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ANALYTICAL MODEL OF THE TECHNOLOGICAL PROCESS OF SOIL PULVERIZATION AND TILLAGE TOOLS

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Abstract

The article deals with the deformation model that is not based on the elastic properties of the soil, which is in agreement with the physical processes of the wedge interaction with the soil.

The presented models agree better with the experimental data than other models, including those based on the elastic properties of the soil, as the tests of flat tillage tools with a variable cutting angle have proved.

Keywords: deformation model, tractive resistance, soil pulverization, two-sided wedge, interaction, optimal parameters.

Introduction

The worldwide attention paid to studying changes of soil properties caused by tillage is unfortunately insufficient. There are no necessary instruments for measuring physical quantities of characterizing the soil. To determine the sufficient soil pulverization with the lowest costs it is necessary to know the soil resistance when it being pulverized under various conditions of interaction of tillage tools with the soil. Up to the present moment, there are no universally accepted models of soil deformation, a significant number of well-known soil deformation models resorting to fracture patters of an elastic body [9, 10, 11, 12].

Numerous attempts of using the investigation methods of elastic materials for soil pulverization have not yet had practical results, since the relationship between the force acting on the soil, and the soil deformation is the function of the soil condition. Therefore, the use of the mathematical apparatus of fracture of elastic bodies in the classical form when designing the working bodies is ineffective. It should be noted that due to the aggregate-size distribution, moisture and compaction degree soils can sometimes have some properties of an elastic body [13].

Methods and results

This article is concerned with one of feasible approaches to investigating the process of soil fracture with tillage tools.

The basics of the approach are:

- the fracture of the soil and its elements happens when the acting force exceeds the soil resistance force;
- the magnitude and direction of the acting force can be determined through analysing the tillage tool interaction with the soil;
- the soil resistance force can be estimated due to the aggregate-size distribution of soil and its humidity at the time of tillage.

Let’s consider some of the elements of the fracture process exemplified with a two-sided wedge (Fig. 1).

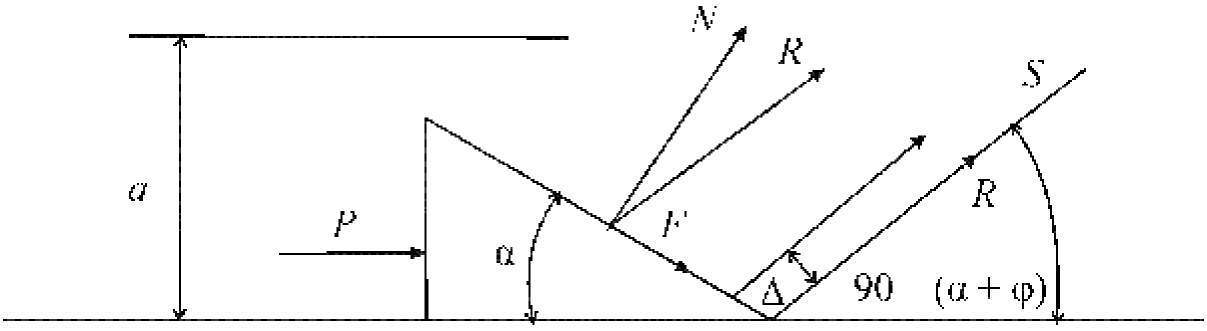

Figure 1 – The soil fracture with a two-sided wedge

When moving in the soil the wedge interacts with the soil normal, declined at an friction angle of the soil movement on the wedge surface. In this direction the wedge moves the soil along the plane and the soil area is:

$$S = \frac{ab}{\sin(90 - (\alpha + \varphi))}$$

or

$$S = \frac{ab}{\cos(\alpha + \varphi)}, \quad (1)$$

where S is the fracture plane of the soil;
a is the depth of the wedge movement;
α is the two-sided wedge angle;
φ is the friction angle when the soil slides on the wedge;
b is the wedge width.

And the magnitude of R force must be equal to:

$$R - \frac{\mu ab}{\cos(\alpha + \varphi)}, \quad (2)$$

where μ is the friction coefficient of the soil particles over the S area.

