Justification of parameters of working body of deep loosener

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Abstract. The article presents the analysis results on the study of physical-mechanical properties of soils in Uzbekistan and experimental studies on the influence of parameters and rational geometric shape of working tools on the quality of soil tillage while reducing energy costs. It has been established that soil moisture and hardness in the periods of basic and pre-sowing tillage differ significantly according to weather conditions, agrophonous background, and sowing and harvesting technology of agricultural crops. The peculiarities of different soils and the main directions of preserving and increasing their fertility are considered. The problems of optimization of physical properties and issues of the fertility state of irrigated soils are highlighted. Special attention is paid to the problems of improving soil's basic physical and mechanical properties. The use of effective technologies for improving and ameliorating irrigated lands, increasing fertility, and reducing and preventing soil salinization is proposed. For prevention of decrease and preservation of soil fertility, purposeful measures on improvement of physical properties of soils are recommended, the mechanism of which solution is the application of innovative technology of processing providing purposeful growth and development of root system, moderate moisture of soil, increased water permeability, moisture stocks, and reduction of salinization. To prevent intensive moisture evaporation after deep tillage, it is recommended to carry out agrophobic treatment by maximum leveling and creating a shallow crumbly surface layer. To substantiate the parameters of the deep loosener were based on the fact that the degree and magnitude of soil deformation depend on both the shape and parameters of interacting working bodies and on the physical and mechanical properties of the cultivated medium.

1 Introduction

Soil cover is the main natural resource that the Republic of Uzbekistan has and on which the development of such sectors of agriculture as cotton growing, grain production, horticulture, vegetable growing, etc., depends. Preservation and rational use of moisture in

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conditions of intensive agricultural production is a priority in planning agricultural crop rotations and the use of machinery. Consequently, loss of soil moisture occurs with soil compaction under the influence of repeated passes of different and heavy machinery during its treatment. Besides, excessive physical evaporation formed during compaction should be attributed [1]. These two types of loss of soil moisture damage agriculture, and a set of measures aimed at optimizing the use of machinery leads to an increase in productive moisture reserves in the soil. It should be noted that atmospheric precipitation in our zone is not enough for reliable farming. For this reason, irrigated agriculture was introduced in Uzbekistan. At irrigation, the requirements for soil protection become even more strict than at non-irrigated agriculture, which is necessary for the prevention of irrigation erosion, the rise of groundwater table, and salinization

Analyses have shown that in irrigated soils, there are practically no horizons with volume weight less than $1.1\ g/cm^3$, the specific weight of the solid phase of soil less than $2.60\ g/cm^3$. Even in the upper horizons of the whole sierozems, the volume weight varies 1.1...1.2 g/cm^3, increasing up to $1.43\ldots1.45\ g/cm^3$. The density of desert soils is compacted and varies from $1.3\ldots1.4\ g/cm^3$ to $1.45\ldots1.50\ g/cm^3$. Profile of irrigated 45...50 years old and more development of old-irrigated sierozems and soils of the desert zone are compacted more than the arable horizon. In the arable horizon, soil density is $1.35\ldots1.50\ g/cm^3$ and in the subsoil $1.45\ldots1.65\ g/cm^3$and more. The specific weight of the solid phase of irrigated soils varies from $2.65\ldots2.70\ g/cm^3$, slightly decreasing to $2.60\ g/cm^3$, in the upper, more humusy horizons of irrigated meadow soils coming from under alfalfa. Total porosity does not exceed 60%, mainly its indicators are within 45...55% at optimal soil density $(1.2\ldots1.3\ g/cm^3)$ [2-5].

Soils of cotton areas of Uzbekistan also have unequal specific resistance, the value of which in soils of loamy texture (at the time of raising the seedbed) is usually 50...70 kPa. In dried and compacted takyr soils of clayey and heavy loamy texture, specific resistance reaches 90...100 kPa and higher. The lowest values of specific resistance (30...50 kPa) are characterized by light loamy sierozems, hydromorphous soils, and soils of the desert zone. Therefore, under conditions of Uzbekistan, ploughing with a turnover of layer and deep tillage without turnover of the layer is an important agricultural technique, which improves moisture availability of plants, reduces the number of irrigations, increases the efficiency of moisture use by more than 12-19%. This makes it possible to increase soil productivity in the cultivation of crops. One of the most common ways of moisture accumulation in the regions of Uzbekistan is the retention of snow and melt water, which requires various methods of cultivation, such as deep loosening and slotting in the long and across the fields and slopes [1, 6].

