Combined machine for preparing soil for cropping of melons and gourds

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Abstract. The most important link in the system of measures to ensure a high culture of agriculture and obtaining high yields of melons and gourds is tillage. Success in the cultivation of melons and gourds largely depends on the period and quality of tillage, and tillage depends on the methods of its implementation and the perfection of machine design. The aim of the study is to justify the optimal design of the energy-resource-saving combined machine for preparing the soil for sowing of melons and gourds, and the parameters of its carcasses based on the theory of the interaction of carcasses with the soil layer. The paper proposed a new technology for preparing the soil for sowing melons and gourds in a single pass of the unit, including loosening the aisle between adjacent planting zones, simultaneous formation of irrigation furrow by turning the layers of the planting zone relative to each other, strip loosening the subsurface soil layers and preparing the soil for sowing seeds along the sowing line. The paper presents the design of the developed combined machine for the implementation of the proposed technology. The types and mutual arrangement of the working parts of the machine are theoretically justified. It has been established that with a longitudinal distance from the toe of the plowshare of the combination unit to a flat-cutter 35.1 cm, a longitudinal distance between flat-cutters 42.3 cm and a minimum longitudinal distance between the support wheel and a flat-cutter 24.1 cm, the field is prepared for sowing of melons with minimal costs energy.

1. Introduction
Forehanded high-quality soil preparation for the cultivation of melons and gourds is an urgent task in agriculture. Modern technologies for preparing the soil for sowing melons and gourds are carried out in steps i.e. with single-operation machines in several passes, which in many cases is agronomically unjustified. It is known that repeated passes of the machine lead to excessive soil compaction, decrease in labor productivity and increase in labor and resources consumption, delaying the soil preparation time, intensive soil drying, which leads to a decrease in crop yields [1, 2]. In world practice, various combined machines are widely used [1, 3-5].

Subsequent paragraphs, however, are indented. The problems of cultivating and preparing the soil for the sowing of melons and gourds are considered in many scientific publications [1, 6-12].
Studies on improving the technology of preparing the soil for sowing melon and gourd crops, creating machines for melon and gourd farming, substantiating the structures and parameters of their working parts were conducted by V I Malyukov [6], V G Abezin [1], A D Em, V N Zhukov [7], P A Uteniyazov [8] and others. V G Abesin [9] substantiated and developed working bodies for pre-sowing tillage and sowing of melon and gourd seeds. The studies of A D Em and V N Zhukov [7] are mainly aimed at developing machines for inter-row processing of melons and gourds. P Uteniyazov [8] theoretically substantiated the interposition of the working parts of the combined unit for the local application of organic fertilizers. V V Sharov [9], Ya P Lobachevsky [10], S A Zolotaryov [11] and I T Ergashev [12] studied the kinematics of the layers and the theory of the interaction of the carcass with the soil during the rotation of the layer within its own furrow. F Mamatov and B Mirzaev [13] considered the issues of interaction between the layer and the carcass in case of incomplete turnover of the layer within its own furrow. All these studies are aimed at improving the traditional technologies and technical means of processing, which does not meet the modern requirements of agricultural production. However, these studies have not comprehensively addressed the issues of processing and preparing the soil for sowing melons and gourds in one single pass of the unit. Listed limitations can be eliminated by developing soil-energy-saving energy-resource-saving technologies and technical means to prepare the soil for sowing melons and gourds in a single pass of the unit.

The aim of the study is to substantiate the optimal design of the combined machine for preparing the soil for sowing of melons and gourds and the parameters of its carcasses based on the theory of their interaction with the soil layer.
2. Materials and methods
The basic principles and methods of classical mechanics, mathematical analysis and statistics were used in this study.

The authors proposed a new technology [2, 14-18], which provides for small loosening of the aisle between adjacent planting zones (see Figure 1a), simultaneous formation of irrigation furrows by turning the layers of the planting zone relatively from each other (see Figure 1b), the loosening of the subsurface soil layers (see Figure 1c), preparing the soil for sowing seeds along the sowing line (see Figure 1d). Simultaneous execution of the above operations saves the soil moisture, saves material and energy resources for processing and soil preparation. Thus, minimal tillage is ensured by reducing the number of passes of the machine by 3-4 times.

