SUBSTANTIATION OF THE PROCESS OF DEEP TILLAGE WITH AGRICULTURAL MACHINES OF DIGGING TYPE

Prof. Eng. **Volodymyr Bulgakov**[1] PhD., Assis. prof. Eng. **Vasil Mitkov**[2] PhD., Assis. prof. Eng. **Vitaliy Movchan**[2] PhD., Assis. prof. Eng. **Vyacheslav Mitin**[2] PhD., Eng. **Yevhen Ihnatiev**[2] PhD.

[1]National University of Life and Environmental Sciences of Ukraine, 15, Heroyiv Oborony Str., Kyiv, 03041, Ukraine;
[2]Dmytro Motornyi Tavria State Agrotechnological University, 18, Khmelnytsky av., Melitopol, 72312, Zaporizhia region, Ukraine;
E-mail:vbugakov@meta.ua, yevhen.ihnatiev@tsatu.edu.ua

Abstract: The paper considers the issue of deep tillage, the use of the latest technical advances, in order to develop new tillage implements that provide better tillage and reduce erosion. The main attention is paid to the preservation of soil fertility and the use of funds in organic farming. The aim of the work is to improve the process of mechanical tillage by digging by developing a new working body and the process of interaction of digging working bodies with the soil, which change its physical properties and improve environmental safety. The most promising for deep tillage is the digger in terms of both energy and agronomic indicators (reduction of compaction, preservation and restoration of water and air balance, preservation of humus, preservation of biomass). Rotary diggers with rotational movement of working bodies are more effective in comparison with diggers having oscillating movement of working bodies. As a result of studying the dependence of the angle of the blades, providing the movement of the formation on the surface of the working body, from their position on the trajectory, it was found that the smallest value ($5\ldots7^0$) is the angle of inclination after turning the blade deepening. When lifting the formation from the bottom of the furrow to a certain height, the required angle of the blades increases, reaching a value of $28\ldots\ 30^0$ when overturning the formation at a height of 0.20…0.25 m

KEY WORDS**:** *DEEP TILLAGE, DIGGER, ENERGY CONSUMPTION, DEGREE OF GRINDING, DEPTH OF CULTIVATION*

1. Introduction

In modern conditions, tillage remains the most important element of the agricultural system, which provides regulation of arable land productivity and energy consumption, preservation of the top layer of soil from erosion, increasing soil fertility.

When choosing the optimal method of mechanical tillage, any landowner pursues one main goal - to create an optimal arable layer for growing crops. In this process, an important factor in quality tillage is to improve its structure, physico-chemical properties and provide the necessary water-air regime, which ultimately contributes to increasing soil fertility.

The main role in increasing soil fertility belongs to biological processes, the activity of which depends on its water-air regime and, accordingly, on the method of mechanical tillage. Therefore, the correct choice of treatment method is the most important means of regulating the vital activity of soil microflora, its number and species composition.

The main tillage is the most energy-intensive in modern agriculture, which involves preparing the soil for normal germination and development of cultivated plants. Paying attention to the invention of new, more advanced tillage bodies can have a great influence on the development of agriculture, improve the condition of soils, reduce the energy intensity of tillage, improve fertility.

The following scientists made a great contribution to the search for fundamentally new methods of tillage: Listopad D.N., Novikov Yu. F., Nadykto V.T., Uleksin V.O., Vasylenko P.M., Dalin A.D., Babiy P.T., Sokolov V.M., Dokin B.D., etc.

To provide plants with sufficient moisture, minerals and compliance with other agricultural requirements, there are four following main functions that must perform tillage tools:

First, the tool must loosen the soil to a certain density, as deviation leads to a decrease in plant yields.

Second - to turn the plow layer. However, agronomic requirements do not recommend such an operation for all cases and not for all climatic zones. However, the inversion of the arable layer in most cases is a useful operation that allows you to earn in the soil the upper layer of soil damaged by tractor running gear, crop residues, stubble and weed seeds.

Third, mix and level the soil layer, creating a looser structure in which fertilizers are evenly distributed.