This coefficient, of course, can hardly be considered as the ultimate soil shearing resistance τ with big assumptions.

The action of the R force can manifest itself only when a soil layer of the thickness Δ is formed on the wedge. The wedge penetrates into the soil without breaking it up until the thickness of the soil layer becomes Δ. The value of the layer thickness can be determined from the condition:

$$R = \Delta b \sigma, \tag{3}$$

where σ is the ultimate normal stress on the layer.

Solving the equations (2) and (3) together we have:

$$\Delta - \frac{a\tau}{\sigma\cos(\alpha+\varphi)} = \frac{\mu a}{\sigma\cos(\alpha+\varphi)}. \tag{4}$$

Figure 2 shows the dependence of the fracture element thickness Δ on the setting angle of the wedge to the furrow bottom, provided: $\sigma_{сж} = 10\tau$.

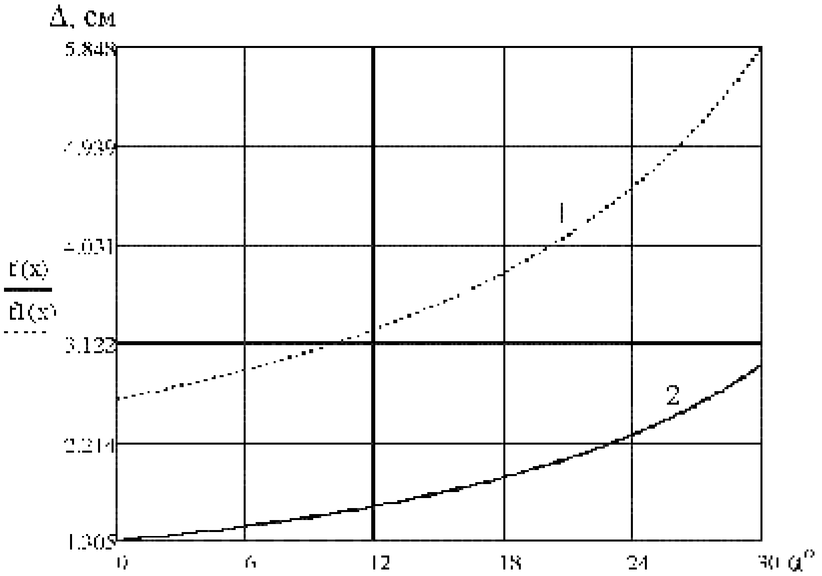

Figure 2 – The thickness of the soil fracture elements depending on the setting wedge angle to the furrow bottom. ($\sigma_{сж} = 10\tau$; 1 – *a* = 20 cm; 2 – *a* = 10 cm)

Applying the Δ value to the equation 3, we get:

$$R - \frac{\mu ab}{\cos(\alpha + \varphi)}, \tag{5}$$

or

$$R - \frac{\tau ab}{\cos(\alpha + \varphi)}. \tag{6}$$

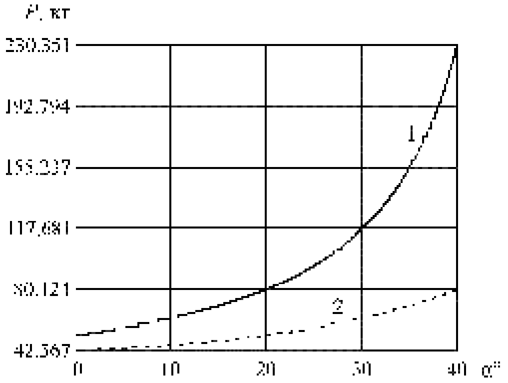

Figure 3 – The power on the wedge when chipping the soil of the Δ thickness
(1 – the depth of the wedge movement 0.2 m,
2 – the depth of the wedge movement 0.1 m)

The power of the P tractive resistance is determined by the obtained fracture force R and the friction force of the soil movement on the wedge at the fracture point F when ignoring the efforts necessary to move the obtained soil layer on the wedge of the length ***L*** (Fig. 3, 4):

$$P = R\cos(90 - (\alpha + \varphi)) + F\cos\alpha, \tag{7}$$

where F is the friction force when moving the soil on the wedge at the fracture point of the continent layer:

$$F = Ntg\varphi, \tag{8}$$

where N is the force of the normal pressure on the soil surface when fracturing the continent soil;

