ \alpha_\gamma = \alpha_1 + \frac{h}{2} = \alpha_\mu + \alpha_v, \]

where \( \alpha \) – is the distance from the bottom of the irrigation furrow to the bottom of the furrow of the arable layer; \( \alpha_v \) and \( \alpha_\mu \) are the specified processing depths of the upper and lower bodies.

The actual depth of \( \alpha_\gamma \) processing with a longline plow will vary depending on the location of the support wheel (Figure 1.a). When rolling the wheel 3 above the x-axis, the depth of processing decreases (Figure 1. b), and increases below the x-axis (Fig.1.a). At the same time, the processing depth of the upper case 1 changes, and the processing depth of the lower case 2 remains constant. From Figure 1a, b we have

\[ \alpha_\gamma = \alpha_\mu + \alpha_0 \]

Actual processing depth of the upper body

\[ A_0 = \alpha_v + Z_{ok} \]  

(2)
where $Z_{ok}$ – is the height of the point of contact with the ground of the support wheel relative to the abscissa $OX$.

Then

$$\alpha_f = \alpha_H + \alpha_{zv} \pm Z_{ok}$$

(3)

The $Z_{ok}$ value of the wheel in each aisle varies depending on the width of the row spacing, the width of the plow and the number of the plow body, as well as the roughness of the terrain.

To establish the regularity of the change in $Z_{ok}$ from the specified parameters, the mounted plow is placed in the row spacing so that the end of the ploughshare of the last body and the middle of the slope of the ridge lie in the same vertical plane. In this case, for the beginning of the coordinate axes, select the point $O$ of the middle of the slope (Figure 2).

From Figure 2 we determine the coordinates of the point $K$ of the support wheel for the first pass of the plow

$$X_{ok}=nB_k+m=B_{pl}+m,$$

where $m$ – is the distance between the wheel and the field image of the last housing.

For subsequent plow passes, it has

$$X_{ki}=K_nB_k+m=B_{pl}+m,$$

Figure 1. Influence of the location of the support wheel in the row spacing on the depth of tillage with the plow
Figure 2. Scheme for determining the actual depth of plowing with a two-tier plow

Figure 3. Scheme for determining the cross-sectional area of the reservoir, which falls on the upper and lower bodies of a two-tier plow

It is known that the quality of two-tier plowing mainly depends on the ratio of the depth of processing of the lower and upper tiers, i.e. $i = \alpha_f / \alpha_b$

When processing fields with uneven terrain
The best arrangement scheme for the upper and lower bodies of two-tier ploughs in terms of plowing depth is: 20:10 \((i=2)\) and 15:15 \((i=1)\) when plowing to a depth of \(\alpha=30\) cm and 20:20 \((i=2)\) at \(\alpha=40\) cm.

The results of computer calculations for 10 plow passes show that when processing fields from under cotton with uneven terrain, the depth of processing varies within large limits, and the bottom of the furrow is obtained stepwise (Fig. 3). At the same time, the unevenness of the processing depth significantly exceeds the permissible value. In the fields with a row spacing of \(M=90\) cm at \(h=18\) cm, the unevenness of the processing depth is equal to and in the fields of \(B_M=60\) cm at \(h=12\) cm - ±5.35 cm.

When \(i=2\), its value changes when processing fields with \(B_M=90\) cm from 1.06 to 8.33, and when \(B_M=60\) cm from 1.49 to 4.21. The value of \(i\) at the set value of 1 varies from 0.82 to 1.53 at \(B_M=60\) cm, and at \(B_M=90\) cm m from 0.63 to 2.42. all this leads to a violation of the technology of two-tier plowing, uneven laying of layers, deterioration of the sealing of plant residues and other agrotechnical indicators of the plow. At the same time, the shape and cross-sectional area of the formation that falls on the body and plow at each pass changes. As a result, the value and point of application of the resultant forces of soil resistance to the plow changes.

The longitudinal-horizontal component \(R_{PH}\) of the resultant force of the plow can be determined by the following formula

\[
R_{PH} = \eta K_{PL} S = \eta K_{PL} \sum_{i=1}^{N} (S_{ib} + S_{ih}),
\]

where \(\eta\) – is the efficiency of the plow; \(K_{PL}\) – is the resistivity of the plow; \(S\) – is the total cross-sectional area of the formation per plow; \(S_{ib}\) and \(S_{ih}\) – are, respectively, the cross-sectional areas of the formation per one upper and lower plow body; \(N\) – is the number of bodies.

To simplify the study of the effect of terrain roughness on the traction resistance and the point of application of the resultant force, we will adopt such a scheme of a two-tier plow, in which the field edges of the upper and lower bodies are on the same longitudinally vertical plane. Placing the X-axis of the abscissa for each plow pass at the bottom of the furrow from Fig.3. we have

\[
S_i = \int_{x_i}^{x_i+(K_i-1)nb_i} (\alpha_i + \frac{h}{2} \sin \frac{2\pi}{BM} x) dx
\]

Here \(x_i=(K_i-1)nb_i=E, \quad x=K_i nb_i=c\).

