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WORKING ELEMENTS WITH REPETITIVE CUTTING ANGLES FOR SUBSURFACE PLOUGHS

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Annotation

The yield of grain crops depends by 25% on the quality of soil tillage. Working elements of plough-cultivators that exist today are not able to deal well with solid and over-dried soil. This is because a flat ploughshare has a constant cutting angle along its entire length that spalls large pieces of soil. Therefore, to improve the crumbling of soil a wedge-shaped working element with a variable cutting angle is developed. The proposed form of ploughshares for working elements of subsurface plough-cultivators with increasing cutting angles on each part activates additional forces inside the tilled soil layer. This ensures a greater interaction of soil and its better crumbling, the innovative working element with repetitive variable cutting angles activates the internal potential of soil. As a result, it changes its inner structure, and its nutrients are better absorbed by plants. The developed working element is 20-50 % more efficient than the serious ones as it ensures a better crumbling of soil. They are patented in the Russian Federation.

Keywords: tractor plough, cutting angle, three-sided wedge, working element, universal characteristic, soil, motion path.

Relevance

Currently, in the Russian Federation 4...7 centners of grain are known to be produced for every person per year. For Russians' complete satisfaction it is necessary to produce approximately 10 centners of grain for every person, i.e. to harvest 17 centners per hectare of arable land on an average [1]. The increase in agricultural production is closely related to the increase in the crop yield, the most important thing here is to provide with the quality performance of field operations and particularly tillage process. According to Russian and foreign scientists data [2] the yield of grain crops depends by 25% on their tillage quality.

Approximately 92 million hectares of arable land used for cultivating crops in the Urals, Western Siberia, and Altai Territory are located in the steppe arid zone [2]. By the time of the main subsurface tillage soils on the above stated lands strongly dry up, harden and it's difficult to cultivate them. Existing working elements for subsurface plough-cultivators (SPCs) poorly cultivate soil, when especially when it deals with solid and over-dried soil. Such soils chip and form the so-called "suitcases" (Fig. 1). Thus, cultivation of such soils needs additional passes of various units, which greatly compress the soil and requires costs comparable to the main tillage. According to design serial deep-cutting working elements (Fig. 2) have flat ploughshares with constant cutting angles along the length which leads to chipping of large pieces of soil, i.e. to bad tillage. This problem is very urgent as drought years in Russia and neighboring countries come rather often.

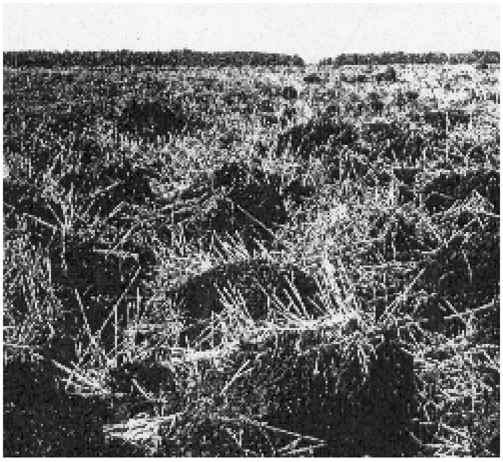

Fig. 1. The soil cultivated with serial deep-cutting working elements

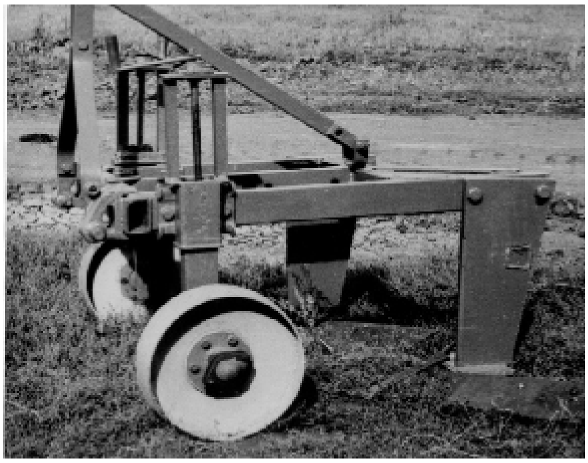

Fig. 2. SPC-250 with serial working elements

Additional soil crumbling can be done by means of agricultural biotechnology, which is, in the modern sense is applicable for soil. This technology allows to get soil of some given quality by forming and using soil structural components (soil pieces) of the right size when changing the direction and the magnitude of interaction between each other.