φ is the friction angle.

$$N = \frac{R}{\cos\varphi}, \qquad (9)$$

or

$$N - \frac{\mu ab}{\cos\varphi\cos(\alpha+\varphi)} \qquad (10)$$

When applying F into the equation 27 we get:

$$P - R(\sin(\alpha+\varphi)) + \frac{\cos\alpha tg\varphi}{\cos\varphi}) \qquad (11)$$

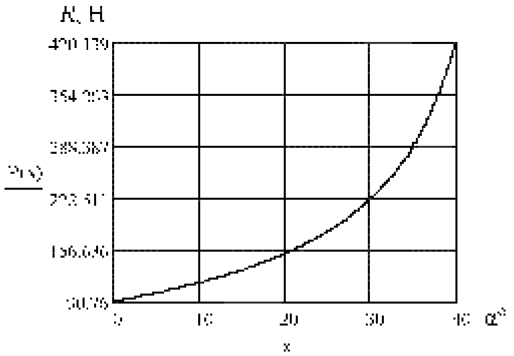

Figure 4 – The wedge resistance force when chipping the soil

(μ = 4000 $\frac{н}{м^2}$, *a* = 0,1 м, *b* = 0,1 м, $\varphi = 40^0$)

The numerical values of the component of the tractive resistance force (R and F) are shown in Figure 5.

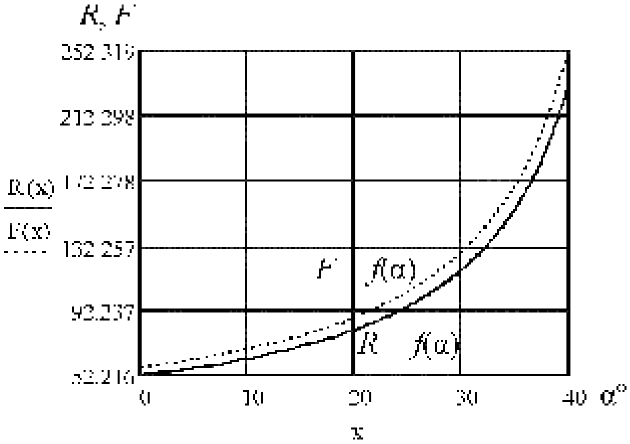

Figure 5 – The components of the wedge tractive resistance force when chipping the soil (*F* is the upper curve, *R* is the lower curve)

$\mu = 4000\,\frac{н}{м^2}$, $a = 0{,}1$ м, $b = 0{,}1$ м, $\varphi = 40^0$)

These theoretical findings were applied to the operating parts of flat-cutting and mouldboard ploughs, with the results of laboratory and experimental tests being presented below.

The operating parts of cultivators and subsurface ploughs currently used for main subsurface tillage are not yet fully meet the agro-technical requirements, when especially concerning the quality of soil pulverization, stubble preservation, furrow sizes, ridgeness, as well as the pulverization uniformity along the width of the operating part of a subsurface plough (Fig. 6).

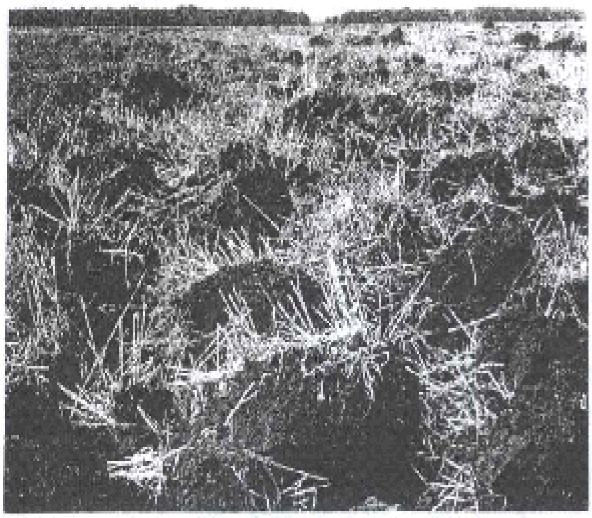

Figure 6 – The field with hard dried-up soil tilled with KPG-250 equipped with serial operating parts

The high-quality tillage with minimum costs is known to be impossible without tillage operating parts that are optimal for the parameters of every soil type.

