IMPROVEMENT OF THE STRUCTURAL LAYOUT OF POTATO PLANTERS' COULTER GROUP
/
УСОВЕРШЕНСТВОВАНИЕ КОНСТРУКТИВНОЙ СХЕМЫ СОШНИКОВОЙ ГРУППЫ КАРТОФЕЛЕСАЖАЛОК

Dorokhov Alexey Semenovich, Ponomarev Andrey Grigoryevich, Zernov Vitaly Nikolaevich, Petukhov Sergey Nikolaevich, Aksenov Alexander Gennadievich, Sibirev Aleksey Viktorovich
FSBSI "Federal Scientific Agronomic and Engineering Centre VIM"/ Russian
Telephone: 89645843518; E-mail: sibirev2011@yandex.ru
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ABSTRACT
Structural layouts of coulters and their groups in potato planters are justified in the article based on the morphological features of the potato plant, its requirements for growing conditions and ensuring the quality of the planting process. The purpose of coulter groups is to form a bed for placing tubers with a loose layer of soil in 5-8 cm and sealing them with loosened soil to a certain depth. To substantiate the type of potato planter coulters that meet the requirements for potato growing conditions to the maximum extent possible, optimize the parameters of coulter groups that automatically ensure the stability of the coulter travel depth when imitating irregularities of the field microrelief. A comparative analysis of the impact on the soil of the most common anchor coulters with a blunt angle of soil entry and a sharp angle with an individual floating suspension is given, and indicators of the quality of their operation are described. It was found that coulters with an individual floating suspension and an acute angle of soil entry meet the requirements for potato growing conditions to the maximum extent possible. In order to ensure travel stabilization of such a coulter at a given depth when imitating field irregularities, a version of the coulter group has been developed that provides automatic correction of the coulter's angle of attack when changing its travel depth. Experimental studies have optimized the parameters of the coulter suspension that ensure automatic imitation of field microrelief irregularities up to 20 cm deep within the initial requirements for potato planting machines. Coulters with an individual floating suspension and a sharp angle of soil entry most fully meet the requirements for potato growing conditions to the maximum extent possible. A coulter group with a suspension aspect ratio of 150:200:400:400 cm and an acute angle of coulter entry into the soil provides automatic maintenance of the set coulter travel depth within the initial requirements (±2 cm) for irregularities in the field microrelief of up to 200 mm. In this case, the bottom and walls of the furrow are not compacted.

РЕЗЮМЕ
Конструктивные схемы сошников и в целом сошниковых групп картофелесажалок в статье обосновываются исходя из морфологических особенностей картофельного растения, его требований к условиям произрастания и обеспечения качественного выполнения технологического процесса посадки. Назначение сошниковых групп - формировать ложе для размещения посадочных клубней с рыхлой прослойкой почвы в 5 – 8 см. и заделки их разрыхленной почвой на определенную глубину. Обосновать тип сошников картофелесажалки наиболее полно удовлетворяющих требованиям к условиям произрастания картофельного растения. Оптимизировать параметры сошниковых групп, автоматически обеспечивающих стабильность глубины хода сошника картофелесажалки при копировании неровностей микрорельефа поля. Дан сравнительный анализ воздействия на почву наиболее распространенных анкерных сошников с тупым углом вхождения в почву и острым с индивидуальной плавающей подвеской, приведены показатели качества их работы. Установлено, что наиболее полно удовлетворяют требованиям к условиям произрастания картофельного растения сошники с индивидуальной плавающей подвеской и острым углом вхождения в почву.

С целью обеспечения стабилизации хода такого сошника на заданной глубине при копировании неровностей поля разработана версия сошниковой группы, обеспечивающей автоматическую коррекцию угла атаки сошника при изменении глубины его хода. Экспериментальными исследованиями оптимизированы параметры подвески сошника обеспечивающие автоматическое копирование неровностей микрорельефа поля глубиной до 20 см. в пределах исходных требований на картофелепосадочные машины. Наиболее полно удовлетворяют требованиям к условиям произрастания картофельного растения сошники с индивидуальной плавающей подвеской и острым углом вхождения в почву. Автоматическое поддержание заданной глубины хода сошника в пределах исходных требований (±2 см) при неровностях микрорельефа поля до 200 мм обеспечивает сошниковая группа с соотношением сторон подвески 150:200:400:400 см и острым углом вхождения сошника в почву. При этом дно и стенки борозды не уплотняются.