Calculating the integral (6) we get
When determining the cross-sectional area of the formation that falls on the upper and lower bodies, depending on the installation depth of the upper body stroke and the height of the irregularities, two cases may arise.

The first case when $\alpha \geq h$. In that case, in any passage of the plow, the blades of the ploughshares of the upper bodies will be below the level of the bottom of the furrow or at the level of it. In this case, the cross-sectional area of the reservoir, which falls on the lower bodies, remains constant in any passage of the plow, i.e. $S_H = \alpha H b_k$

The second case is when $\alpha_b < h$. In this case, we first determine the cross-sectional area that falls on the upper bodies, and then the cross-sectional area of the reservoir that is removed by the lower bodies according to the following relationship.

For the first case, the cross-sectional area of the formation falling on any upper body of the plow, taking into account (7)

$$S_i = \alpha_i n b_k - \frac{h}{2} \left[ \cos(AK_i - nb_k) - \cos(Ab_k (K_i - 1)) \right]$$

(7)

The obtained dependence (9) allows us to determine the horizontal component of the elementary soil resistance forces overcome by the plow bodies for any passage of the plow, depending on the roughness of the terrain and the design parameters of the plow.

Using the dependence (10), it is possible to analyze the unevenness of the soil resistance that falls on different bodies, depending on the width of the capture and the number of bodies, the specified depth of processing, the width of the row spacing and the height of the irregularities for any passage of the arable unit.

Assuming that the resultant of the soil resistance forces acts in the center of the cross-sectional area of the soil layer, we determine the coordinates of its center when processing fields with uneven terrain.

The coordinates of the center of the cross-sectional area of the reservoir are determined by
\[ x_i = \frac{M_{x_i}}{S_i} = \frac{\int x \alpha S}{S_i} \]  
(11)

\[ y_i = \frac{M_{y_i}}{S_i} = \frac{1}{2} \int y^2 \alpha y \]  
(12)

where \( M_x \) and \( M_y \) are the static moments of the cross-section of the formation along the x and y axes.

\[ M_{x_i} = \int (\alpha_i + \frac{h}{2} \sin Ax) x \, dx \]  
(13)

\[ M_{y_i} = \int (\alpha_i + \frac{h}{2} \sin Ax)^2 \, dx \]  
(14)

Calculating the integrals (13) and (14) we have

\[ M_{x_i} = \frac{nb_i^2(2K_i - 1)di}{2} - \frac{he}{2A} \cos(AC) + \frac{hE}{2A} \cos(AE) + \frac{h}{2A^2} \sin(AC) - \frac{h}{2A^2} \sin(AE) \]  
(15)

\[ M_{y_i} = \frac{1}{2} \alpha_i^2 nb_i - \frac{\alpha_i h}{2A} \cos(AC) + \frac{d}{2A} \frac{h}{2A} \cos(AE) + \frac{h^2}{16} \sin(2AC) + \frac{h^2}{32A} \sin(2AE) \]  
(16)

The value of the displacement of the coordinates of the center of the cross-sectional area of the formation in the presence of uneven terrain relative to the coordinates of the center of the cross-sectional area of the soil on an equal field area for any plow passage is determined by the following dependencies

\[ \Delta x_i = (E + \frac{hb_i}{2}) - x_i \]  
(17)

\[ \Delta y_i = \frac{\alpha_i}{2} - y_i \]  
(18)

The appendix contains the results of computer calculations of the numerical values of \( d, i, S_i, S_{i'_i}, K_{i'_i}, M_{x_i}, M_{y_i}, AX_i \) and the obtained analytical dependencies (4), (5), (7), (8), (9), (11), (12), (15), (16), (17) and (18). The analysis of the obtained data shows that when the width of the body grip and the width of the plow grip do not correspond to the width of the row spacing, the uniformity of the plowing depth sharply deteriorates. In this case, the depth of plowing changes at each pass of the plow, respectively, the bottom of the furrow turns out to be stepped. Uneven plowing depth leads to a violation of the technology of two-tier plowing. The ratio of the processing depth of the lower body and the processing depth of the upper body varies greatly. The cross-sectional area of the reservoir, which falls on the upper and lower bodies, is also variable and changes at each pass of the plow within large limits, which
causes a change in the coordinates of the center of the cross-sectional area of the reservoir. Consequently, the magnitude and point of application of the soil resistance forces \( R_{xy} \), which fall on individual cases, are different and change at each pass of the plow. Thus, if the gripping width of the bodies and the plow does not match the width of the row spacing, the agrotechnical and energy performance of the plow deteriorates.

If the width of the body and the plow and the width of the row spacing correspond (for example, when \( B_m=60 \text{ cm}, \nu_k=30 \text{ cm}, \nu_{pl}=1.20 \text{ m} \)), the depth of plowing does not change and the same housing is loaded equally on all plow passes. The plow works stably. All this allows us to conclude that when processing cotton fields with uneven terrain, the width of the body and plow \((B_k\text{ and }B_{pl})\) should be a multiple of the width of the row spacing.

