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Selection and substantiation of cultivator adjustment parameters for differential soil treatment on potato based on the rheology state of soil horizons

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Abstract. The article presents results of theoretical studies on the determination rational parameters of placement tines on the frame interrow cultivator for differential tillage of potato field. Differential tillage means depth adjustments of tines according soil condition and their placement on the cultivator frame. The main goals of differential tillage by inter row cultivators are the elimination of soil compaction between ridges, formed by potato planters, as well as loosening of the zone of location of the potato tubers. Deep loosening after planting provides good conditions for the complete assimilation of water by soil after rain or irrigation, protects the top soil layer from erosion and also eliminates the over moistening in the autumn. Loosening the soil in the zone of the tuber placement ensures the obtaining of a fine-grained soil structure, which helps to create best conditions for the growth of plants and development their root system, as well as to ensure favorable conditions for soil separation during harvesting. The substantiation of rational parameters for tine placement on the frame of row cultivator was carried out on the base of the regularities of soil rheology, the heterogeneity of soil composition in different layers of arable and subsoil horizons, as well as the variability of their physic-mechanical properties. These regularities influence the development of deformation and cracked zones during the interaction ripper tines with the soil. As a result of the theoretical studies was developed a method for calculating the rational placement of ripper tines on the frame of the row cultivator for fulfil differential tillage on the potato based on the rheological state and heterogeneous structure of the soil horizons. Using of this method allow ensure high quality structure of tilled soil.

1. Introduction

Removing of compacted zones during hilling of potato is an important factor in increasing crop yields and product quality. Investigations of traditional European technology of potato growing have established [1] a significant increase in soil density occurs after potato planting. Increasing of soil density in this case is a result of man-made impact after action of the wheel systems of heavy tractors and planters (Figure 1).

In order to eliminate the compaction after planting it is proposed to use the differentiated tillage that allow provide deep loosening inter row space during hilling of potato [2, 3]. For the implementation of this tillage method on the row cultivator was installed rigid tines (ripper tines) with chisel points (Figure 2), which performs deep loosening between rows, and two side spring tines with chisel points that moves along borders of protective zone c [4]. All installed chisel points are adjustable in height and lateral ones



can also move relative to the center. For final ridge forming behind all these tines are installed ridging mouldboard or ridging hood [5]. The proposed scheme of tines placement on the frame of row cultivator in addition to destroying of compacted zone make it possible to create the best conditions for the development of plants and spreading their roots into soil as well as providing fine crumbling of soil layers around potato tubers. In order to fulfill these actions by row cultivator during differential tillage of the potato were justified rational location of all offered type of tines on the cultivator frame based on the carried out theoretical studies.

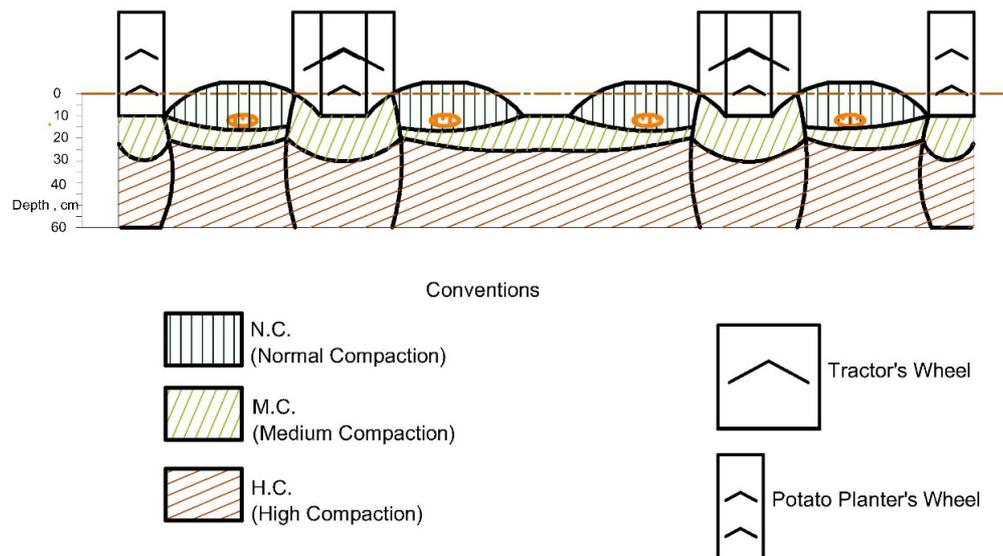


Figure 1. Distribution of compacted zones in the soil after the potato planting.