INTRODUCTION

Coulter groups of potato planters include coulters with furrow-closing working bodies intended to form a bed for placing tubers and sealing them to a certain depth. Currently, the most common are anchor coulters with a blunt angle of soil entry and a rigid or individual floating suspension (foreign planters). Soviet-made planters were equipped with coulters with a sharp angle of soil entry and an individual floating suspension *(Aldoshin N.V. et al, 2015; Aldoshin N.V. et al, 2014; Kukharev O.N. et al, 2018; Kurdyumov V.I. et al, 2019; Kurdyumov V.I. et al, 2016)*.

Substantiation of the structural layout of coulters and coulter groups in general should be carried out based on the morphological features of the potato plant and its requirements for growing conditions.

The root system of potatoes grown from tubers is fibrous. The roots initially spread mainly deep into the soil and to the sides. The main mass of roots (60–80 %) extends deep into the arable layer under the mother tuber. In highly compacted soils (up to 1.35 – 1.50 g/cm^3), the root system develops very poorly and is concentrated in the surface layer of the soil, which leads to late emergence of crops and loss of yield. The root system of potatoes develops much better on loose soils with a density of 1.10–1.20 g/cm^3. *(Bashkirtsev V.I. et al, 2017; Lobachevsky Ya.P. et al, 2016; Laryushin N.P. et al, 2015).*

An important factor is the effect of the coulter on the density of soil – compaction of the furrow bottom and walls or loosening. The loose soil layer in the furrow provides normal emerging crops. When the furrow bottom is loosened sufficiently well, the rolling of tubers during planting decreases, the power of the root system increases and this ensures higher yields *(Sibirev A.V. et al, 2019).*

Thus, based on biological characteristics of potato plants, the basic requirements for coulter groups of potato planters are as follows: the furrow bottom should not be compacted; a layer of loose soil at the furrow bottom should be 4 to 5 cm; when placing mineral fertilization between potatoes and fertilizers, a layer of loose soil with a minimum thickness of 2 cm should be provided; the coulter suspension must satisfactorily replicate field roughness up to 200 mm high; the deviation from a predetermined depth of tubers should not exceed 2 cm *(Zykin E.S. et al, 2017; Kukharev O.N., 2006; Kalinin A.B. et al, 2015; Kalinin A.B. et al, 2016; Kukharev O.N. et al, 2018).*

The purpose of our research is to justify the type of potato planter coulters that meet the requirements for potato growing conditions to the maximum extent possible. Optimize the parameters of coulter groups that automatically ensure the stability of the coulter travel depth within initial requirements for potato planters when imitating irregularities of the field microrelief up to 20 cm deep.

MATERIALS AND METHODS

A coulter with a blunt angle of entry tends to dig out under the action of the soil from the force P_2 (Figure 1). At the defined depth, it is held by the weight of the planters significantly unloading the support and driving wheels of the machine.

This reduces the grip of the drive wheel on the ground and its slippage while increasing the set planting pitch until the formation of gaps.

Minor fluctuations in the values of soil density in different parts of the field significantly change the value of the traction force P_1, and, consequently, the reaction of the soil from the force P_2, which also changes its value (as a component of the resulting force P). All this affects the depth of the coulter travel and can even result in that tubers are not covered with soil and emerge on the field surface. In addition, the uneven depth of tuber planting is affected by the field roughness; especially this affects the rigid suspension of the coulter.

A coulter with a blunt angle of soil entry pushes soil particles into the furrow bottom and shifts them to the sides. As a result, the bottom and walls of the furrow are compacted. This phenomenon is especially seen on heavy soils with variable humidity along the rut length.