The authors developed and manufactured prototypes of trailed two-tier plows PYA-4-30 for plowing soil for cotton sowing with a row spacing of \( B_m=60 \text{ cm} \); the width of the \( B_K \) of the lower and upper bodies is 30 cm. The total width of the plow grip \( B_{pl}=1.2 \text{ m} \), i.e. it is a multiple of the row spacing width. The displacement of the upper tier hulls relative to the lower tier hulls in the direction of the untilled field was 150 mm.

Comparative experimental studies of the plow PYA-3-35 and PYA-4-30 were carried out in November-December 1990 on a plot of cotton with a slight slope. The microrelief is uneven with the presence of irrigation furrows and ridges 12 cm high. The width of the aisles is 60 cm. The weight of the stems is 287 g / m², the average length of the stems is 93 cm. The soil is medium loam. The soil hardness in the 0-40 cm horizon was 3.88 MPa, and the humidity was 16.1%.

The plows were aggregated with a T-4A tractor. The direction of movement of the unit is along the direction of the cotton rows. The plowing depth was set constant-30 cm according to the scheme 10+20 (respectively, the upper and lower tiers).

The table shows the main results of the agrotechnical and energy assessment of the work of the compared plows.

At a speed of 5.46-7.81 km / h, the coefficient of variation of the plow depth of the plow PYA-4-30 is 5.76-6.41%, which is less than the coefficient of variation of the plow depth of the plow PYA-3-35 by 2.65-2.8 times. The uniformity of the plowing depth of the experimental plow, which meets the requirements of agricultural technology, is achieved due to the multiplicity of the plow's grip width to the width of the row spacing, since the field wheel of the experimental plow moves along the bottom of the furrow in all passages.

When working with a standard plow, the value of the coefficient of variation of the processing depth goes beyond the limits of the agrotechnical tolerance \((i_c>10\%)\), reaching 16.8%. This unevenness in the processing depth of a standard plow is due to a change in the position of the field wheel in the row spacing of the cotton at each pass of the plow.
The coefficient of variation of the width of the willows of the experimental plow is 3.85% less than that of the standard plow, since at each pass of the arable unit, the plow processes the soil of two row spacing. This improves the driving accuracy and handling of the tractor.

The depth of embedding of cotton stems and plant residues was from 20.8 to 22.6 cm when plowing with a plow PYA-4-30, and with a plow PYA-3-35 – from 9.2 to 11.1 cm. The experimental plow provides 100% sealing of guza-pai stems. During plowing, the odd upper bodies of the experimental plow remove the ridges of the row with the stems of the guza-pai. In this case, the stems fall on the middle of the blade of the ploughshare. Thanks to this indicator, as well as the stability of the plow course, the sealing of plant residues improves.

The experimental plow PYA-4-30 provides the best indicators for the equalization of the field surface and the crumbling of the soil. The crumbling of the soil by the plow PYA-4-30 was 76.2-84.2%, which is more than 4.9-6.19% of the crumbling of the soil by the serial plow. The crest of the surface of the arable land when plowing with the plow PYA-4-30 was 6.7-6.61 cm, since it, well copying the relief of the cotton field, works stably in depth and width of the grip. In this case, the cross-sectional area of the reservoir, which falls on the upper and lower bodies, does not change in any passage of the plow.

The resistivity of the plow PYA-4-30 is greater by 2.36-3.05% than that of the plow PYA-3-35. This is due to the fact that the experimental plow was equipped with standard plow bodies with an overlap of the ploughshares by 5 cm. However, the coefficient of variation of the traction resistance of the plow PYA-4-30 is 2.44-2.83 times less than the serial one. All this results in a uniform operation of the arable unit with the experimental plow and increases productivity by 15-20%.

Thus, the results of field experiments show the high efficiency of the plow PYA-4-30 for plowing soils from under cotton with a row spacing of 60 cm. All this confirms the relevance of research on the development of ploughs, the width of which is coordinated with the row spacing of cotton, combined arable aggregates that perform several operations simultaneously (plowing, chopping stems, sub-tillage loosening, taking into account the characteristics of the soil, fertilizing).

3. Conclusions

a) Analytical expressions are obtained for determining the uniformity of the course, the load of the bodies and the center of resistance of the plow, depending on its main parameters and the roughness of the relief of the cotton field.

b) Serial two-tier plows, due to the discrepancy between their working width and the width of the row spacing, do not meet the requirements of agricultural technology: the plowing depth is not stable, the coefficient of variation of the plowing depth reaches 16% of the trailed plow, and the mounted plow 25.8%;
the transverse direction of the plow, the bottom of the furrow turns out to be stepped; the value of the traction resistance changes at each pass of the plow.

c) To improve the quality of plowing fields from under cotton, a new plowing method has been developed, carried out by a two-tier plow, the width of which is a multiple of the width of the row spacing of cotton. The width of the plow bodies is equal to half the width of the row spacing.

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