Rational plough arrangement for plowing with turnover of the soil layer

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Abstract. The method of basic tillage in the form of dump plowing continues to be dominant in the cultivation of agricultural crops, so plows are being improved in many directions. In some models of ploughs, a full rotation of soil layers, an alternative direction of their rotation, smooth adjustment of the width of the grip, various ways of alternating left-and right-hand working bodies, and many more variations are used. The aim of the study is to summarize the latest achievements in these areas in order to design a rational plow. A rational design should combine the best performance indicators for the quality of work and energy costs as well as ease of maintenance and management of the arable unit. The proposed scheme of a hinged rotary plow can be considered rational, since it performs plowing with high quality at the level of agricultural technology. It provides a smooth state of the plowed surface, a full turn of the layers, deep burying of all plant residues and weed seeds in the soil, and aligns the ridges on the surface layer of the soil. Power consumption during plowing is reduced due to the absence of coulters, field boards, reduced plow weight and accurate orientation of the thrust force vector. The management of the ploughing unit is facilitated by automating the rotation of the working bodies, the absence of idle crossings across the field, reducing the length of the plough, the absence of side loads, as well as by more convenient adjustments.

1. Introduction
Ways of the main processing of the soil are very diverse. The choice of method is influenced by soil and climate conditions, biological characteristics of the cultivated crop, the allowed time of work and the cost of material and technical resources for the field operation. Despite the appearance of simpler and more economical methods of soil cultivation, plowing with plows is widely used because of the better quality of work that implements all the requirements of agricultural technology. The processing depth may be easily increased; plant residues fall into the zone of increased microbiological activity and quickly decompose [1]. After plowing, the soil should be loose with a density of no more than 1.3 g/cm³. Moldboard plough provides the best soil loosening [2]. The layer turnover contributes to deeper sealing of plant residues, and at the same time weed seeds are covered with a thicker layer of soil and lose their ability to germinate [3, 4]. The advantages of the plow become clear when plowing the same field for many years. Then, even without the use of herbicides, a multiple decrease in the number of weeds becomes noticeable [5]. As for herbicides, we should keep in mind not only the harmful effect on the environment, but also the adaptation of weeds to them, since there is an increase...
in the number of weed species resistant to herbicides [6]. Of all the methods of mechanical weed control, only plowing turns the soil layers, so it is considered the main method of weed control [7] and plows continue to improve in many areas of structural modernization and technological impact on the soil. There are several promising directions for development, including use of vibration [8, 9], increasing the angle of rotation of soil layers [10], smooth plowing of the soil with rotary or reversible plows without idling across the field [11].

The plow design can be considered rational if it is characterized by the following qualities:
- moderate overall dimensions and low metal consumption compared to analogues;
- reduced drag;
- alternative direction of rotation of soil layers to obtain smooth plowing without idling moves to the field;
- total turnover of soil layers;
- matching the traction force vector with the direction of travel and the centerline of the tractor to facilitate driving the unit.

Let us look at possible ways to implement these advantages.

2. Results
The simplest and most reliable way to turn soil layers is to expand the furrow before placing another layer in it [10]. This is done by vertical shields mounted at the back of each plough working body. They are installed with the same angle of inclination to the direction of movement as the moldboard of the working body, so during the movement, the angular part of the overturned formation is pushed aside. This shift occurs by 8-10 cm only at the first working pass. After this, the layers are completely inverted, the furrows are wide, and the shields perform only a control function, so they require almost no additional energy. To reduce the metal consumption and for simplicity of construction, options for attaching shields directly to the dumps of the working bodies of the plough were tested (figure 1).

\[ l = a \cdot \cos \left( 0.5 \cdot \pi - \arcsin \left( \frac{a}{b} \right) \right), \]  

Figure 1. Placement of the shield on the working body of the plough (front view): 1 – ploughshare; 2 – moldboard; 3 – shield mounting details; 4 – shield; a – plowing depth; b – width of the soil layer

Theoretical analysis with the use of graphical constructions of the process of turnover of soil layers revealed the dependence of the value of the shift of the soil layer and the minimum required length of the shield:

\[ l = a \cdot \cos \left( 0.5 \cdot \pi - \arcsin \left( \frac{a}{b} \right) \right), \]  

(1)
\[ L = 2 \cdot a \cdot \cos \left( 0.5 \cdot \pi - \arcsin \left( \frac{a}{b} \right) \right), \]  

(2)

where \( l \) is the layer shift, or the width of the zone where the shield operates, m; \( a \) is the depth of ploughing, m; \( b \) is the working body width, m; \( L \) is the minimum length of the shield, m. The graph of dependencies (1) and (2) is shown in figure 2.

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**Figure 2.** The Effect of plowing depth on the width of the zone where the shield operates (1), and on the minimum possible length of the shield (2)

The experiments were carried out on a plough with a working body width \( b=0.35 \) m. At a plowing depth of 0.26–0.27 m, the height of the ridges on the soil surface was equal to 0.04–0.05 m, the average angle of rotation of the soil plates was 176°, and all plant remains were embedded in the soil. Conventional plows with right-hand rotation of soil layers were replaced by plows with an alternative direction of rotation. They implement smooth plowing, that is, without pre-marking the field into separate sections, without the irregularities of the formed microrelief at the borders of the sections. In addition, such plows do not require idling across the field. Smooth plowing is only possible with rotary or reversible plows.