Objective of our researching is determination of technological parameters for the rational placement of ripper and spring tines on the frame of inter row cultivator carry out on the basis of calculation zones of soil deformation, taking into account the rheological state of soil horizons having a heterogeneous structure and various physical and mechanical properties.

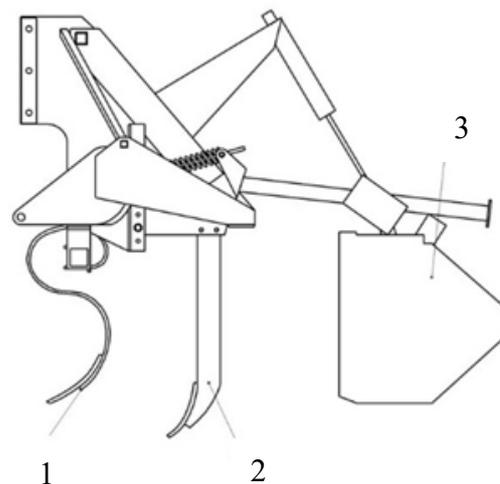


Figure 2. Scheme of placement of working elements on the row cultivator section, where 1 is side spring tine; 2 is ripper tine; 3 is ridge former plate with spring suspension.

2. Experimental

According to the generally accepted theory [6, 7], the cultivator's tines are placed taking into account the possible zone of deformation of the soil that occurs during their interaction with soil. When tines move in the soil, their points cause deformation of the treated horizons, which leads to the formation of

a network of cracks after cultivator passes [8]. In turn, the fracture network creates the conditions for the crumbling of the soil in the upper horizons and the formation in them of small soil particles. Taking into account the main provisions of the soil rheology it is assumed that for a horizon with homogeneous soil structure the boundary zone of deformation in the longitudinal direction is limited by a line of the friction angle φ "steel-soil" from the normal to the point of the tines. In the transverse direction the boundary zone of soil deformation is limited by line of internal friction with angle ψ . It is assumed that a homogeneous soil structure is characterized by certain physical-mechanical properties such as density, hardness, humidity, internal and external coefficients of friction. According to the data obtained by [9] the depth of the potato's roots penetration zone, which ensures the highest yield, is at least 70 cm. Therefore working area of ripper tine will consist of several heterogeneous horizons, each of them has own structure with characteristic parameters mentioned above. This working area can be conditionally divided into three horizons A_1 , A_2 and B [10]. Layer A_1 represents the upper part of the arable horizon, which, as a rule, coincides with the planting depth of potatoes; layer A_2 is the lower part of the arable horizon, and layer B placed below plowing depth. As rule, horizon B needs to be loosened for better penetration of the root system of the potato and good water infiltration.

3. Results and consideration

Scheme of boundary zones of soil deformation after interaction with by ripper tines of a row cultivator in heterogeneous soil horizons during differential tillage of the potatoes is shown in the Figure 3. In view of the fact that the row cultivator works on the ridge surface formed by the potato planter, then, in addition to the width of the main row spacing, it is necessary to take into account such parameters as the ridge height h_0 and the furrow bottom width b_0 . We will assume that the position of the seed tubers in the ridge is at the depth of potato planting a , measured in the XOY plane relative to the flat surface of the soil.

We define the zone of possible spreading of soil deformation in the longitudinal direction. When the ripper tine with the point width b_c (Figure 3) aimed for deep loosening is interaction with the soil a crack is formed [11, 12], which propagates in the longitudinal direction at an angle φ_B to the normal to the share at the point m . The angle φ_B is the angle of friction "steel-soil" valid for subsoil horizon B. When the crack reaches the boundary of horizons B and A_2 its further direction will depend on the angle of internal friction "soil-soil" ψ_{A_2} valid for horizon A_2 . Therefore, at the point n , the line direction of spreading crack in the longitudinal direction is changed. When crack reach the point p at the boundary of the horizons A_1 and A_2 , the line direction of its spreading changes again according the angle ψ_{A_1} , which is valid for the horizon A_1 . The deformation zone in the longitudinal direction can propagate to the point q at the top of the ridge.

Thus, taking into account the individual parameters of the physics mechanical properties valid for each soil horizons, treated by ripper tine, the length of a deformation zone in the longitudinal direction L_c is determined by the expression:

$$L_c = L_c^0 + tg(\varphi_B + \alpha_c) \cdot B + A_2 \cdot tg\psi_{A_2} + (A_1 + h_0^t) \cdot tg\psi_{A_1}, \quad (1)$$

where L_c^0 is the protrusion of bottom end of point; α_c is the inclining angle of point; h_0^t is height of the ridge relative to the initial level of the soil.