Figure 1. The scheme of the technological process of preparing fields for sowing of melons and gourds and the profile of the cross-section of the field: a - after loosening the aisle between adjacent planting zones; b – after layer turnover; c - after loosening the subsurface soil layer; d - after preparation of aisle for sowing and formation of irrigation furrow.
The combined machine (see Figure 2) implementing the proposed technology consists of a circular knife 1, flat-cutters 2, right- and left-turning screw housings 3 and 4, screw guide plates 5, subsoilers 6 mounted on the rack of the buildings and the roller 7. The roller 7 is mounted to the frame by swivel type. Subsoilers are made like “paralau” [2, 19].

During the operation of the unit, the flat-cutters 2 loosen the soil between the adjacent sowing zones, the right- and left-turning housings 3 and 4 together with the guide plates 5 wrapping the layers of the sowing zone with a width of up to 1.05 m relative to each other, form a preliminary irrigation furrow. In the process of turnover of the layers, subsoil cultivators 6 loosen the subsoil layers of the soil by lanes, and the roller 7 prepares the sowing zones for sowing.

![Figure 2. The layout of the working parts of the combined machine: 1 - circular knife; 2 - flat-cutter; 3 and 4 - right- and left-turning cases; 5 - guide plates; 6 - subsoiler; 7 - roller.](image)

3. Results and discussion

Based on the chosen method, according to the calculations obtained from analytical expressions, the width of the sowing zone took 105 cm, and the width of the strip processed by flat-cutters 180 cm.

The longitudinal distance between the support wheel and the flat-cutter is determined from the condition of a free shift of the deformed soil by the flat-cutter by the following expression

\[ L_1 \geq l_k + a_f \tan(\alpha_f + \phi), \]  

where \( a_f \) - depth of processing of a flat-cutter, m; \( \alpha_f \) - the angle of insertion of the flat-cutter into the soil, degree; \( \phi \) - is the angle of external friction of the soil, degree; \( l_k \) - half length of the depressed part of the support wheel into the soil, m.

At \( \alpha_f=30^\circ; \phi=25^\circ; l_k=7 \text{ cm and } a_f=12 \text{ cm} \) by expression (1) the minimum distance should be \( L_1=24.1 \text{ cm} \).

To determine the longitudinal distance between the flat-cutter and the body, according to the condition, the zone of formation deformation processed by the body did not reach the structural elements of the flat-cutter, the following expression

\[ L_{2_{\text{min}}} \geq (a_c - a_f)((1 - \cos(\gamma + \phi))\sec\gamma \sec\psi + b_c \sec\gamma - l_f), \]

where \( b_c \) - the width of the carcass, m; \( a_c \) - depths of processing of the carcass, m; \( \gamma \) - aitting coulter blade angle to the furrow wall, degree; \( l_f \) - length of a flat-cutter, m; \( \psi \) - the angle of spallation of the soil in a continuous direction, degree.

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Considering that \( a_c = 25 \text{ cm} \); \( a_f = 12 \text{ cm} \); \( \gamma = 45^\circ \); \( \varphi = 25^\circ \); \( l_f = 26 \text{ cm} \); \( \psi = 45^\circ \) and \( b_c = 52.5 \text{ cm} \) according to expression (2) the longitudinal distance between the flat-cutter and the body should be at least 35.1 cm.

The longitudinal distance between the flat cuts is determined from the condition that the deformation zone of the soil with the rear flat-cutter does not reach the structural elements of the front flat-cutter

\[
L_{f \min} \geq \left( \frac{b_f}{2} - \Delta b \right) \tan(\gamma_f + \varphi) + l_f
\]

(3)

where \( b_f \) - the width of the flat-cutter, m; \( \Delta b \) is the overlap of the width of the flat-cutter, m.

With the values of \( b_f = 33 \text{ cm} \); \( \gamma_f = 32^\circ 30' \); \( \varphi = 25^\circ \); \( l_f = 26 \text{ cm} \) and \( \Delta b = 6 \text{ cm} \) by the expression (3) the longitudinal distance between the planers should be at least 42.3 cm.

To select the rational type of the combined aggregate’s carcass were carried out comparative tests of the PLN-4-35 hinged plow carcass, the semi-screw carcass of the revolving plow, the helical hull of the frontal plow and the screw carcass of the frontal plow with guide plates. The results of comparative tests show that the use of a screw housing with guiding plates in the combined assembly as a working body that performs soil tillage with the simultaneous formation of an irrigation furrow provides the formation of the required preliminary irrigation furrow and enables the implementation of a new technology.

