Calculation of the working element for layer-by-layer soil-free tillage

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Abstract. The paper proves the scheme and proposes a technique of engineering calculation of the working element for layer-by-layer soil-free tillage in conditions of insufficient moisture. Soil treatment causes significant changes in the volume ratio of the solid, liquid and gaseous phases influencing the chemical, physico-chemical and biological processes, accelerating or slowing down the rate of synthesis and destruction of organic matter. Soil cultivation creates favorable physical conditions for soil fertility. It continues to be one of the most important ways to control weeds, pests and diseases of crops. However, the use of known working elements for soil cultivation does not allow to intensify all the factors ensuring the increase and reproduction of effective fertility. The most effective way to achieve this can be the use of a working organ that decompresses the lower horizons, providing differential crumbling of soil layers, creating a mulch layer on the surface and increasing erosion resistance, i.e. layer-by-layer loosening. This improves the structure of the soil, moisture accumulation and aeration of the root layer, which activates the processes of nitrification and will allow plants to use additional nutrients.

When developing and justifying the parameters of the working bodies, it is necessary to take into account the physical and mechanical properties of the soil environment to be treated in such a way that technological processes of the developed machines contributed to the accumulation and conservation of moisture in the soil in conditions of insufficient moisture.

In conditions of insufficient moisture, an exceptional role is played by the moisture reserve in the soil at the beginning of the growing season. Since at the end of the summer in this zone in the root layer the reserves of moisture available to the plants are absolutely insignificant, then its content by the spring of next year is almost entirely determined by the amount of late fall precipitation, rate of use of meltwater, as well as methods for its accumulation and conservation, which include layer-by-layer soil-free tillage.

Low quality of loosening of over-dried soils due to increased hardness, which linearly correlates with the density, can be improved due to rationally chosen parameters and modes of functioning of the working element. It is known that crumbling occurs on the surfaces of least resistance, If the working body does not aspire to directly create the interface, which occurs only when the undercutting layer. Therefore, improving the quality of crumbling should not lead to an increase in energy consumption for soil cultivation, which can be

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reduced due to a rational combination of crumbling and cutting elements of the working element.

The initial stage in the formation of the working elements scheme is the analysis of known structures.

Analysis of known structures of working elements for basic soil-free tillage made it possible to identify trends in the development of the object [1].

So to the original design of the deep loosener in the form of a rectilinear rack with a chisel added paws (slit wideners, moleners, etc.), serving to improve the quality of soil cultivation by forming the required furrow profile.

To reduce the traction resistance of the working element and improve the deepening, rectilinear racks are transformed into curvilinear or inclined along the motion [2].

Giving the degree of mobility to the working element relative to the rack (for example, paws in a transverse-vertical or a bit in a longitudinally horizontal plane) It allows to reduce the traction resistance and improve the loosening quality.

The further tendency of improving the working body is the inclination of the rack not only in the direction of movement, but also in the side direction (for example, Paraplow from Howard company), which provides the best decompression of the formation and is the initial stage in the formation of the trend of development of layer-by-layer tillage.

This tendency finds its logical continuation in equipping the structure with a working element for shallow soil cultivation fixed to the rack.

This construction provides layer-by-layer loosening with the following elements: chisel, inclined part of the rack and working body for shallow tillage. However, by increasing the deformation zone, the traction resistance of the working element increases, which can be reduced by using a curved cutting edge instead of a straight [3,4].

The analysis of trends in the development of the working organs of digging machines makes it possible to identify the curvilinear cutting edge as a constructive solution having a promising direction for improving the technological process of loosening in terms of reducing the energy consumption. The study of the shape of the working organ showed that when processing a layer of increased hardness with a curved edge, the cutting force, and consequently the traction resistance, is reduced in comparison with the rectilinear treatment under the same conditions. This is due to the nature of the interaction of the formation with the working element, the presence in addition to the frontal also oblique cutting, in which along with deformation of compression in the direction of motion, there is a shift of the soil to the sides along the sliding surfaces (least resistance). Reduction of the traction resistance of the working element with an arcuate shape in comparison with the straight-line form is due to the shorter length of the cutting edge with respect to the entire cross-sectional area of the treated formation. Curvilinear cutting profiles are effective to use even with a small width of the working body of the digging machine [5,6,7].