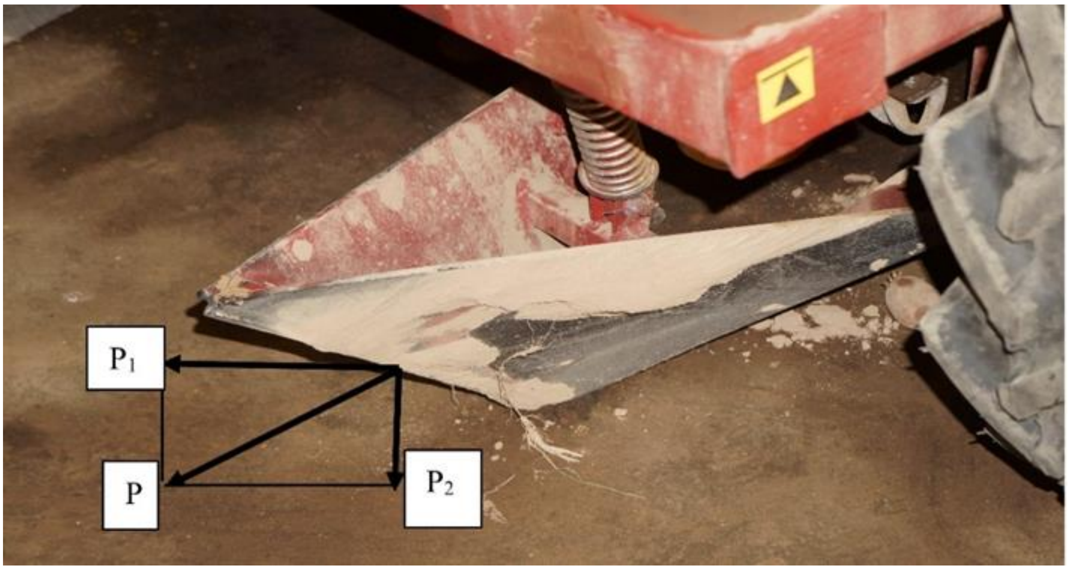

Fig. 1 – Coulter with a blunt angle of soil entry of L-202 potato planter

P_1 – is the tractor pulling force; P_2 – is the force of the planter weight; P – is the resulting force

The coulter with an acute angle of soil entry works in a self-deepening mode. The coulter tries to go deeper into the soil under the action of the soil from the force P_2 (Fig. 2) – the vertical component of the resulting force P when the tractor applies the pulling force P_1. The gauge wheel limits the depth of the coulter travel. In this case, the coulter does not compact, but loosens the bottom and walls of the furrow.

To increase the thickness of the loose layer at the furrow bottom, and to form a soil layer between fertilizers and tubers when working with fertilizers, *8* blades are usually provided in the front part of the coulter body, or a V-shaped sweep is installed *(Kukharev O.N. et al, 2018; Sibirev A.V. et al, 2018).*

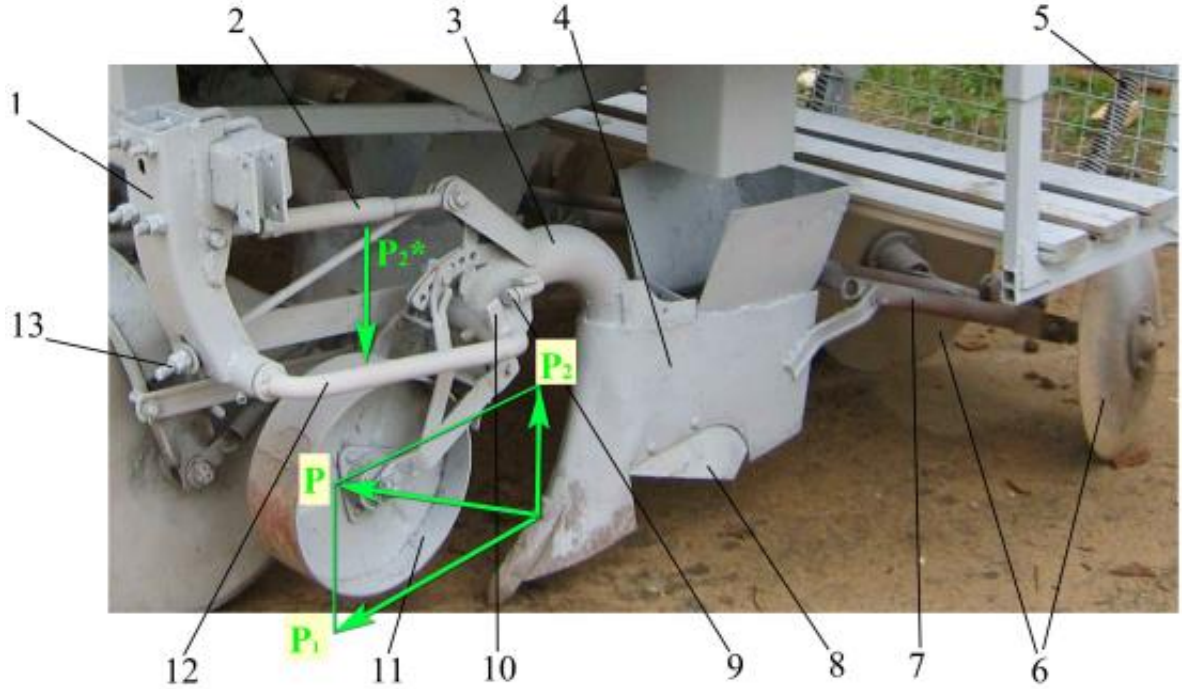

Fig. 2 – Coulter group of the KSU-4 clone potato planter (VIM)

1 – bracket attaching the coulter to the planter frame; 2 – upper link of the suspension; 3 – coulter bracket; 4 – coulter; 5 – push-rod; 6 – burrow-closing discs; 7 – disc mounting frame; 8 – blade; 9 – stop's adjusting bolt; 10 – stop; 11 – gauge wheel; 12 – lower suspension; 13 – Panhard rod

Figure 2 shows a coulter group for machines used to plant potato clones designed by the Federal State Budgetary Research Institution "Federal State Agricultural Centre VIM" (FGBNU FNAC VIM) with self-deepening coulters and an individual floating suspension of parallelogram type, pos. *5, 6, 7*. Such coulters were installed on Soviet-made potato planters SN-4B, SKS-4, KSM-4, etc.