On the basis of above – stated the following scientific hypothesis was suggested: a cutting angle changing along the ploughshare length improves the crumbling of soil layers. Thus, to confirm the scientific hypotheses theoretical, laboratory and industrial experiments were carried out.

Theoretical, laboratory and on-the-farm researches

The angle between two lines in space given with their canonical equations

$$\frac{\chi-\chi_1}{l_1}=\frac{\gamma-\gamma_1}{m_1}=\frac{z-z_1}{n_1}$$
$$\frac{\chi-\chi_2}{l_2}=\frac{\gamma-\gamma_2}{m_2}=\frac{z-z_2}{n_2}$$

is known to be found according to the following formula:

$$\cos(180-\chi)=\frac{l_1\cdot l_2+m_1\cdot m_2+n_1\cdot n_2}{\sqrt{l_1^2+m_1^2+n_1^2}\cdot\sqrt{l_2^2+m_2^2+n_2^2}} \quad (1)$$

If one of the lines will be the path of moving soil along the wedge (S) and the other will stand for the direction of the moving wedge (OX), the angle between them will be the cutting angle.

χ is the angle between the direction of moving wedge and the direction of moving soil along the wedge, i.e. the angle of soil cutting (Fig. 3).

This definition of the soil cutting angle was introduced for the first time in our inventor's certificate №1771549.

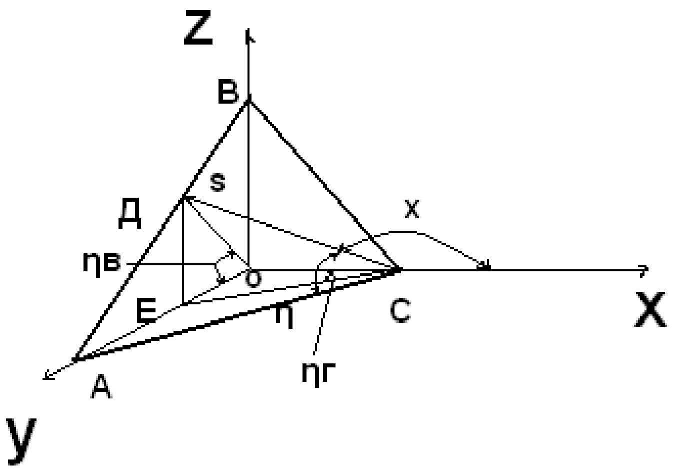

Fig. 3. Cutting angle of soil (χ) with a three-sided wedge

The line S has the following direction cosines:

$$\cos\alpha_{\vec{N}}=\frac{l}{\sqrt{l^2+m^2+n^2}}=\cos\eta\cdot\sin\gamma-\cos\varepsilon\cdot\cos\gamma\cdot\sin\eta$$
$$\cos\beta_{\vec{N}}=\frac{m}{\sqrt{l^2+m^2+n^2}}=-(\cos\eta\cdot\cos\gamma+\cos\varepsilon\cdot\sin\gamma\cdot\sin\eta)$$
$$\cos\gamma_{\vec{N}}=\frac{n}{\sqrt{l^2+m^2+n^2}}=\sin\varepsilon\cdot\sin\eta$$

Let us put in the formula (1) the values of obtained direction cosines:

$$\cos(180-\chi) = -\cos\chi \frac{1}{tg^2\eta_\Gamma + 1 + tg^2\eta_\Gamma \cdot tg^2\eta}$$

After some transformations we obtain:

$$\cos\chi = \sqrt{\cos^2\gamma + \cos^2\varepsilon\cdot\sin^2\gamma} \tag{2}$$

Let us write another three equations to establish the connection between the cutting angle, the direction of moving soil along the wedge and the wedge angles:

$$\begin{cases} \cos\chi\cdot\sin\eta = \cos\varepsilon\cdot\sin\gamma \\ \cos\chi\cdot\cos\eta = \cos\gamma \\ \sin\chi = \cos\gamma\cdot\sin\varepsilon \end{cases} \tag{3}$$

The analysis of the 3rd equation shows that:
when $\gamma = 90^0$ $\chi = \varepsilon$; when $\gamma = 0^0$ $\chi = 0^0$.