The main pulverization of a soil layer is also well known to occur at the point of its compression and separation from the continent soil.

Thus, each specific cutting angle of operating parts corresponds to a piece of the tilled soil of specific sizes.

Thus, the foregoing caused to put forward the following scientific hypothesis: the variable cutting angle along the blade length improves the soil layer pulverization.

To confirm this scientific hypothesis the above mentioned theoretical and laboratory-industrial experiments were conducted.

The laboratory tests needed a specially designed soil channel (Fig. 7) and a set of two-sided wedges that differ from each other in cutting edge angles set to the furrow bottom (Fig. 8). Moreover, the tests were carried out in environments of a wide range of physical and mechanical properties (typical chernozem, sand, peas, clay), with the influence of the variable cutting angle on the bending of clay, plasticine and wet chernozem being determined (Fig. 9).

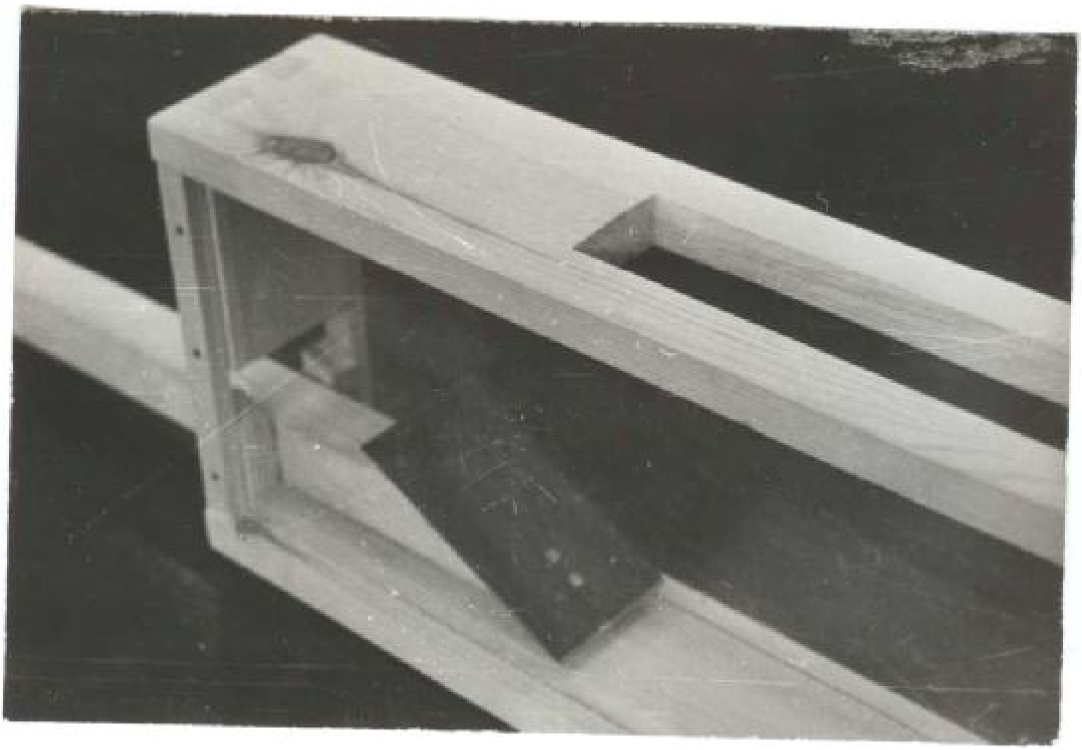

Figure 7 – The soil channel

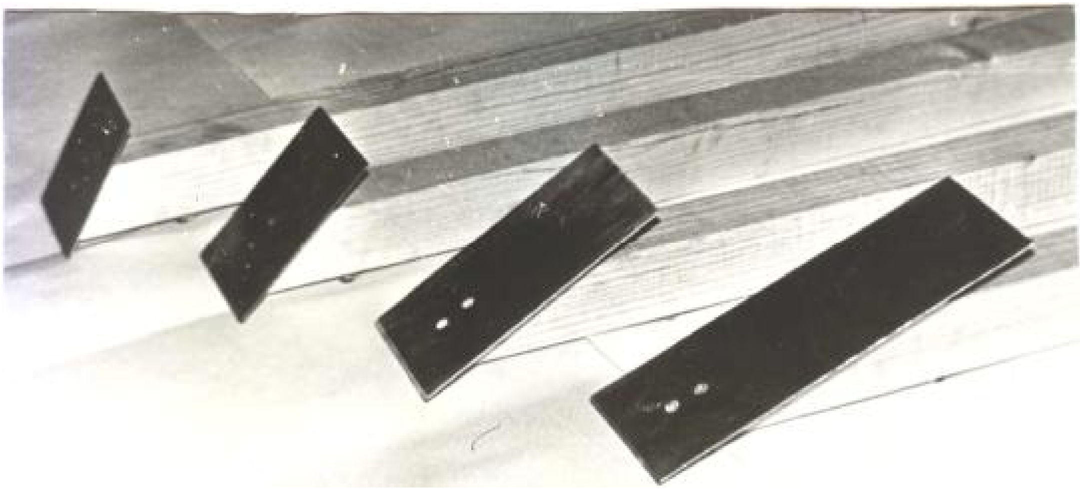

Figure 8 – Different types of two-sided wedges

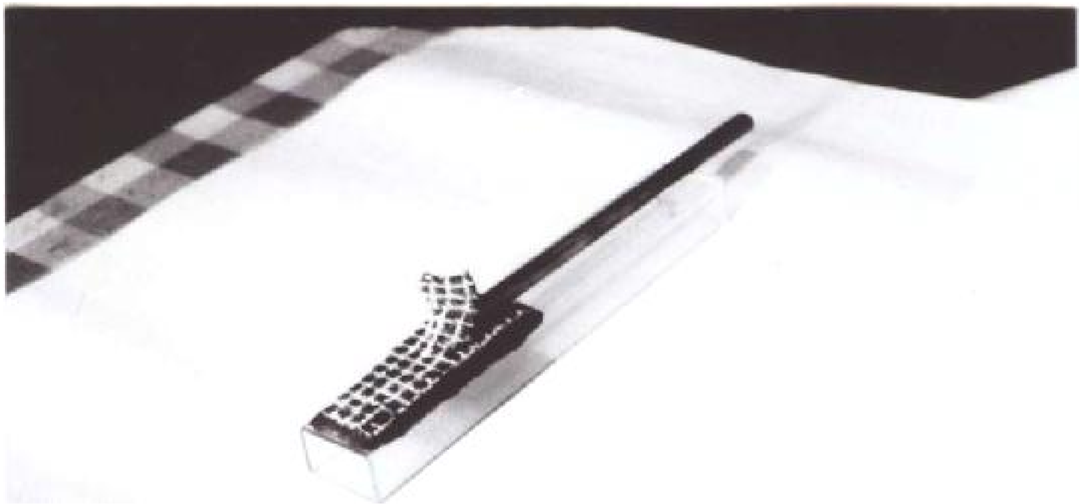

Figure 9 – The bending and twisting of the soil layer when applying the wedge with a variable cutting angle

а

б

a – the operating part of the cultivator and surface plough with a variable cutting angle (the cutting angle increases fore and aft); *b* – the operating part of the cultivator and surface plough with a variable cutting angle
(the cutting angle decreases fore and aft)
Figure 10 – The KPG operating parts with a variable cutting angle:

The laboratory tests showed:

- Despite the differences of physico-mechanical properties and the outer layer formation appearance, all media when interacting with the wedge have some common characteristics dependant on the wedge parameters.
- The blade with a variable cutting angle causes the stress state in the soil layer more than the blade with a constant cutting angle.