The angle of soil entry of coulter *4* depending on soil density is set by the length of upper rod *2* of the suspension. The depth of the coulter travel is changed by turning the fork of gauge wheel *11* relative to the coulter bracket. In the front part of the coulter body there is a shield that forms a channel for directing mineral fertilizers into the bed formed by the coulter tip. Blades *8* form a loose layer of soil at the furrow bottom and provide a soil layer between the fertilizer and tubers.

To limit the coulter lowering when transferring the planter to the transport position, there is stop *10* at the end of rod *12*. Adjustment bolt *9* is installed in front of the stop in coulter bracket *3*. This bolt touches thrust stop *10* when lifting the planter to the transport position.

The parallelogram provides diagonal rod *13*, one end of which is pivotally attached to the coulter bracket and the other one, having a threaded and screwed nut, is passed through the slot of front bracket *1*. The rod restricts the coulter raising preventing the coulter body from resting against structural elements of the planter during operation.

Frame *7* is pivotally attached to the coulter sidewalls for mounting through the curved half-axes of furrow-closing disks *6* and clamping telescopic rod *5*. The upper part of rod *5* is pivotally attached to the planter frame. Semi-axes of the furrow-closing disks can be rotated relative to the frame in order to regulate the angle of attack of the disks, which determines the shape of the ridge. Rod *5* provides holes for adjusting the compression of the pressure spring, and, consequently, the pressure of the disks onto the soil, which affects the depth of tubers and the height of ridges.

A coulter with a sharp angle of soil entry, a gauge wheel and a floating parallelogram suspension with a length of longitudinal rods of 400 mm satisfactorily imitate the field irregularities with a height up to 150 mm. Blades *8* in the front part of the coulter body provide a loose layer of soil at the furrow bottom up to *5* cm. The disadvantage of the potato planter coulters considered is that, despite imitating field irregularities, the depth of tuber planting in the soil is not always uniform. This is due to the fact that when imitating field irregularities while moving the coulter down vertically, the tip of the coulter falls into denser soil layers, and since the parallelogram suspension mechanism keeps the coulter's angle of attack constant, the reaction of the soil under the action of the vertical component of the resultant force *P* (Figure 2) increases.

The vertical component of the force pressing the wheel to the soil P_2^* is proportionally increased, this force makes the wheel pressed into the loose surface layer of soil, the planting depth of tubers increased (uneven depth of planting along the rut length, depending on the soil density, up to ±4 cm). Uneven depth of the coulter travel affects the seedling vigour, especially when planting mini-tubers in elite potato seed production.

The value and direction of the resultant force *P* (Figure 2) depends on the operating speed of the planting machine, the coulter travel depth, the soil density, its humidity, coefficient of friction of the coulter surface with the soil and the angle of soil entry of the coulter (angle of attack). In the design of the coulter group, we can adjust the value of the coulter angle of soil entry. When the angle of attack increases, the coulter tries to go deeper into the soil, which is prevented by the force P_2* on the side of the gauge wheel *11* (Figure 2), pushing it into the soil. When the coulter angle of attack decreases, the force P_2* decreases and the gauge wheel is less pressed into the ground.

To stabilize the coulter travel at a given depth, when imitating irregularities, it is necessary to automatically change the value of the angle of attack β (Figure 4), depending on the change in the field microrelief.

The stated technical problem is achieved by that the individual floating suspension of the coulter in the coulter group of planters (Figure 3 and Figure 4) is not a parallelogram, but a hinge quadrilateral with the sides formed by the mounting bracket of the coulter group of planters to frame *1* (side AB), coulter body *5* (side CD) and longitudinal upper *2* (side BC) and bottom *4* (side AD) rods.

In this case, the distance between the hinges of side *1* is less than that of side *5*, and the upper rod *2* and lower rod *4* are equal to each other. Moreover, the straight line passing through the attachment points of the longitudinal rods to the mounting bracket of the coulter group is perpendicular to the field surface, and the upper suspension rod has telescopic coupling *3* for setting the initially set coulter angle of attack.