The works of M.Kh. Pigulevskii, G.I. Pokrovskii, V.V. Katsygin, A.N. Gudkov, G.N. Sineokov, V.A. Zheligovsky, T.M. Gologursky, A.S. Kushnarev, M.L. Nichols, W.R. Gill, W. Soehne and many others. Theoretical and experimental studies of scientists on soil deformation during the interaction of working tools of tillage machines show contradictory results. According to well-known scientists [7], it is argued that the main type of deformation under the influence of wedge-shaped working tools is shear. The results of experimental studies conducted by T.M. Gologursky, V.P. Goryachkin, G.N. Sineokov, and other scientists also testify that the main type of deformation at the interaction of working tools with soil monolith is shear. According to these scientists influence of the working organ on soil causes its compression, and at reaching a limit state, the shift of soil is observed. However, other scientists say that the destruction occurs by tearing off at the interaction of working bodies on soil mass with heavy texture, especially on clayey and loamy soil masses. The studies of V.V. Borodkin and V.G. Kiryukhin established that loamy and clayey soils under the influence of the working body are destroyed by tearing away. The given data testify that the separation of soil particles from monolith by shearing or tearing off occurs depending on the constructive form and parameters of working tools, the type of soil and its condition. It is stated that tillage of the soil, which has a cohesive structure, leads to the separation of soil layer from monolith by tearing off, and in soils with more loose structure - by shearing. According to the data of I.M. Panov and I.V. Suchkov [8] and other scientists, the character of soil monolith destruction depends on the parameters of the working body (shape of the lateral profile, crumbling angle, ripping depth) and physical and mechanical soil properties (moisture, density, hardness, external and internal friction angles). According to scientists, the values of the sum of crumbling angles and external friction, equal to 500, destroy the soil monolith by tearing, with more than 500 - due to shear. Research analyses show that the resistance of soil to tearing is always less than the shear resistance. V.P. Goryachkin, concerning G. Gologurskiy, gives the following values of strength criteria of soils: at tension 0.05...0.1 kgf/cm^2; at compression 0.1...0.5 kgf/cm^2. This indicates that tearing deformations develop faster than shear deformations. This is explained by the fact that under the impact of the working body on the soil monolith, when the normal stresses reach the value of time resistance to rupture, the plane of the bottom of the furrow appears ahead of the crack of the tear-off surface. Also, I.M. Panov and V.I. Vetokhin [9] note that the temporary tensile strength decreases significantly with increasing humidity, especially sharply beginning with a 19...20% humidity. This indicates that the tensile and shear resistances depend on soil moisture and, in addition, that the bending resistance is much greater than the tearing resistance.

2 Materials and Methods

Taking the soil out of circulation could lead to an ecological catastrophe for all mankind. Nevertheless, today the biggest problem of the 21st century is still the problem of food security worldwide, and it continues to exist.

Projections show that while there were 3.5 billion people worldwide in 1970, that number now exceeds 7.5 billion. It is expected that by 2050 that number could reach 10 billion. Whereas in 1950, fertile soils were 100 percent, the food needs 80 percent, by 2050, soil fertility is expected to decrease to 25 percent, increasing food needs to 160 percent [4].

Only 20.7 percent of our country's 20.2 million hectares of agricultural land is irrigated. Over the past 15 years, the availability of irrigated land per capita has decreased by 24 percent (from 0.23 ha to 0.16 ha).

This results from population growth, declining water supplies, and the conversion of agricultural land to other land fund categories. Approximately 16.4 million people (49.4% of the total population) live in rural areas of the country (2018). The population under the age of 25 is 45.5%, and more than 55% of the population is under 30.

Over the next 30 years, irrigated acreage is projected to decline by another 20 to 25 percent.

Given the high degree of dependence of farming on irrigation, the situation may worsen with increasing aridity due to climate change and the continued use of traditional irrigation methods.

According to the World Resources Institute forecast, by 2040, Uzbekistan may become one of the 33 countries with the greatest water deficit. Declining crop yields will lead to serious negative consequences for food security and the balance of payments, emphasizing the need to transition to sustainable water management practices and resource-saving technologies in crop cultivation.

The absence of a mechanism for reimbursement of costs for water supply for agricultural needs restrains the widespread introduction of water-saving technologies. The main task of this priority is to ensure rational and efficient use of natural resources and environmental protection in the sustainable development of agriculture. It is planned to use effective technologies to improve and provide reclamation of irrigated land, increase soil fertility, and reduce and prevent soil salinization [4].

To achieve these objectives, the following tasks are defined: reducing water use per hectare of the irrigated area by 20 percent by 2030; improving state support mechanisms for local producers of water-saving technologies; increasing the total area of land irrigated using water-saving technologies [4].