To ensure the operation of the ripper tines without clogging, it is necessary that the parameter L of their placement on the cultivator's frame in the longitudinal direction is greater than L_c . Therefore, when placing the side tines on the frame of row cultivator for differential tillage of potatoes, it is necessary to fulfill the requirement $L \geq L_c$.

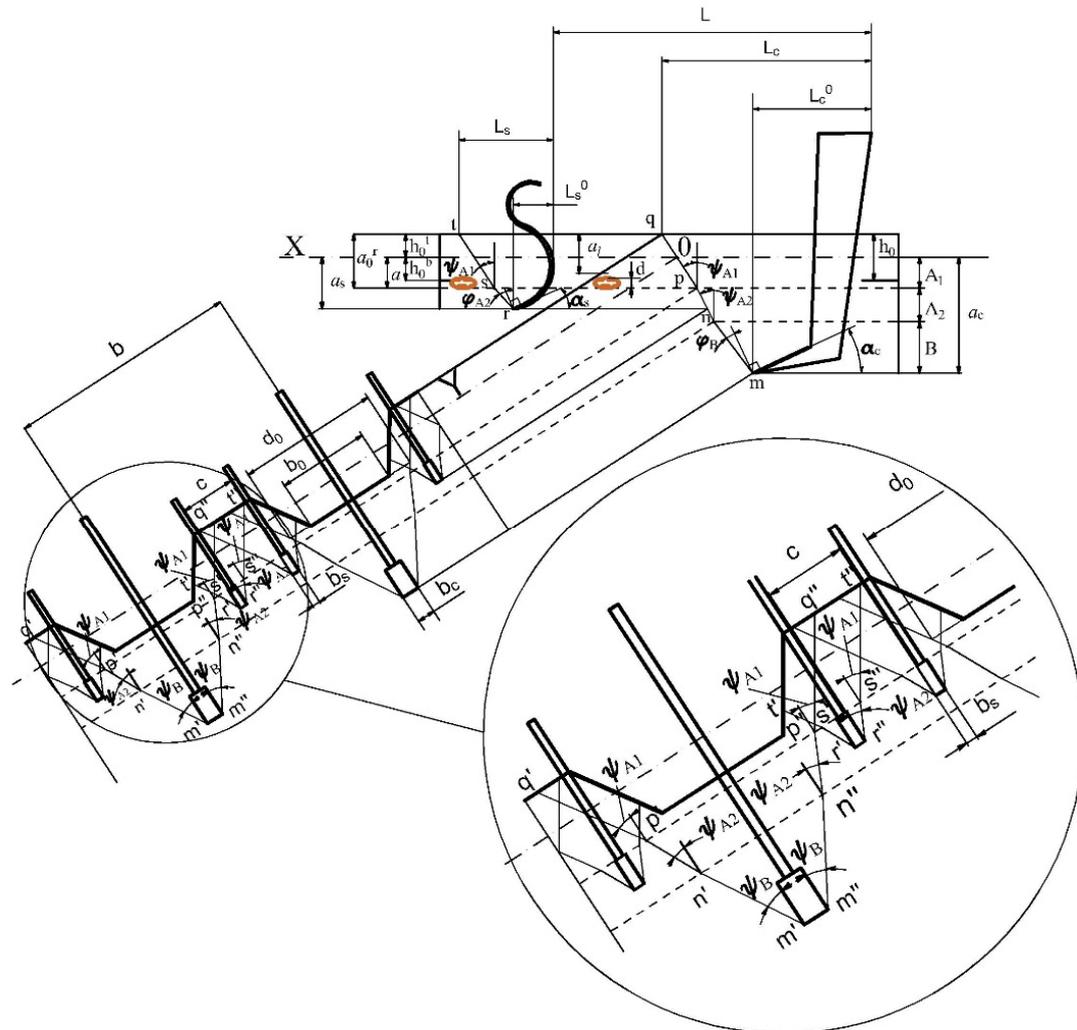


Figure 3. Scheme of spreading of soil deformation caused by ripper and side spring tines of a row cultivator in heterogeneous soil horizons during differentiated tillage of potatoes.