The values of the angle χ for the most used angles γ and ε in working elements of tillage machines are shown in Fig. 4.

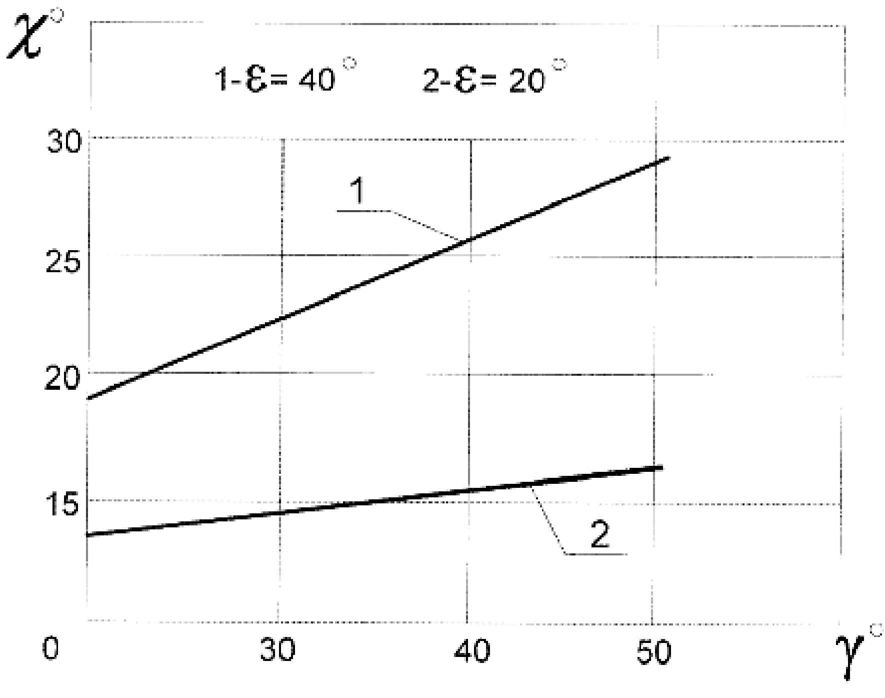

Fig. 4. The cutting angle of soil with a three-sided wedge

Thus, the concept of a cutting angle of soil with a three-sided wedge is introduced. The mathematical formulas for its determination and dependence are obtained to unite into a whole the angles of soil cutting with a three-sided wedge and of the contact of the soil layer with the wedge and the angles characterizing its parameters. The cutting angle of soil with a three-sided wedge has never been used in the design of soil-cultivating working elements is a universal power and it's technological characteristic to meet specified agricultural requirements more accurately. We have theoretically defined and experimentally confirmed the path of moving soil along a three-sided wedge due to the analysed interaction of the wedge with the soil which allows to obtain the desired result of tillage machines when changing the path of moving soil layer via changing the parameters of working elements [3,4].