We obtained [1] the mathematical formula for determining the equivalent stress (the stress state) produced by a blade with a variable and constant cutting angle.

$$\frac{\sigma^{I}_{\text{экв}}}{\sigma^{II}_{\text{экв}}} = \frac{1}{2} + \frac{1}{2}\sqrt{1 + 1{,}5 \cdot \rho^{2}\left(\frac{\Delta\varepsilon}{l}\right)^{2}}\ , \qquad (12)$$

where $\sigma^{I}_{\text{экв}}$ is the stress state generated with a blade with a varying cutting angle in the soil layer;

$\sigma^{II}_{\text{экв}}$ is the stress state generated with a blade with a constant cutting angle in the soil layer;

ρ is the radius of the soil layer bending;

$\Delta\varepsilon$ is the intensity of the cutting angle changing along the length of the blade (in $\Delta\varepsilon$ experiments varied from 20^0 to 45^0);

l is the blade length.

Analyzing the results it can be noted that the wedge with variable cutting angle creates more stress state in the formation of soil than the wedge with a constant cutting angle. Assuming that a voltage proportional to the crumbling we come to the conclusion that wedge with variable cutting angle ensures a better crumbling.

The theoretical and laboratory studies have helped to create the working bodies of cultivators, chisel plows subsurface cultivator with variable cutting angle (Fig. 10).

The nature of the stresses arising in the formation with different soils. The action on the ground working body, with a constant angle along the length of the cutting ploughshare state of stress occurs in the formation of the bending strain, while working body with variable cutting angle - from the strain of bending and torsion.

The experimental data on fracture and traction resistance demonstrate the validity of this scientific hypothesis (Figure 11, 12, 13).

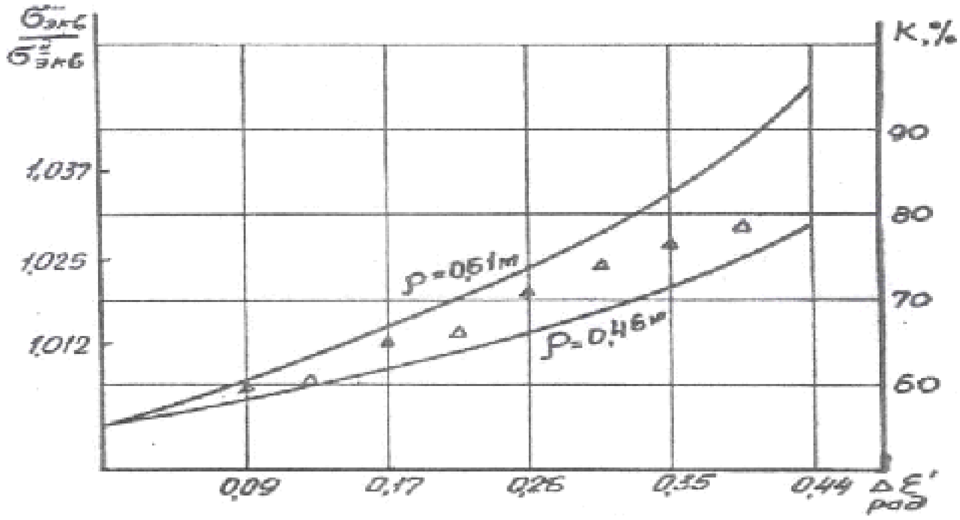

Figure 11 – The influence of changes in the cutting angle intensity along the ploughshare length (Δε) on the equivalent stress and the soil layer pulverization:
Δ is the experimental data concerning the tilled soil layer pulverization

Figure 12 – The field tilled with the KPG operating parts with a variable cutting angle