Since the row cultivator forms a ridge from the soil taken from the middle rows, it is important to fulfill two conditions to ensure the high quality soil crumbling:

- ✓ the crumbling zone d_0 after the passage of the ripper tine must exceed the furrow bottom width b_0 ;
- ✓ the zones of the deformation soil from the side tines must intersect directly above the mother tuber at a depth of representing the distance from the top of the ridge to tuber upper part.

To fulfill the conditions for forming ridges with fine loosed soil, will consider the zone of propagation of soil cracking in the transverse direction. This zone is limited by the projection of the line $mnpq$ in the direction of spreading of the crack and is determined by the internal friction angles ψ_B , ψ_{A_2} and ψ_{A_1} in the horizons B, A2 and A1, respectively. Thus, in the transverse direction, the width d_0 of propagation the soil deformation after passes ripper tine for deep loosening of potatoes, is bounded at the level of the furrow bottom by the lines $m'n'p'q'$ and $m''n''p''q''$ is determined as:

$$d_0 = b_c + 2 \left[\frac{B \cdot tg \psi_B}{\cos(\varphi_B + \alpha_c)} + \frac{A_2 \cdot tg \psi_{A_2}}{\cos \psi_2} + \frac{(A_1 - h_0^b) \cdot tg \psi_{A_1}}{\cos \psi_1} \right], \quad (2)$$

where $h_0^b = h_0 - h_0^t$ is distance from bottom of furrow to the flat soil surface.

To provide a sufficient zone of loosening of rows by ripper tines we determine the required working depth a_c . Since $B = a_c - (A_1 + A_2)$, the condition for depth setting will be determined by the expression:

$$a_c \geq (A_1 + A_2) + \left[\frac{d_0 - b_c}{2} - \frac{(A_1 - h_0^b) \cdot tg \psi_{A_1}}{\cos \psi_{A_1}} - \frac{A_2 \cdot tg \psi_{A_2}}{\cos \psi_{A_2}} \right] \cdot \frac{\cos(\varphi_B + \alpha_c)}{tg \psi_B}. \quad (3)$$

When calculating the adjustment values for the side spring tines placement relative to the ridge center, we make the assumption that their arrangement is completely determined by the width of the protective zone c , where the deformation zones from the interaction of adjacent tines must intersect above the mother tuber at a distance a_l from the ridge top. Assume that $a_l = a_0^r - 1,5d$. Here $a_0^r = a + h_0^t$ is the distance from the top of the ridge to the depth of planting and d is an average diameter of the mother tuber.

Since the setting depth of the side spring tines is below the planting depth, they will treat the soil layer with layers A_1 and A_2 . When the side spring tines are moved in the soil at the point r appears a crack, which propagates in layer A_2 at the angle of external friction "steel-soil" ψ_{A_2} from the normal to the chisel point. When the crack caused by side spring tine reaches the point s at the boundary of the layers A_2 and A_1 , direction of its spreading line changes depending on the value of the angle of internal friction "soil-soil" ψ_{A_1} and further it reaches the surface of the ridge at the point t . In the transverse direction the boundary of the soil deformation will be limited by lines $r's't'$ and $r''s''t''$.

To determine the depth of the side spring tines we need take into account the width of the protective zone c , which is characterized the complete crumbling of the soil above the mother tuber by the expression:

$$c = 2 \cdot \left[\frac{(a_s - A_1) \cdot tg \psi_{A_2}}{\cos(\varphi_{A_2} + \alpha_s)} + \frac{1,5 \cdot d \cdot tg \psi_{A_1}}{\cos \psi_{A_1}} \right]. \quad (4)$$

By solving the inverse task we determine the value of the side tines depth when adjust it on the frame of row cultivator by expression:

$$a_s \approx A_1 + \left(\frac{c}{2} - \frac{1,5 \cdot d \cdot tg \psi_{A_1}}{\cos \psi_{A_1}} \right) \cdot \frac{\cos(\varphi_{A_2} + \alpha_s)}{tg \psi_{A_2}}. \quad (5)$$

4. Conclusion

A method based on the rheological state and the heterogeneous structure of soil horizons A_1 , A_2 and B has been developed the for calculating the rational placement on the frame of row cultivator the ripper and side spring tines for differential tillage of potatoes.

It has been obtained the theoretical substantiation of the technological parameters of tines depth adjustments that takes into account physical and mechanical of soil properties and allow to provide high quality soil treatment.

It was obtained regularities of interaction tillage tool with soil during differential tillage can be used to calculate its technological parameters while improving existing and designing new machines for potato growing.

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