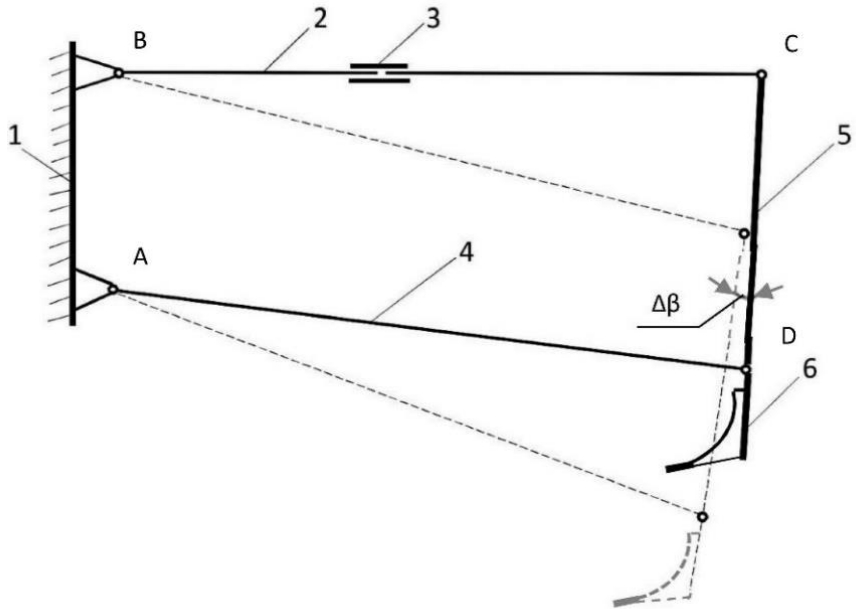

Fig. 3 – Schematic diagram of the coulter individual floating suspension operation
1 – planters to frame; 2 – longitudinal upper rods; 3 – telescopic coupling; 4 – longitudinal bottom rods; 5 – coulter body; 6 – coulter

The value of change in the angle of attack ∆β depending on the change in the coulter travel depth is achieved by reducing the distance between the hinges of the quadrilateral of side *1* (AB) in relation to side *5* (CD) (Figure 3).

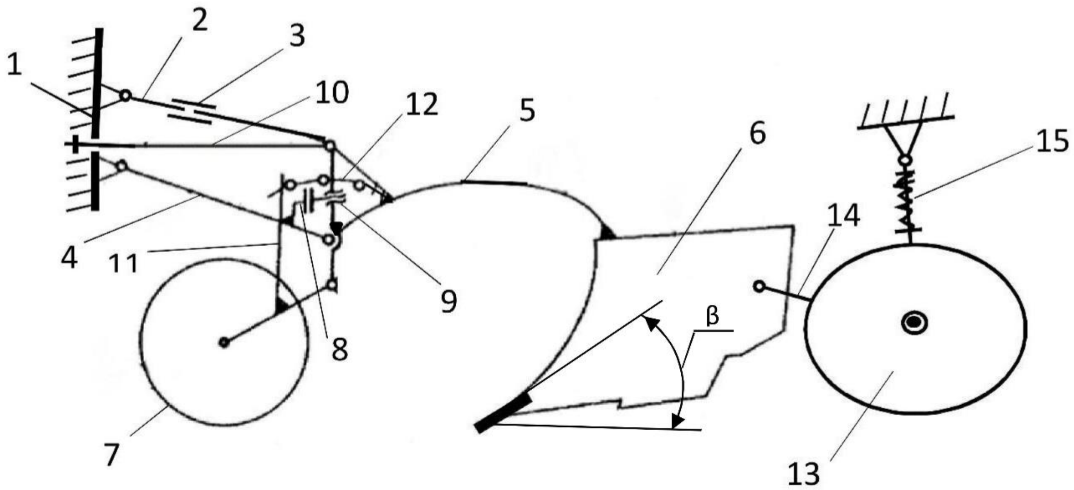

Fig. 4. – Coulter group of potato planters with automatic stabilization of planting depth
1 – frame; 2 – upper rod; 3 – telescopic coupling; 4 – lower thrust; 5 – coulter body; 6 – coulter; 7 – gauge wheel; 8 – stop of coulter lowering limiter; 9 – stop's adjusting bolt; 10 – diagonal thrust of coulter raising limiter; 11 – plug of gauge wheel; 12 – adjustment sector for coulter depth; 13 – burrow-closing disks; 14 – disk fixing frame; 15 – spring-loaded push rod

The developed coulter group of planters with automatic stabilization of planting depth (Figure 4) contains the bracket attaching the coulter to planter frame *1*, upper rod *2* of coulter suspension with telescopic coupling *3* to set the initial angle of attack *β* of the coulter, lower thrust *4* of coulter suspension, coulter body *5*, coulter *6*, gauge wheel *7*, stop of coulter lowering limiter *8*, stop's adjusting bolt *9*, diagonal thrust of coulter raising limiter *10*, plug *11* of gauge wheel, adjustment sector *12* for coulter depth, burrow-closing disks *13*, disk fixing frame *14*, spring-loaded push rod *15*.