It should be noted that intensive farming systems based on repeated passes over the field with the more powerful and heavy machinery and tractor aggregates, and deprivation of soil vegetation cover, led to the expansion of wind and water erosion zones. Negative phenomena of modern farming systems have caused an intensive search for new crop cultivation technologies and tillage methods. However, analyses show that not all new technologies can fundamentally solve the problem of rational and efficient use of natural resources and environmental protection.

In the "Tashkent Institute of Irrigation and Agricultural Mechanization Engineers" National Research University, the research works on the mechanics of the interaction between ripper working tools and soil are conducted. Research work is based on studies of several domestic and foreign scientists, and it is established that in the process of interaction of tillage working tools with the soil, the following phenomena occur in the soil [10-12-15]:

- Compaction of the soil in front of the working body compared to its natural state that the soil density in individual clods becomes higher than before tillage.
- When the surface geometry and implement parameters do not match the physical and mechanical properties of the soil, the furrow bottom below the implement and the formation of a compacted core in front of the implement are compressed.
- These phenomena lead to additional energy costs and affect the quality of deep tillage.
- In connection with this, when developing and designing the main technological parameters of ripping working tools, according to recommendations of scientists [10-15], the following was used:
- Agrotechnical requirements for the quality of loosening the soil;
- Physical and mechanical properties of soil.

The designed working body should provide deep loosening within agrotechnical limits and a fine crumbly structure without removing lower soil layers to the day surface, even unconsolidated undersurface and soil surfaces.

According to the Coulomb-More theory of strength, the main indicator of the mechanical strength of the soil is the angle of internal friction. Based on the results of research [14-16], the side profile of the ripper working body made in the form of a logarithmic curve with the initial angle of installation to the bottom of the furrow equal to no more than $\beta = 45 - \varphi_n/2$, does not compact the bottom of the furrow. In the case when the inclination of the tool to the bottom of the furrow will be more $\beta = 45 - \varphi_n/2$, then two sliding surfaces are formed. The presence of two sliding surfaces leads to soil stratification. The soil layer (called by A.N.Zelenin) as a "compaction core" between the working body and the resulting soil block is compacted and brought to the surface. The formation of soil block is produced not by the working body but by the moving compaction core [11].

We propose to justify lateral and transverse shapes and basic parameters of the ripping working tool (width, inclination angle, and outreach).

According to the results of the analysis of scientists [4, 7, 8, 11, 12], the best crumbling is provided by ripper working tools with a lateral profile made in the form of a logarithmic curve or on the arc of a circle.

In this case, the bottom of the furrow is obtained even and unconsolidated at the angle of installation of the ripper to the bottom of the furrow

$$\beta \leq 45 - \frac{\varphi_n}{2}$$

where φ_n is the angle of internal friction, deg.

At the same time, the greatest slope of the side profile of the loosening tool tine to the bottom of the furrow should not exceed $90 - \varphi_n$ on the condition of the normal descent of soil, weeds, and crop residues from the working body.

The height of the breast of the ripping tine h and the outreach of its toe L depend on the soil condition and are determined by the angle of internal friction of the soil and the depth of the working body.

As the angle of internal friction of soil in conditions of irrigated agriculture depends on moisture, it is necessary to aspire to make so that to provide high-quality loosening of soils of various conditions, the design of a working body corresponds for dry and damp soils.

Based on those mentioned above, it is recommended to make the lateral profile of the loosening tool in the form of the logarithmic spiral of the following form

$$r_i = r_0 e^{\pm \theta_i tg \varphi_n} \quad (1)$$

where r_i is the current radius vector, mm; r_0 is the initial radius vector, mm; θ_i is the current polar angle, rad; φ_n is the angle of internal friction, deg; e is the base of the natural logarithm.

In equation (1), the sign "plus" is taken for the values of current polar coal θ_i, in the area θ_n, and the sign "minus" - in the area θ_B. The pole of the logarithmic spiral (O_1) is taken at the level of plowing depth, i.e., subsoil horizon where soil density is higher than the allowable density ($\rho > 1.3 \div 1.5$ g/cm^3).

The upper part of the lateral profile of the working body, made by the logarithmic spiral, is limited by point C and defined by angle θ_B. From point C, the lateral profile transitions to a vertical straight line. The lower edge of the lateral profile of the implement is defined by the outreach of the ripper blade.