Comparing these two types of plows, we will note their advantages and disadvantages. Reverse plows have fewer moving joints, so they wear out less and are easier to maintain. Their working bodies have the correct geometry of the left and right working bodies. A significant advantage of rotary ploughs is that they are less metal-intensive, so they can be manufactured as attachments with a larger width of the grip than for reversible mounted ploughs. In rotary plows, the left-hand and right-hand working bodies are mounted on the same rack, which means that the field boards are no longer needed [11]. Shields can be placed on rotary plows to widen the furrow and complete the rotation of the layers. In addition, shields can also act as field boards (figure 3).

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**Figure 3.** Placement of shields on the working body of the rotary plough: 1– rack; 2 – rotary beam of the frame; 3 – the axis of rotation of the working body; 4 – the crank of working body; 5 – common connecting rod for all working bodies; 6 – left and right ploughshares; 7 – moldboards; 8 – spacer; 9–fixing bolts; 10-shields
In order to reduce the size of the plough, process passes for soil layers were calculated, provided that the plough was operated without coulters. Based on this condition, for conventional plows, the distance between the working bodies in the longitudinal direction is expressed as a dependence

$$l_1 = \frac{1.7b(1-\sin \delta)}{\sin \gamma_0} + c,$$

where $l_1$ is the distance between the working bodies in the longitudinal direction, m; $b$ is the width of one working case, m; $\delta$ is the angle between the ploughshare and the bottom of the furrow; $\gamma_0$ is the angle of the blade of the ploughshare to the furrow wall; $c$ is the thickness of the rack, m.

For plows with a working body width of $b=0.45$ m, the distance $l_1 = 0.8$ m, and the angle of inclination of the line of the working bodies from the direction of movement is 29°. For more reliable operation of the plows without cluttering the soil and plant residues of the working aisles, we designed plows for production in the city of Voronezh with a distance $l_1 = 0.9$ m and an angle of 27° between the line of location of the working buildings and the direction of movement. Compared to mass-produced plows, this reduced the longitudinal size of the plow with six working bodies by almost one meter. The same dimensions can be applied to a rotary plow, although in this case they will be critical, that is, extremely possible due to the presence of shields.

If the positive results of studies of the process of dump plowing, both ours and existing in the literature, are embodied in one plow design, then we get a rational model that has the qualities listed above (figure 4).

**Figure 4.** Rotary plow rational design: 1 – frame; 2 – guide arc; 3 – turning beam; 4 – slider; 5 – connecting rod; 6 – crank of the working case; 7 – axis of rotation of the beam; 8 – hydraulic cylinder; 9 – shields
The plow works as follows. Let us say plowing starts on the right side of the field. In the raised position of the plow, the hydraulic cylinder 8 rotates the beam 3 with the front end to the right. The plow is lowered into working position and plowing begins. All working bodies are turned so that the right ploughshares and moldboards cut off and turn over layers of soil and the left ploughshares and moldboards rest on their entire curved surface and slide along the wall of the furrow. Therefore, field boards are not appropriate here. At the same time, the right shields 9 expand the formed furrows for a complete turn of the layers, and the left shields 9 rest on the wall of the furrow. Full rotation of the layers eliminates the need for coulters. The second working pass is performed in the opposite direction. Before doing this turn the beam 3 with the front end to the left with the hydraulic cylinder 8. In this case, all working housings are automatically rotated to the position symmetrical to the previous one. In this position, the left sides of the working bodies work, and the right ones create a side support. The automatic rotation of the working bodies around their axes is performed by a crank mechanism consisting of a slider 4, a connecting rod 5 and cranks 6. The slider 4 moves along the beam 3 due to the fact that the ends of the guide arc 2 are at different distances from the axis of rotation 7 of the beam 3. All plow adjustments are simple and easy to perform. The depth of plowing and the horizontal position of the frame are regulated by moving the height of all three support wheels that go through the field, which has not yet been plowed. The width of the grip can be changed by rearranging the stops at the ends of the guide arc 2, but the orientation of the working bodies should be corrected by changing the lengths of the connecting rod 5 and the cranks 6. The plough belongs to the category of rotary, so it is less massive than the reversible, since the paired working body is lighter than two separate bodies. The weight reduction was also achieved due to the elimination of coulters and field boards. The axis of rotation of the beam, on which the working bodies are located, is located in the middle of the distance between the extreme working bodies, so the thrust force vector passes through this axis in both positions of the turning beam and coincides with the axis of symmetry of the tractor. The tractor does not have side loads and steadily maintains a straight direction of movement.

3. Conclusion
The proposed mounted rotary plow scheme can be recognized as rational, since it performs plowing with high quality on the level of agricultural technology, including a smooth state of a plowed surface, a complete turn of the strata, burying all plant residues and weed seeds, as well as aligning ridges on the surface soil layer. Power consumption during plowing is reduced due to the absence of coulters, field boards, reduced plow weight and accurate orientation of the thrust force vector. The management of the ploughing unit is facilitated by automating the rotation of the working bodies, the absence of idle crossings across the field, reducing the length of the plough, the absence of side loads, as well as by making its adjustments more convenient.

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