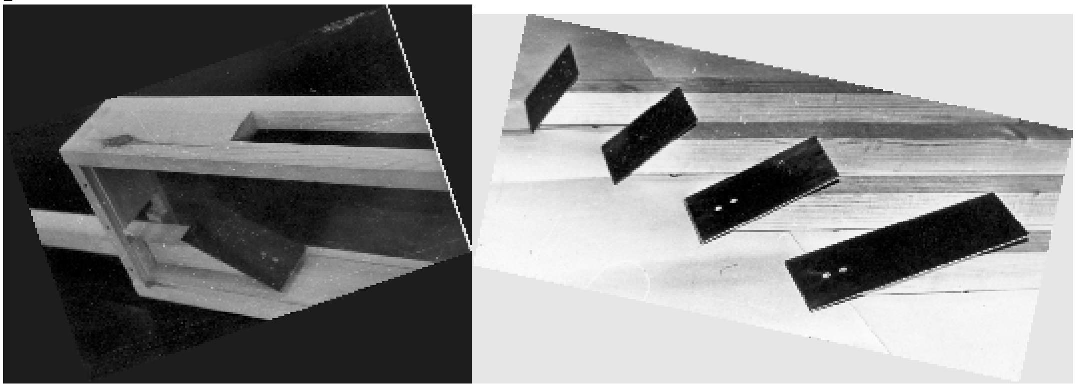

Fig. 5. Tillage bin with wedges for laboratory research

For laboratory experiments we used a specially designed tillage bin and a set of two-sided wedges that differ from each other in the angles of arranged working sides to the furrow bottom (Fig. 5), with the experiments carried out in mediums with wide ranges of physical and mechanical properties (ordinary chernozem, sand, peas, clay). The effect of a variable cutting angle on the bending of clay, plasticine, moist chernozem was determined. The laboratory experiments showed the following:

1. Despite the different physico-mechanical properties and the surface pattern of the forming soil layer, all mediums when contacting with the wedge have some common characteristics depending on the parameters of the wedge.

2. The coulter with a variable cutting angle creates a more stressed state in the soil layer than the coulter with a constant cutting angle.

We obtained [4] the mathematical formulas for determining the equivalent tension (the tense state) caused by the coulters with fixed and variable cutting angles.

When analyzing the obtained results, it can be noted that a wedge with a variable cutting angle creates a more stressed state within the soil layer than the wedge with a constant cutting angle. Assuming that the crumbling is proportional to the arisen tension, we can conclude that a wedge with a variable cutting angle ensures better crumbling.

Research technique

The proposed working elements of tillage machines were tested in laboratory and field conditions in accordance with the GOST, OST and particularly developed techniques. Theoretical research was done on the basis of classical mechanics laws and mathematical modeling. Theoretical results are proved experimentally by laboratory and pilot-plant installations. The convergence of the obtained theoretical and experimental results is satisfactory, with the inaccuracy being within 5 ... 10%. The experimental findings were processed with Math-CAD software.

According to the above-stated the deep-cutting working elements with a repetitive variable cutting angle from the tip to the tail of the plowshare were developed, the active side of the ploughshare was divided into three parts with an increasing cutting angle on each one (Fig. 6).

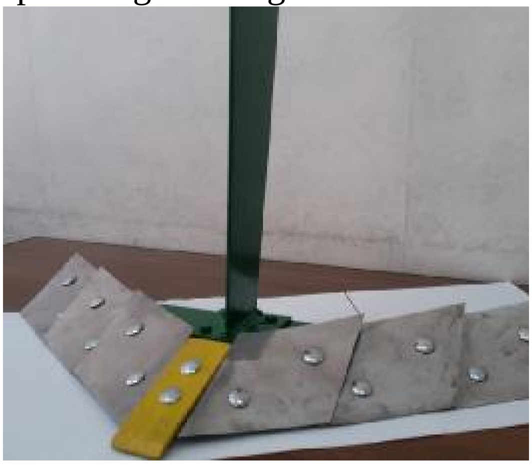

Fig. 6. The deep-cutting working elements with a variable cutting angle

Fig. 7. The field tilled with innovative deep-cutting working elements

It is generally known that soil crumbling is proportional to stresses arising therein during tillage. The nature of stresses is different. When the soil is cultivated with a working element with a constant cutting angle along the coulter length (a standard working element), the stresses within the soil layer are caused by its bending and deformation; when the soil is treated with a working element with a variable cutting angle (the proposed working element), the stresses within the soil layer are caused by bending, deformation and torsion. The proposed form of ploughshares for deep-cutting working elements with an increasing cutting angle at each part contributes to further soil crumbling due to the agrobiocrumbling technology. Such forms of ploughshares create additional forces within soil layers which differ in their directions, values and points of application. All this contributes to more active contacts between soil pieces and consequently, improves soil crumbling. The specific quality of soil crumbling depends on the length of the bent part of the ploughshare (the difference between the maximum and minimum cutting angles at one part of the ploughshare). Thus, the deep-cutting working element with a repetitive variable cutting angle activates the internal soil resources, as a result the soil internal structure changes so that plants can assimilate soil nutrients better. This leads to stable yields in dry periods as well.