The upper θ_B and lower θ_n polar angles can be determined by the formulas

$$\theta_B = \frac{3}{2}\varphi_n - 45^0; \quad \theta_n = 90^0 - \varphi_n \quad (2)$$

The total angle defining the logarithmic part of the lateral profile is equal to the sum of the angles θ_B and θ_n

$$\theta = \theta_n + \theta_B = 45 - \frac{\varphi_n}{2} \quad (3)$$

These angles depend only on the angle of internal friction, that is, on the type and condition of the soil.

To build a side profile, it is necessary to have the value of the initial radius vector (r_o), which is determined from the ratio

$$r_0 = \frac{h_0}{e^{\theta_n tg\varphi_n}\cos\theta_n} \qquad (4)$$

It should be noted that for a given value of the depth ($H = 45 \div 50$) of the stroke of the working body, the value of the initial radius vector of the lateral profile depends on the state of the soil. We chose average values of the angle of internal friction of soil for conditions of Uzbekistan ($42^0 ... 47^0$).

3 Results and Discussion

The main criterion for determining the necessity and depth of loosening was soil density. From the energy point of view, the efficiency criterion of the deep loosening process was the minimum specific energy input for breaking the dense soil monolith.

Based on the above method, the side profile of the stand was designed (Fig.1).

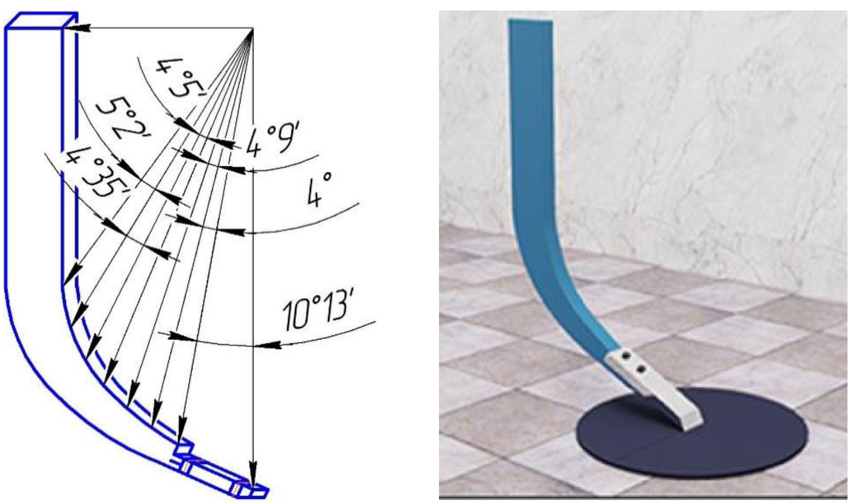

Fig. 1. To the method of construction and designed side profile of the deep loosener post

During the experiments, the working tool parameters were selected based on the above criteria, i.e., the width b and thickness δ of the ripping bit and its offset relative to the front face of the stand, the bit installation angle relative to the horizontal plane β, its sharpening angle i, the width B and the thickness S of the stand.

Based on earlier studies by famous scientists [1, 8, 9], some parameters are justified without additional research. The thickness of the bit and the stand was chosen based on material strength equal to 15...40 mm [4, 7,8]. The angle of bit installation to the horizontal plane $\beta = 30^0$. To improve the penetration and stability of the bit's depth stroke, the bit's sharpening angle was made in limits $i = 40^0...45^0$ [4, 7, 8].

Field experiments were conducted in the fields of "Tashkent Institute of Irrigation and Agricultural Mechanization Engineers" National Research University ("TIIAME" NRU) training and experimental farm in the Middle-Chirchik district of Tashkent province. Soil analyses were conducted on the plots of cotton and grain fields. Soil analyses were taken up to 0.8 m depth (Fig. 2).

Fig. 2. Excavated pit for soil analysis by horizon

Soil conditions during the experimental studies are presented in Table 1.

Table 1. Soil moisture and density

Indicators	Soil horizons, *m*						
	0…0.1	0.1…0.2	0.2…0.3	0.3…0.4	0.4…0.5	0.5…0.6	0.6…0.7
Humidity, *%*	9.78	13.42	13.60	13.65	13.80	14.50	15.10
Density, g/cm^3	1.07	1.13	1.20	1.31	1.42	1.50	1.54

In the experimental studies, we solved the problem of the influence of the working body lateral profile on the processing quality and energy intensity of processing based on soil and climatic characteristics of the irrigated agriculture zone in the production of cotton and grain crops to establish the rational shape of the lateral profile of the deep loosener's legs.

We made different variants of the working body's racks. In the first and the second variants, the lateral profile is made on the arch of the circle. In the first variant, the circle center is on the soil surface, and in the second variant, it is at the level of the ploughing horizon considering the height of soil lifting by ripping chisel. The third and fourth variants are made according to the logarithmic spiral but with different stem extensions. The results of field tests are presented in tables 2-5.