Based on the analysis of patent and research works for waste processing of the sowing zone with the simultaneous formation of an irrigation furrow provided for in the proposed technology, the scheme of buildings with a pair-symmetrical arrangement in the form of a lister and consisting of right and left turning cases 1 and 2, equipped with guides plates 3 and 4 (see Figure 3a).

To select the method of layer turnover, which provides the implementation of the proposed technology, theoretical studies were carried out on various methods of layer turnover. The results of the studies showed that it is necessary to carry out the turnover of the layers according to the following method: first, the turnover of the layers is relative to each other without shifting their center of gravity in the transverse direction from 0 to \((\pi/2 + \varphi + \gamma)\) (see Figure 3b). Moreover, each layer, relying on its ribs, is displaced along the bottom of the furrow by a distance of \( e \); then the turnover of the layers from \((\pi/2 + \varphi + \gamma)\) to \((\pi - \delta)\) with a shift of their center of gravity until they touch the furrow edge of the treated field (see Figure 3c). At the same time, \( \varphi = \arctg(a/b) \) and where \( \delta \) is the angle of inclination of the outlined formation.
To determine the angle of inclination of the layers to the horizon $\delta$, the width of the open groove $B_2$ and the height of the ridge, i.e. furrow depth $h_g$, the following expressions are obtained

$$\delta = \arctg \frac{2a}{b + 2e}, \quad h_g = \frac{b}{2} \sin \arctg \frac{2a}{b + 2e}, \quad B_2 = b \cos \arctg \frac{2a}{b + 2e},$$

(4)

where $a$ is the thickness of the layer, m; $b$ - layer width, m.

The calculations performed using expressions (4) - (6) with $a=25$ cm, $b=52.5$ cm and $e=10$ cm showed that the formation slope angle is $34^\circ$, the height of the ridge relative to the bottom of the furrow is $14.7$ cm, the width of the furrow in the middle $43.5$ cm seam. It sufficiently meets the requirements of the proposed technology.

In studying the process of layer movement, an equation of the trajectory of any point of the layer in a fixed coordinate system was obtained with its rotation from $0$ to $(\pi / 2 + \phi + \gamma)$ and from $(\pi / 2 + \phi + \gamma)$ to $(\pi - \delta)$.

The equations of the trajectory of any point of the layer in the fixed coordinate system $AXYZ$ when the layer rotates from $(0)$ to $(\pi / 2 + j)$, obtained with the account of the studies of V.V. Sharov, Ya.P. Lobachevsky, I.T. Ergashev [9, 10, 12] have the following form:

$$\begin{align*}
X &= \frac{b}{2} + R_i \cos(\phi + \omega t), \\
Y &= \frac{\mu b}{\pi} \omega t, \\
Z &= \frac{d}{2} \sin(\omega t \pm j) + R_i \sin(\phi + \omega t)
\end{align*}$$

(5)

where $R_i$ is the distance from the origin $0$ to the sought $i$-th point of the layer in its cross section; $\phi$ is the angle in the $OX,Y_1,Z_1$ system between the $X_1$ axis and the radius $R_i$; $\omega$ - instantaneous angular velocity; $t$ is the current time value.
The results of the study of the kinematics of the layer, based on the obtained expressions (5), show that the main factors for the implementation of the proposed technology are the body width and the length of the guide plate. Based on the kinematics of the formation movement, the length of the guide plate is determined by the following expression

\[ L_z \frac{L(\pi - \delta)}{\pi} \]

(6)

where \( L \) is the length of the layer with its turnover on \((\pi-\delta)\).

For \( L=95 \text{ cm}, \delta=30-35^\circ \) in expression (6), the length of the short heir should be within 73.8-79 cm.