Fourth - level the ground. Waves and ridges interfere with the operation of machines, create uneven water regime, increase evaporation, increase air erosion [5].

In connection with the above, more and more attention is paid to the means of tillage with active working bodies - rotors. If the traction efficiency of the tractor does not exceed 65… 75% when working with the plow, then when working with traction-drive machines with energy transfer through PTO, the traction efficiency increases significantly [6].

In addition to the traditional principle of tillage by wedge cutting, which is used in plowing, scientists have identified seven different ways to grind the soil.

When designing tillage machines, you should try to create conditions for grinding with the lowest energy consumption, for which you should pay attention to the phenomena of friction between the surface of the working body and the soil.

Interesting in this regard is the application in tillage machines of the principle of grinding on the "cross sections of weak bonds", which is as follows. Instead of destroying the soil layer along the cross-sections caused by the tractors of the working bodies, which we call cutting, it is divided into parts of indefinite shape along the weakened cross-sections formed by cavities - cracks and porosity in the soil. This reduces the overall energy consumption of the process.

The following positive factors are a convincing factor in favor of diggers:

1. When digging, no plow sole is formed. As a result, precipitation penetrates more freely into the lower horizons, improves water permeability and soil aeration, the development of the root system of plants, the inflow of moisture and nutrients from the lower horizons.
2. After cultivation by diggers in the field there are no dumping ridges and collapsible furrows that excludes need of additional processing.
3. A large number of micro-depressions remain on the soil surface, which contribute to the retention of precipitation.
4. The diggers have a separate drive, which reduces the traction force required for operation and helps to reduce the traction class of the tractor for aggregation.

When tillage by rotary diggers, the translational movement of the unit is performed simultaneously with the rotational movement of the working body, which significantly increases the intensity of the impact of the working body on the soil. During this process, the length of the cutting path is of great importance, which varies in rotary machines from 0.03 to 0.3 m. In the first tillage machines with a mechanical drive, the working bodies performed a reciprocating motion and had the shape of shovels or forks. This is due to the fact that the scientists who invented such a machine followed the path of imitating manual techniques. [7].

2. Preconditions and means for resolving the problem

An important element of the farming system is the tillage system. The importance of mechanical tillage is due to the effect on all its properties and the presence of terrestrial factors of plant life, which determine fertility. Improper tillage causes significant damage to it, reducing potential and effective fertility. Observations of scientists have established the levels of impact on the yield of cultivated crops of agronomic measures with their joint use: soil fertilization - 50%, tillage - 20%, varieties - 10%, protection against pests - 20% [1].

Intensive use of systematic plowing of soils in Ukraine in the 60's and 80's, even against the background of organic and mineral fertilizers, was not the last reason for a significant reduction in the amount of humus in them. Its average content in soils for these 20 years decreased from 3.5% to 3.2%, which is 1…2% less than the optimum [2]

In the country now 48% of arable land is negatively affected by water and wind erosion. The intensity of erosion processes now exceeds the natural soil formation by 2… 10 times [2]. Soils are also negatively affected by physical erosion, which is manifested in their compaction under the influence of passages in the fields of tractors and agricultural machinery. With modern intensive technologies, the number of passes of units in the fields reaches 8…16, and soil compaction extends to a depth of 60… 100 cm.

Today, intensive agriculture uses three main tillage systems: mini-till, notill and clean ploughing.

Dump tillage system is considered traditional [3]. This system provides as the main cultivation - autumn plowing with rotation of the soil layer and the use of plowshares and anglers. Cultural plowing, therefore, is the main link of intensive agriculture.

The positive phenomena of plowing with traditional plows include: earning nutrient residues in the soil and creating conditions for their decay; deep earning of pathogens and weed seeds, which prevents their germination; good loosening of the top layer of soil, which accumulates in the root layer a large amount of moisture before the growing season of cultivated plants and creating conditions for active work of microbes involved in the process of humus mineralization, providing the culture with nutrients [4]

The disadvantages of this tillage system are the degradation of soil quality due to the accelerated mineralization of humus in the upper layer of the soil. High ridge increases the impact of water and air erosion. The weight of the tractor performing the operation has a great influence on the condition of the soil. The need to drive a wedge-shaped working body with horizontal cutting due to traction requires the use of heavy tractors that compact the soil to a depth greater than the stroke of the plow, which contributes to the formation of the plow sole - a compacted layer of soil below. The plow sole interferes with the normal gas and water exchange in the soil, prevents the development of the root system of cultivated plants and, as a consequence, leads to a decrease in crop yields. The soil compacted in this way loses a structure that is not restored by purely mechanical loosening..