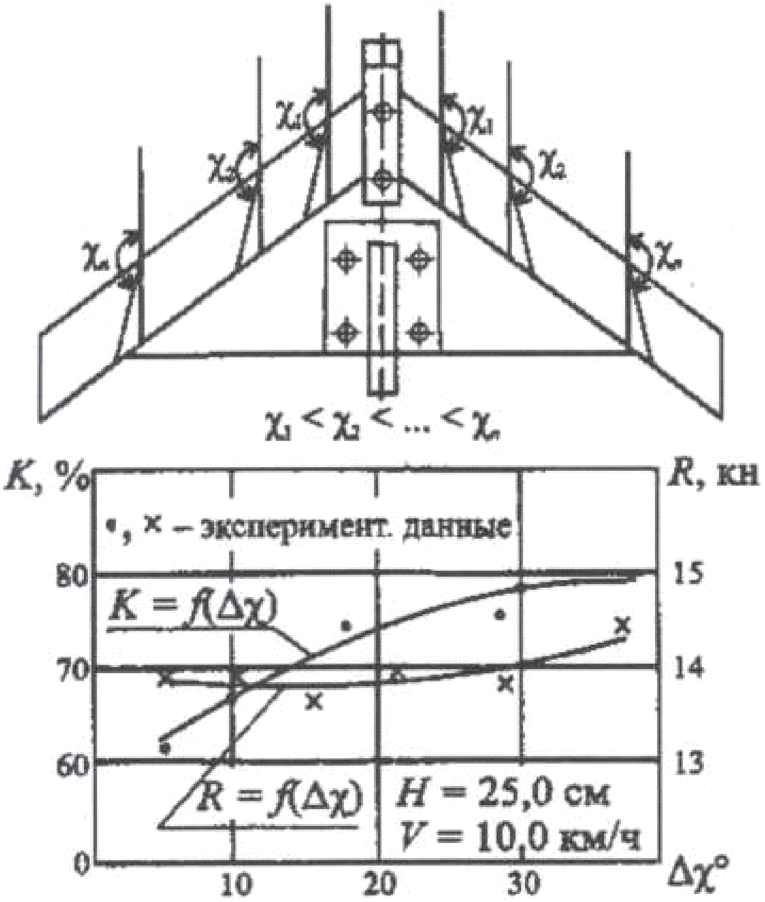

Figure 13 – The dependence of the soil layer pulverization *K* the tractive resistance ***R*** on the intensity variation of the cutting angle of the soil $\Delta\chi$, ^{0}, the KGP operating part: $\Delta\chi = \chi_n - \chi_1$ intensity variation of the angle of cut of the soil, where χ1 - the minimum angle of cut; χn - the maximum angle of the cutting Soil

Thus the model considered the destruction of the soil is in good agreement with the physical processes of interaction with the soil wedge, as shown in Figures 2-5 correspond correctly calculated data with the experimental data obtained by many authors in Russia and abroad [2, 3, 4, 5, 6 7].

Conclusion

Convergence of the models with experimental data is much higher than convergence of other models, including those based on the elastic properties of the soil.

To obtain the necessary quality of crumbling soil formation the working bodies of the KKE with variable cutting angle are suggested in this paper.

Improved soil crumbling formation occurs at the mutual action of the torsion and bending deformation simultaneously, whereas working with a constant angle of the main cutting crumbling occurs due to deformation of bending.

As the experimental data show the working bodies of the KKE with variable cutting angle along the length of the coulter 20-50% crumble the processed layer better than serial working bodies.

The economic effect of the introduction of the working bodies of the KKE with variable cutting angle is 200-1300 rubles per one hectare of the cultivated area.

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Түйін

Топырақтың серпімділік қасиеттеріне базаланбаған, сынаның топырақпен әрекеттесу физикалық үрдіспен жақсы сәйкестенетін бұзу үлгісі қарастырылған.

Ұсынылған үлгінің тәжірибелік үлгімен сәйкестігі, басқа үлгілермен салыстырғанда, соның ішінде топырақтың серпімділік қасиеттеріне базаланбаған, біршама жоғары. Бұл айнымалы кесу бұрышы бар жазық кескіш жұмыс органдарын зерттеуде анықталған.

Резюме

Расмотрена модель разрушения, не базирующаяся на упругих свойствах почвы, которая хорошо согласуется с физическими процессами взаимодействия клина с почвой.

Сходимость представленных моделей с экспериментальными данными намного выше сходимости других моделей, в том числе базирующихся на упругих свойствах почвы, о чем свидетельствует исследорвания плоскорежущих рабочих органов с переменным углом резания.

Summary

The article deals with the deformation model that is not based on the elastic properties of the soil, which is in agreement with the physical processes of the wedge interaction with the soil.

The presented models agree better with the experimental data than other models, including those based on the elastic properties of the soil, as the tests of flat tillage tools with a variable cutting angle have proved.