Preparing the coulter group for operation and imitation of field irregularities is as follows.

The initially set angle of soil entry of coulter *6* is provided by the length of upper rod *2* of the suspension using telescopic coupling *3*. The travel depth of coulter *6* is set by turning fork *11* of gauge wheel *7* relative to sector *12* fixed to the coulter body. The sharp angle of the coulter entering into the soil loosens the furrow bottom.

By adjusting the length of bolt *9* and changing the position of the nut on rod *10*, the necessary amount of the coulter travel in vertical direction is achieved, which makes it possible to imitate field irregularities.

The travel depth of coulter *6* is set and maintained by the gauge wheel. When the coulter group overcomes field irregularities and moves the coulter down vertically, the coulter tip falls into denser soil layers. In this case, the resultant of soil resistance forces on the coulter increases, but due to the pre-set aspect ratio of the four-link suspension mechanism, the angle of attack of coulter *6* decreases (Figure 3), and the vertical component of the resultant of soil resistance forces remains approximately constant. The vertical component of the force pressing the gauge wheel to the soil remains a constant value.

As a result, the gauge wheel is pressed into the surface layer of the soil by about the same amount, and the tuber bed formed by the coulter at the furrow bottom is automatically stabilized at a given depth.

RESULTS AND DISCUSSION

In order to optimize the ratio of sizes of suspension rods that provide the most stable coulter depth travel, four variants of side lengths of the four-link mechanism were adopted in experimental studies (Figure 3) with the following AB:CD:BC:AD ratio, respectively:

a) 4:4:8:8 or 200:200:400:400 in mm - parallelogram;

b) 3:4:8:8 or 150:200:400:400 in mm;

c) 2:4:8:8 or 100:200:400:400 in mm;

d) 1:4:8:8 or 50:200:400:400 in mm.

Researches of experimental coulter groups were carried out on a two-row clone planting machine developed and manufactured by the FGBNU FNAC VIM experimental plant (Figure 5).

The test site is the experimental field of Redkinskaya Agro-Industrial Complex LLC in Koshelevo village, Konakovsky District, Tver Region. During the tests, the planter was combined with MTZ-82 tractor of traction class 1.4.

Fig. 5 – Experimental coulter group on VIM clone landing machine

Soil type during testing – sod-podzolic (light loam), structure – small-lumpy, relief – smooth, microrelief-ridged with a difference of ridges up to 200 mm (*Sibirev A.V. et al, 2018, Sibirev A.V. et al, 2019).*

Soil moisture and hardness in the layers, respectively:

0 to 5 cm.	14.5 %	0.35 MPa
5 to 10 cm.	16.7 %	0.54 MPa
10 to 15 cm.	19.5 %	1.29 MPa
15 to 20 cm.	22.8 %	1.34 MPa

Soil temperature during testing in the layer from 0 to 20 cm was + 10.0°C, air temperature was +12.0°C.

In order to obtain correctly comparable experimental data, a section of the field with a specially cut microrelief was prepared for testing (Figure 6).

Fig. 6 – Experimental field section

Express assessment of the surface microrelief of the experimental field section was carried out for test sections 5 meters long (Figure 7). This made it possible to carry out a reliable comparative assessment of the tested coulter groups of potato planters (*Sorokin A.A., 2006*).