In connection with the foregoing, it is advisable to use a working element with a curvilinear cutting edge when cultivating the soil in conditions of insufficient moisture to reduce the energy intensity of the loosening of the layer. At the same time, some improvement in the elements of the construction of digging work elements is required in the part of their adaptation to the technological process of cultivation of soil without turnover of the layer taking into account the physical and mechanical properties of the environment to be treated.

Data on the physico-mechanical properties of the soil in the experimental field FBBU "Agrarian Science Center Donskoy".

The data of mechanical analysis indicate that the soil cover of the study area is represented by black earth, weakly humus powerful light-clay on lesslike clays, which are their soil-forming rock. Studies have shown that the content of waterproof aggregates increases with increasing depth of sampling of the soil and is due to the structural features of solid phases, the amount of organic matter that forms as a result of irreversible coagulation a film around the aggregates. A higher water resistance of the lower half of the arable (15-25 cm) and sub-arable (25-35 cm) soil layers is noticeable. So in the lower half of the arable layer the amount of water-soluble aggregates is 17.4% higher compared to the upper one, and in the sub-arable layer - by 24.6%. From the foregoing it follows that on the chernozem soil the deepening of the arable layer and mixing with the sub-arable is quite advisable, since structural layers with more water-resistant aggregates are introduced into the culture and microbiological processes are accelerated. From the physics of agriculture it is known that by processing (even at the optimum moisture content) it is impossible to provide an increase in water resistance in soil aggregates. The water solubility of microaggregates in different soil horizons is in accordance with the distribution of humus along the soil profile. However, at high temperatures of the soil and the surrounding air, the decomposition of plant residues can proceed intensively only in the presence of moisture inside the formation, which ensures the formation and accumulation of humus. Otherwise, the decomposition of plant residues continues until the formation of minerals, and the formation of organic substances is not observed. In this regard, measures are required for moisture accumulation and water conservation, i.e. apply layer-by-layer soil-free tillage.

The use of a working element with an open ring element will improve the soil-free tillage, carrying out a layer-by-layer shallow (up to 16 cm) processing and deep loosening with a chisel (25-35 cm). Layer-by-layer loosening provides moisture different in the density and structural composition of the soil layers, which allows moisture under arid conditions to accumulate inside the formation and move under the influence of thermal diffusion processes in the area of the root system of plants.

The proposed working body performs a qualitative crushing of the formation at the lowest energy costs due to deformation of the stretching and bending, less energy-intensive than compression, created on the surface and inside the elliptical ring, whose parameter is a function of the angle of shear of the soil in the longitudinally vertical plane [8, 9].

An ellipse is formed when the ring is designed in the form of a circle on the plane of the soil shear, where (according to Mor's theory) the cutting force by the working body is the least. This achieves the smallest traction resistance of the proposed working body with a curved elliptical ripper.

Since the surface of the field is assumed to be topographically smooth at the macrolevel, the annular element is transformed into a semicircle open in the direction of the day surface, curved in the shape of a half-ellipse whose ends are at the same level in the horizontal plane. This prevents the clogging of the working body with lumps of soil and plant residues

When the soil is loosened by the proposed working element due to the small thickness of each layer being treated, cracks within the formation are observed both in the longitudinal and transverse directions, which allows obtaining the required crumbling quality.

The principle of operation is as follows: when the unit moves at a given depth, the chisel installed on the stand splits and deep loosens the soil layer by 25-35 cm, and the guide installed in the front of the rack produces a soil cleaving due to the blade sharpening angle. The open ring element, mounted on the guide, performs fine processing of the upper layers of the soil, while cutting crop residues. The range of shallow soil cultivation is specified by the parameters of an open ring element made in the form of a half-ellipse. Cutting of plant residues is carried out due to two-sided sharpening of the working edge of the semi-ellipse, both from the outside and from the inside. The grinding angle for the outer working part is 20° – 25°; for the inner working part is 30° – 35°.

The scheme of the proposed working element is shown in Fig. 1.