To determine the carcass resistance with the guide plate, the following expression was obtained [20]

\[
R_x = \frac{3\pi h_0^2 K_0^2}{4L^2} + \frac{\sigma_p}{\sin \gamma_1} \sin (\gamma + \varphi) \sin (\alpha + \varphi) + \frac{2\pi a^2 \tau_{sh} \tan \varphi}{\nu} + \\
\frac{a_d \nu_2 (\nu_1 - d_1)}{2 \sin \alpha_r \sin \beta_{sh} \cos \varphi} + \sigma_{pl}(a - a_d) + \\
\frac{q(a - a_d) \nu_2^2}{2 \sin \alpha_r \sin \beta_{sh} \cos \varphi} + f \nu_1 b_1 (1 - \nu_1) \nu_2^2 (1 + \frac{W}{100}) \rho g f_1 + \\
f \nu_1 b_1 h \nu_2 \nu_3 + p \nu_1 b_1 \nu_2 \nu_3 + \frac{1}{2} p_{ch} h \nu_2 f c t g \beta_{sh} + \\
+ f \nu_1 b_1 h \nu_2 \nu_3 + p \nu_1 b_1 \nu_2 \nu_3 + \frac{1}{2} p_{ch} h \nu_2 f c t g \beta_{sh} + \\
+ (ab_w - \frac{b_w^2 \sin \beta_{sh}}{2}) (1 + \frac{W}{100}) \cos \beta_w l_w r g \sin \beta_w \sin \gamma_2 + f \left[ \cos^2 \gamma_2 + \sin^2 \gamma_2 \cos \beta_w \right] + \\
\cos \beta_w - f \sin \gamma_2 \sin \beta_w \\
+ \frac{a p h \nu_2^2 \sin \gamma_2 \left[ \sin \beta_w + f \sin \gamma_2 \left[ \cos^2 \gamma_2 + \cos \beta_w \right] \right]}{c t g \gamma_2 \nu_2 (c t g \beta_w - f \sin \gamma_2)} \left(1 + \frac{W}{100}\right) \rho,
\]

where \( L \) is the length of the twist layer, \( m; [\sigma_p] \) - ultimate strength of soil for tearing, Pa; \( b_p \) - width of the plowshare, \( m; \rho \) - density of the soil, \( \text{kg/m}^3; \alpha \) - the angle of crumbling plowshare, degree; \( m \) - coefficient depending on the size of the layer section; \( [\nu] \) - dimensionless coefficient taking into account the size of the layer; \( \tau_{sh} \) - ultimate strength of the soil during shear, Pa; \( g \) - gravitational acceleration, \( \text{m/s}^2; \nu_1 \) - body length, \( m; d \) - length of the diagonal of the layer, \( m; W \) - soil moisture, \( \%; f \) - the coefficient of friction of the soil on the working surface of the guide plate; \( f_1 \) is the coefficient of friction of the formation along the bottom of the furrow; \( h_0 \) and \( l_0 \) - height and length of the guide plate, \( m; b_r \) - rack width, \( m; \beta_{sh} \) is the angle of sharpening the blade of the stand, degree; \( l_r \) - length of the upper part of the rack, \( m; t_r \) - rack thickness, \( m; p_r \) - specific soil pressure on the side of the rack, Pa; \( \alpha \) - the angle of installation of the rack to the horizon, degree; \( p_h \) is the soil specific pressure on the upper part of the stand, Pa; \( a_d \) - depth of the course of the disk, \( m; t_d \) is the disk thickness, \( m; q \) - coefficient of bulk soil crushing, \( \text{N/m}^3; \sigma_0 \) - temporary resistance of the soil to wrinkling with a blade, Pa; \( b_b \) - blade thickness, \( m; \gamma_1 \) and \( \gamma_2 \) - the installation angle of the initial part and the wing of the guide plate to the direction of movement, degree; \( l_p \) and \( l_w \) - the length of the initial part and the wing of the guide plate, \( m; b_p \) - width of the initial part of the guide plate, \( m; b_w \) - width of the wing of the guide plate, \( m; \beta_w \) - the angle of the wing of the guide plate to the horizon, degree; \( V_c \) - the velocity of the body, \( \text{m/s} \).