One of the first known machines for mechanized main tillage was the Cooper steam engine (1875), which was called a digger because of its similarity to manual digging. The scheme of operation of this machine minimized cutting of the soil, and satisfactory quality of loosening was achieved by rupture of the formation by fork-shaped working bodies. It is noted that after the passage of the machine there was a well-leveled and loose surface, no compaction was created on the bottom of the furrow, but the rotation of the formation and wrapping of plant debris in comparison with the plow were unsatisfactory.

Other inventors were: William Mers, Francis Cohn, Lucius Gibbs, John Gilmore Jones, Jordan Hills and William Maches. Due to the unsatisfactory quality of work, these machines were not further developed and only in Italy, research continued.

Nowadays in Italy a number of companies such as Gramegna, FALC, Chelly, Sikma, Nardi produce diggers with oscillating movement of working bodies.

The disadvantages of these diggers include: incomplete rotation of the formation due to a slight deviation from the vertical trajectory of the cutting edge of the blade at the time of rejection of the cut layer.

Imants (Netherlands) produces tillage machines for tillage to a depth of 25 ... 90 cm. The shovel-like working bodies of this machine perform only rotational movement. Four working bodies are fixed on each rotor flange. The cut layers are discharged by a cleaner installed between two working bodies, in relation to which its position is regulated.

If it is necessary to prepare the soil for sowing in one pass, the blade rotary machine can be equipped with a second rotor of the original design.

In Croatia, since 1980, research and production of the rotary machine TL-8-LOPATOR at the plant Sloveniya cesta tehnika under the license of the Italian company Vangatrici [8]

The principle of operation is similar to "FALC". Processing width is 1800 mm. The width of the digger's blade is 170 mm. Depth of processing to 30 cm. It is aggregated with tractors of a class of 0.6 ... 0.9 kN [9].

In our country such tillage machines as LT-1.4, KR-1.5 and MPT-1.2 have been developed. The most common machine MPT-1.2 is designed for milling and plowing [9, 10, 11].

A more advanced machine that was mass-produced is the MPT-1.2 . It consists of a frame, a cardan shaft (1), a gearbox with a gearbox, a side drive (2), a drum shaft with L-shaped knives (4), two support skis (3), a casing and a cardan shaft with a safety clutch. At slow rotation of a drum (0.71 s^{-1}) digging of soil is carried out, at fast (2.71 s^{-1}) - milling [12].

Після проведеного огляду існуючих конструктивних схем копачів та аналізу науково-технічної літератури з основної обробки After reviewing the existing structural schemes of diggers and analysis of scientific and technical literature on the main tillage machines with machines with active working bodies, the following conclusions can be drawn:

1) the most promising for the main tillage is the digger in terms of both energy and agronomic indicators;

2) diggers with the active drive have three schemes of arrangement: with the working bodies rotating a layer; with working bodies, cultivating the soil without rotating the formation, but placed on one crankshaft; with working bodies without rotation of a layer with the working bodies located in pairs;

3) rotary diggers with rotational movement of working bodies are most effective in comparison with diggers having oscillating movement of working bodies.

The purpose of the work is to improve the process of mechanical tillage by digging by developing a new working body.

To achieve this goal, the following tasks are set in the work:

- to substantiate the relevance of machining by digging in modern conditions;
- to analyze the latest achievements in the use of rotary tillage machines;
- theoretically substantiate the parameters and design of tools for tillage by digging;
- to carry out ecological assessment and technical and economic calculations of tillage by digging.

The object of research is the process of interaction of mining working bodies with the soil, which changes its physical properties and improves environmental safety.