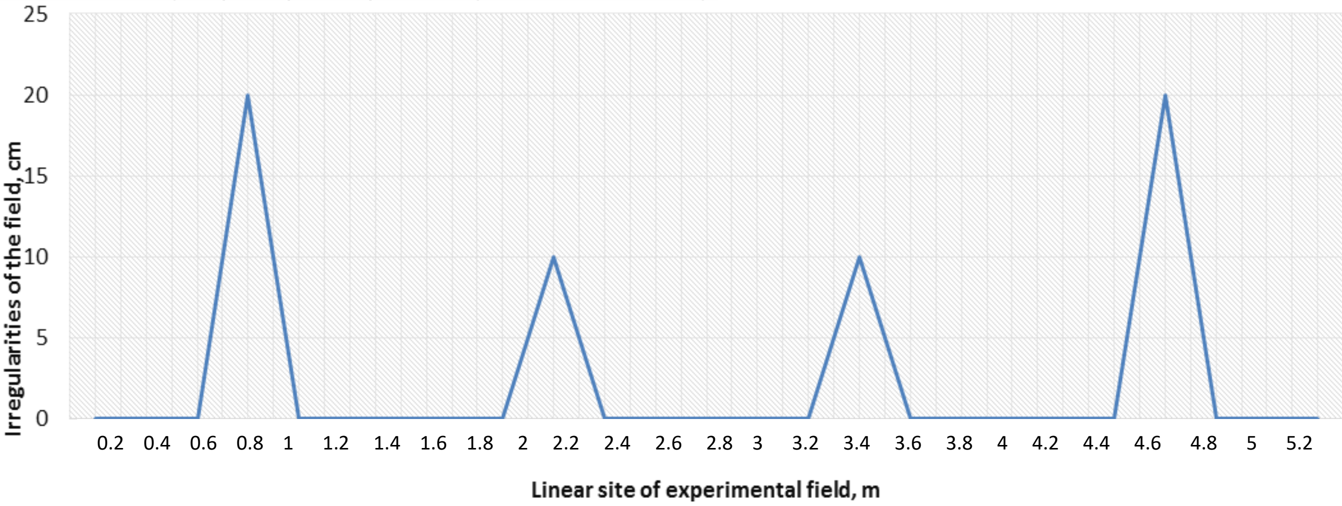

Fig. 7 – Microrelief of the experimental field

During the research, four pairs of coulters with different ratios of suspension rod lengths were alternately installed on a two-row clone planter in accordance with the experiment plan and the planter was rolled three times over the experimental field section in the direction perpendicular to the cut irregularities with a constant movement speed of 3.0 km/h.

The coulter travel depth was the distance from the surface of the field formed after running planters with raised sealing disks (edges of the formed bed for tubers) to the loose layer of the furrow bottom. Measurements of the coulter travel depth on a linear section of the experimental field were made every 20 cm. From six repetitions of measurements at each point (2 coulters with 3 repetitions), the average value was determined and graphs of the coulter depth were drawn for each suspension typical size (Figure 8).

For each coulter group, average values of the coulter travel depth, average square deviations and coefficients of variation were then determined from measurements that were average for points.

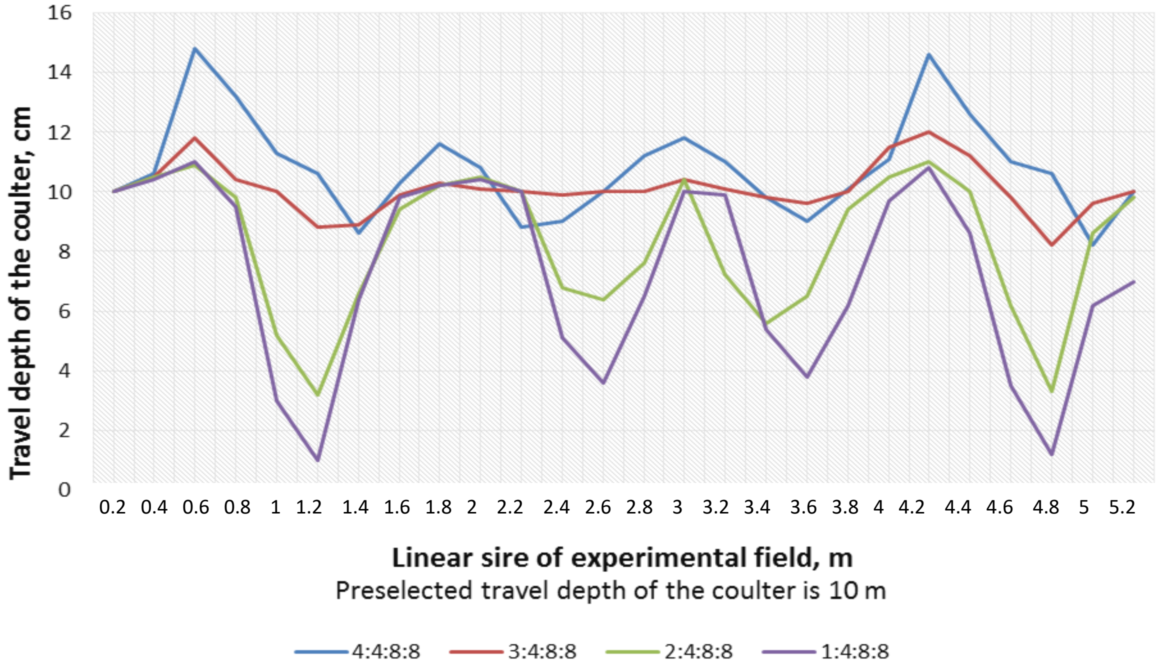

Fig. 8 – The effect of the coulter suspension ratio AB CD BC AD to the uniformity of the coulter travel when passing rough spots

The test results after mathematical processing of the obtained data are shown in Table 1.