The resulting analytical expression allows us to determine the carcass resistance with the guide plates, depending on its design parameters, physical and mechanical properties of the soil and speed of movement.
By the expression (7) with $L=1.5 \, \text{m}$; $K_2=0.56 \, \text{m}$; $[\sigma_p]=5.3 \times 10^3 \, \text{Pa}$; $a=0.25 \, \text{m}$; $b=0.525 \, \text{m}$; $b_p=0.45 \, \text{m}$; $\gamma=45^\circ$; $\varphi=30^\circ$; $m=0.25$; $[n]=0.795$; $t_{sh}=11.4 \times 10^3 \, \text{Pa}$; $g=9.8 \, \text{m/s}^2$; $l_c=0.777 \, \text{m}$; $d=0.58 \, \text{m}$; $W=14\%$; $f=0.5774$; $f_1=0.8391$; $b_p=0.17 \, \text{m}$; $l_p=0.8 \, \text{m}$; $b=0.15 \, \text{m}$; $\beta_{sh}=21^\circ$; $l=0.46 \, \text{m}$; $t=0.025 \, \text{m}$; $p=1.64 \times 10^2 \, \text{Pa}$; $a_6=65^\circ$; $p_{sh}=1.92 \times 10^4 \, \text{Pa}$; $a_6=0.12 \, \text{m}$; $t=0.005 \, \text{m}$; $q=1.107 \, \text{N/m}^2$; $\sigma_0=1.44 \times 10^6 \, \text{Pa}$; $b=0.001 \, \text{m}$; $\gamma_1=18^\circ$; $\gamma_2=21^\circ$; $l_{ip}=0.496 \, \text{m}$; $l_w=0.796 \, \text{m}$; $b_p=0.165 \, \text{m}$; $b_w=0.295 \, \text{m}$; $\beta_w=41^\circ$; $V_c=2-2.5 \, \text{m/s}$ the carcass traction resistance is $4.16-4.48 \, \text{kN}$.

The main parameters affecting the quality of plowing the planting zone and the implementation of the planned process include the arrangement of the relative position of the carcasses, the catch width of the carcasses, the depth of the soil and the length of the guide plate. To determine the rational values of the above parameters, a special laboratory setup has been developed. The change in the relative position of the parts and their width in the range of 40-55 cm, was carried out by shifting the mounting brackets along the transverse beam of the installation. Experimental plates with lengths of 0, 20, 40, 60, 80 and 93 cm were made to determine the rational length.

The results of the experiments show that in both variants of the mutual arrangement of the carcasses, the technology of layer turnover within the limits of its furrow is provided (with a hull width of 52.5 cm and a guide plate of 93 cm).

The main agrotechnical indicators of both variants differ slightly from each other. In the variant in the form of a lister with fixed left- and right-turning housings per rack (Figure 3a), a slight decrease in the depth and completeness of plant residues was observed. However, its quality indicators fully comply with agrotechnical requirements. In the variant of oppositely located working surfaces of each other cases, that is, in the first variant, a ridge with a height of 10-12 cm was formed in the middle of the treatment zone. During the operation of the second variant, a furrow of 9-11 cm deep in the middle of the treated zone was observed.

The formation of a furrow in the middle of the treated zone allows the implementation of the proposed technology for preparing the soil for sowing of melons and gourds. This facilitates the formation of irrigation grooves in the middle of the planting zone. Therefore, to implement the technology provided for, the second option is suitable (see Figure 3a), that is, the layout of the buildings in the form of a lister.

An analysis of the experimental studies shows (see Figure 4 and 5) that with the layout of the buildings in the form of a lister with a pair-symmetric arrangement and a width of capture of each of them 52.5 cm and a length of the guide plate 80 cm, the turnover of the layers and the formation of irrigation furrows are provided minimal cost of energy.
4. Conclusion

- A new technology for preparing soil for sowing melons and gourds makes it possible to reverse the seams of the sowing field of melons with each other while simultaneously forming an irrigation furrow and a strip under-crop loosening, small loosening the aisle between neighboring sowing zones, and preparing the soil for sowing seeds along the sowing line.
- It was established that with a longitudinal distance from the toe of the plowshare of the casing of the combined unit to a flat-cutter 35.1 cm, a longitudinal distance between flat-cutters 42.3 cm and a minimum longitudinal distance between the support wheel and flat-cutter 24.1 cm, the field is prepared for sowing of melons with minimal cost of energy.
- Turn of layers of the sowing zone at the beginning without displacing their center of gravity in the transverse direction, then with a displacement enables the implementation of high-quality plowing of the sowing zone with simultaneous formation of an irrigation furrow.
- The implementation of the combined unit buildings in the form of a lister with a pair-symmetrical arrangement, the width of each of them is 52.5 cm and the length of the guide plate is 80 cm, ensuring the high-quality execution of technological processes of layer rotation relative to each other and the formation of irrigation furrows with minimal energy consumption.

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