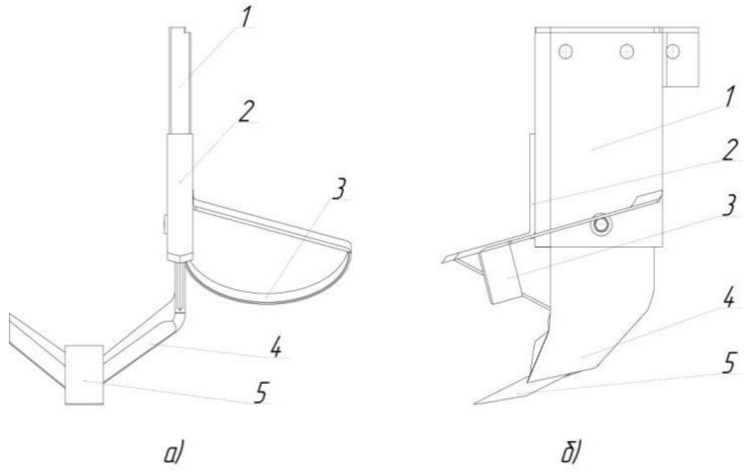

Fig. 1. The scheme of the proposed working element: a – front view; б – side view; 1 – rack; 2 – guide; 3 – curved ripper; 4 – ripper; 5 – chisel

From all the foregoing, it should be noted that, with the help of the proposed working element, layer-by-layer soil-free loosening is provided, while both shallow and deep tillage and a mulching layer of plant residues is created on the surface of the field. On the basis of the conducted researches the technique of engineering calculation of a working element for layer-by-layer soil-free tillage.

The engineering calculation procedure is carried out in the following sequence:

- depending on the physical and mechanical properties of the soil, the working element conditions (hardness, humidity, type and composition of the soil) are determined and the required process parameters (degree of compaction by layers, crumbling quality, combing, depth of shallow processing);

- According to the reference data for the adopted soil conditions, the angles of the outer (φ) and inner (ρ) friction;

- The angle of the cutting edge setting is chosen - the angle of crumbling (β) from the condition of penetration of the working element

$$\beta < \pi - \phi - i \tag{1}$$

where i - angle of sharpening of the cutting edge of the working body,

- the parameter ε_g of the ring elliptic element of the working element is calculated

$$\varepsilon_g = \frac{\pi - (\beta + \phi + \rho)}{2} \tag{2}$$

- taking into account the selected parameter (ε_g) for the required depth of shallow soil processing, the circle element (α) determines the width of the ellipse (b_e)

$$b_e = \frac{2\alpha}{\cos \varepsilon_g} \tag{3}$$

- in case of inconsistency of the width of the ellipse (b_e) with the required indices of the technological process (for example, the depth of the shallow processing (α), a correction factor is introduced that takes into account the angle of deviation of the working plane from the vertical (α_e);

- the stress intensity factor (K_σ) determines the area of the greatest layer pressure along the perimeter of the ellipse, which is specified by the polar coordinate (μ), as the intended zone of local wear of the working member

$$K_\sigma = \frac{\sigma\sqrt{\pi\alpha}}{\frac{\pi}{8}\cdot(3+\cos^2\varepsilon_g)}\cdot\sqrt{\sqrt{\sin^2\mu+\cos\varepsilon_g}\cdot\cos^2\mu} \tag{4}$$

- proceeding from *min* drag resistance (P_T) the angle of crumbling (β) is specified and the rational speed of the unit

$$P_T = f\cdot\sigma+(K+\varepsilon\nu^2)\cdot\left(\begin{array}{c} L'\cdot b_g\cdot\sin\beta+\frac{b_g\cdot b_p}{2} \\ (L-L')\cdot\sin\beta+\pi\cdot\frac{b_e^2}{8}\cdot\left|\sin\frac{\beta+\varphi+\rho}{2}\right|\cdot\cos\alpha_e \end{array}\right) \tag{5}$$

where b_g - chisel width;
b_p - ripper width;
b_e - ellipse width;
L - ripper length;
L' - chisel length.

According to the above technique, the parameters of the working element for layer-by-layer soil-free tillage were obtained (Table 1) at a speed ν, providing high productivity of the unit, traction resistance of which P_T is minimal.

Table 1. Parameters of the working element for layered soil-free tillage

Name	Symbol	Value
Cutting angle,	β	20 – 25
Width of the ellipse, m	b_e	0.33
Ripper width, m	b_p	0.34
Width of the chisel, m	b_g	0.075
Ripper length, m	L	0.25
Length of chisel, m	L'	0.10

The developed technique makes it possible to determine the parameters of the working element for layer-by-layer, soil-free tillage under conditions of insufficient moisture content, depending on the physical and mechanical properties of the medium to be treated and the required indices of the technological process.

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