Table 2. Qualitative indicators of the experimental working tools of the deep loosener

№	Setting depth of loosening, m	Actual ripping depth, H_D, m	The average forward speed of the unit, υ_{cp}, m/s	The area of the loosened deformation zone, F_p, m^2	Width of soil deformation A, m	Quality indicators of crumbling (fractions smaller than 50 mm), %
Var-1	0.40	0.42±0.03	1.14	0.24±0.04	0.85±0.13	52.4
	0.45	0.46±0.01	1.11	0.26±0.04	0.87±0.04	55.6
	0.50	0.50±0.06	1.09	0.29±0.01	0.97±0.11	55.9
Var -2	0.40	0.41±0.06	1.22	0.22±0.02	0.78±0.06	50.9
	0.45	0.42±0.02	1.16	0.24±0.02	0.78±0.05	49.8
	0.50	0.50±0.04	1.11	0.29±0.01	0.94±0.06	53.6

Var -3	0.40	0.40±0.02	1.22	0.19±0.01	0.73±0.08	65.7
	0.45	0.45±0.02	1.14	0.23±0.01	0.86±0.07	68.3
	0.50	0.50±0.01	1.11	0.31±0.01	1.00±0.04	71.4
Var -4	0.40	0.41±0.04	1.22	0.23±0.03	0.76±0.05	63.9
	0.45	0.48±0.03	1.11	0.27±0.05	0.82±0.04	66.0
	0.50	0.50±0.06	1.08	0.30±0.01	0.97±0.10	67.8

Table 3. Energy performance of experimental working tools of the deep loosener

№	Setting depth of loosening H_{ust}, m	Actual ripping depth, H_D, m	Traction resistance R_x, kN	Specific traction resistance $K_{ud}, N/cm^2$	Specific traction resistance per unit of ripping depth $R_x/H_D, kN/m$
Var-1	0.40	0.42±0.03	11.32±1.93	4.71±0.83	26.95
	0.45	0.46±0.01	15.13±2.50	5.81±0.86	32.89
	0.50	0.50±0.06	18.70±3.67	6.44±0.18	37.40
Var-2	0.40	0.41±0.06	13.66±2.54	6.21±0.76	33.31
	0.45	0.42±0.02	17.55±3.40	7.31±0.39	41.78
	0.50	0.50±0.04	19.76±2.87	6.81±0.15	39.52
Var-3	0.40	0.40±0.02	10.96±1.20	5.76±0.19	27.40
	0.45	0.45±0.02	12.52±1.91	5.44±0.20	27.82
	0.50	0.50±0.01	18.14±2.12	5.85±0.45	36.28
Var-4	0.40	0.42±0.04	11.93±1.31	5.18±1.31	28.40
	0.45	0.48±0.03	14.60±2.65	5.41±1.10	30.41
	0.50	0.52±0.06	21.93±3.68	7.31±0.28	42.17

Quality and energy indices of working tools were determined at different working depths and at different, forward speeds (set working depth 0.40, 0.45, 0.50 m; movement speed of aggregate was in the range 0.98...1.76 m/s).

The given experimental data show that the highest quality of deep tillage is provided by the third and fourth variants of experimental working tools of deep loosener. However, the third variant is stable in depth tillage (deviation from the set depth 0.1-0.2 cm) and in specific traction resistance. The quality of tillage is inferior to the fourth variant.

Obtained experimental data confirmed the theoretical assumptions on the interaction of working tools with soil. They made it possible to evaluate the work of working tools in terms of energy and quality of tillage from the shape of their lateral profile.

4 Conclusions

The theoretical and experimental studies allow us to draw the following conclusions and suggestions:

1. The analysis of the literature and research suggests that deep loosening is necessary for the decompaction of subsoil horizons, contributing to an increase in moisture storage and the development of the root system of agricultural plants. All this, in general, leads to an increase in crop yields.
2. One of the ways to improve the quality of tillage with simultaneous reduction of energy consumption is to study the influence of parameters and the rational geometric shape of working tools.
3. The results of experimental studies confirm that the geometric shape of the working body's cutting profiles significantly affects the tillage process's energy intensity.
4. To reduce traction resistance and improve the quality of machining, the working body is proposed, the lateral profile of which is made in the form of a logarithmic curve

initial setting to the bottom of the furrow, equal to no more than $\beta = 45 - \varphi_n/2$, the distinctive features of which are the possibility of tillage with high values of the quality of cultivation and lower energy costs.

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