Table 1

Uniformity of the coulter travel depth depending on the aspect ratio of its suspension

Aspect ratio of the coulter suspension mm	**Δβ at the height of irregularities mm**		**Coulter travel depth cm**					
	100	200	defined	max	min	av.	ϭ±cm	V %
200:200:400:400	0°	0°	10.0	15.0	8.0	10.8	3.67	34.0
150:200:400:400	6°	7°	10.0	12.0	8.0	10.0	1.78	17.8
100:200:400:400	10°	16°	10.0	11.0	3.0	8.1	3.92	48.4
50:200:400:400	18°	29°	10.0	11.0	0.5	6.8	5.28	77.6

Δβ is the change of the coulter angle of attack when overcoming irregularities
ϭ - *standard deviation*
V - *the coefficient of variation*

The graphic images in Figure 8 clearly show the effect of the coulter suspension aspect ratio on the deviation of its travel depth from the set depth when passing rough spots of the field surface.
The deviation of the coulter travel depth with a conventional parallelogram suspension (200:200:400:400) is observed to be increased within 4 cm from the depth defined for field irregularities up to 20 cm, which exceeds the initial requirements by 2 cm. For field irregularities up to 10 cm, this coulter group easily meets the initial requirements.

In a coulter group with a suspension aspect ratio of 150:200:400:400, the deviation of the travel depth from the set one does not exceed 2 cm, even if the field is uneven, the average travel depth of the coulter remains at the set level.

Travel of the coulter with the third type of suspension (100:200:400:400) deviates from a predetermined value decreasing to a depth of 6 cm for field irregularities of 10 cm and to a depth of 3 cm for microrelief irregularities of 20 cm, which exceeds the limit of tolerances defined by initial requirements for potato planting machine.

The travel depth of the coulter with the fourth type of suspension (50:200:400:400) deviates even more from the set point, and for irregularities of 20 cm the furrow bottom almost reaches the field surface.

The travel deviation of the coulter of the third and fourth types of suspensions in terms of depth decrease from the set point is explained by a decrease in the coulter angle of attack *β* to a negative value, which causes its abrupt deflection and a tendency to reach the field surface due to inertia forces. It is obvious that with an increase in the planting machine speed, the operation quality of the last two types of coulter suspensions will deteriorate further and the machine will have oscillatory movements. Therefore, the third and fourth types of suspensions are unacceptable, as they do not meet the initial requirements for potato planting machines.

Conclusions from the analysis of graphs (Figure 8) are confirmed by averaged probabilistic indicators (Table 1). Thus, the average value of the coulter travel depth with a parallelogram suspension deviates slightly (by 0.8 cm) from the set value since it increases with an average square deviation of ±3.67 cm and a coefficient of variation of 77.6%. The average value of the coulter travel depth with a suspension aspect ratio of 150:200:400:400 corresponds to its set value with a much less significant mean square deviation of ±1.78 cm and a coefficient of variation of 17.8 %. The average values and variational indicators of suspensions with an aspect ratio of 100:200:400:400 and 50:200:400:400 are far beyond the initial requirements for potato planting machines and therefore cannot be applied to planters in the practice of potato planting.

CONCLUSIONS

Coulters with an individual floating suspension and an acute angle of soil entry meet the requirements for potato growing conditions to the maximum extent possible.

A coulter group with a suspension aspect ratio of 150:200:400:400 cm and an acute angle of coulter entry into the soil provides automatic maintenance of the set coulter travel depth within the initial requirements (±2 cm) to potato planting machines for irregularities in the field microrelief of up to 200 mm. In this case, the bottom and walls of the furrow are not compacted.

Coulters with a parallelogram suspension (ratio of rod lengths is 200:200:400:400 cm) ensure uniformity of the coulter travel depth along the rut length within ±2 cm with irregularities in the field microrelief of up to 100 mm.

Reducing the length of the AB rod (Figure 3 position 1) of the coulter suspension up to 100 cm or less causes oscillating movements of the coulter, which results in its travel depth uniformity going far beyond the initial requirements.

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