The surface of the tilled part of the field of proves the proposed scientific hypothesis (Fig. 7).

Tests conducted on-the-farm prove the deep-cutting working element with a repetitive variable cutting angle from the tip to the tail of the coulter to have better agronomic performance than the serial ones (Table 1). The designed deep-cutting working elements aren't stuck with soil in practice, they are rarely subject to soil chip in the course of cultivation of over-dried soil pieces more than 200 mm in diameter.

Table 1. Modes and performance indicators of the SPC working elements when tested

Indicators	The serial working element	The designed working element with a repetitive variable cutting angle from the tip to the tail of the coulter
1	2	3
Soil hardness, kg/cm^2	41.2	41.2
Absolute soil humidity, %	12.5	12.5
Machine brand	SPC-250	SPC-250
The speed of a moving unit, m/s	2.2	2.2
Field surface unevenness, cm	10.5	8.0
Stubble preservation, %	70.2	75.2
Soil layer crumbling, %	62.7	87.0
The contents of erosion-hazardous soil particles (less than 1 mm), %i n the layer 0...50: Before tillage	39.2	39.2
After tillage	32.2	30.0

The developed deep-cutting working elements are patented (12 patents) and have some RF inventors' certificates. The implementation acts prove the economic effect of the developed SPC working elements to be 200 ... 1300 rub. for 1 hectare of tilled area. The proposed working elements make it possible to have stable yields even during droughts that often happen in Russia.

Conclusions

1. The concept of a tree-edged wedge angle for cutting the soil is introduced. The mathematical formulas for its determination and dependence are obtained to unite into a whole the angles of soil cutting with a three-sided wedge and of the contact of the soil layer with the wedge and the angles characterizing its parameters. The cutting angle of soil with a three-sided wedge that has never been used in the design of soil-cultivating working

elements is a universal power and it's technological characteristic to meet specified agricultural requirements more accurately.

2. We have theoretically defined and proved experimentally the path of moving soil along a three-sided wedge due to the analysed interaction of the wedge with the soil which allows to obtain the desired result of tillage machines when changing the path of moving soil layer with the parameters of working elements.

3. The deep - cutting working elements with a repetitive cutting angle along the length of the ploughshare cause a greater stress state in the soil layer than serial ones. These working elements ensure soil crumbling 20...50% more efficient than serial and in both cases energy costs are the same.

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Түйін

Топырақтың танап бойынша қозғалу бағыты мен түреннің атыз түбіне түсу бұрыштарына тәуелді топырақты кесу бұрыштары тоериялық анықталған және тәжіребелік дәлелденген. Үшқырлы сынамен топырақты кесу бұрышы топырақты өндеу кезіндегі әмбебап күштік сипаттамасы болып табылады.

Теориялық зерттеулер негізінде түреннің әрбір бөлігінде ұлғаятын және қайталанатын кесу бұрышы бар терең қопсытқыш жұмыс органы даярланды, ол топырақтың үгітілуін жақсартады.

Тіректі сөздер: тракторлық сыдыра жыртқыш, кесу бұрышы, үш қырлы сына, әмбебап сипаттама, топырақ, қозғалыс траеториясы.

Резюме

Теоретически определен и экспериментально подтвержден угол резания почвы, зависящий от углов направления движения почвы по клину и постановки лемеха ко дну борозды. Угол резания почвы трехгранным клином является универсальной силовой характеристикой при обработке почвы.

На основании теоретических исследований разработан глубокорыхлительный рабочий орган с увеличивающимся и повторяющимся углом резания на каждой части лемеха, что улучшает крошение почвы.

Ключевые слова: тракторный плоскорез, угол резания, трехгранный клин, универсальная характеристика, почва, траектория движения.

Summary

Cutting angle of soil that depends on the corners of the moving soil direction along the wedge and position of a ploughshare towards the furrow bottom is theoretically defined and proved experimentally. Cutting angle of soil with a three-sided wedge is the universal power characteristic when cultivating soil.

On the basis of theoretical researches the deep-cutting working elements with the increasing and repetitive cutting angles on each part of a ploughshare is developed and it improves soil crumbling.