The subject of research - the pattern of influence of structural and technological modes of operation of working bodies of the mining type.

The nature of the influence of the design width of the shovel and the number of shovels on the power required to overcome soil resistance was calculated on a PC using Microsoft Excel.

3. Results and discussion

Based on the comparison of the obtained characteristics, the influence of design parameters and operating modes on the torque required to overcome the soil resistance force is evaluated.

The obtained data will help to determine which parameters of the design or operating mode should be increased or decreased to increase the performance of the unit without a significant increase in torque.

In order to substantiate the parameters and design of a rotary mechanized tillage unit, we compare the operation of such a unit with a similar process performed manually. It is known that mechanical tillage with the help of macne and tractor unit (MTU) has a higher energy consumption than performing the same work manually [13]. Therefore, energy consumption can be reduced by using the features of manual digging and the application of these features in mechanical devices. The features and advantages of hand digging are presented in [14]. The process is presented in the form of 6 separate phases (Fig. 1).

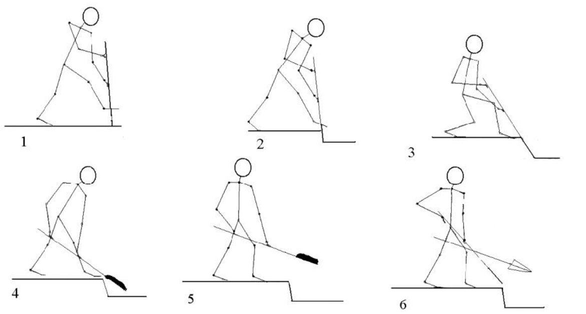

Fig.1. Phases of the working process of manual digging: 1 - setting the shovel to its original position; 2 - immersion of the shovel in the soil; 3, 4 - separation (separation) of slices; 5 - rise of a slice; 6 - laying slices

The degree of grinding is the main indicator that takes into account the quality of soil loosening. For a commonly used plow type PNL, the degree of grinding is 2.6 ... 2.8 units, with the required degree of grinding - 46 units [15]. Therefore, in practice, several types of tools are used, performing sequential technological operations for tillage. One of the promising areas is the creation of such tool designs, which simultaneously combine several methods of soil destruction and which allow to ensure the required quality of processing. For this case, the degree of grinding of the soil will be:

$$i = i_1 \cdot i_2 \cdot i_3 ... i_j , \quad (1)$$

where i_1, i_2, i_3, i_j – respectively the first, second, third and j-th methods of soil grinding.

При обробці ґрунту ротаційним робочим органом буде використано відразу декілька видів подрібнення: невелике, але різання у вертикальній площині, гравітаційне падіння та розколювання. Враховуючи приведені у [16] данні щодо ступені подрібнення різними способами можна підрахувати загальну ступінь подрібнення:

When cutting $i = 5$; when falling $i = 3$; when splitting $i = 3$. Then the total degree of grinding will be equal to:

$i_{\Sigma} = 5 \cdot 3 \cdot 3 = 45$

That is, a rotary digger, in its work can achieve the required quality of tillage, meeting the requirements for tillage implements.

Consider the movement carried out by the working body of the proposed mining unit (call it "Digger-1") [17].

The general view and the principle of operation of the tillage body are presented in Fig. 2. It works as follows: from the energy source (not specified) torque is transmitted to the drive shaft on which the hub is mounted, with racks on which are hinged blades (cutting working bodies). When the hub rotates, the blade deepens into the ground and cuts off the slice and moves it up, and the pusher located in the housing, through the roller, copies the surface of the eccentric and when it reaches its top, the cut piece of soil is turned and shifted. Then, under the action of the spring, the pusher returns the blade of the working body to its original position [17].

In accordance with the technological scheme in the work of mining working bodies there are the following characteristic phases: cutting the chips, lifting it and laying in the furrow. The trajectory of the working body during immersion in the soil and lifting of the formation corresponds to the equation of the trochoid (Fig. 2). When the blades are discarded, an additional movement is created, the law of which depends on the discard mechanism.

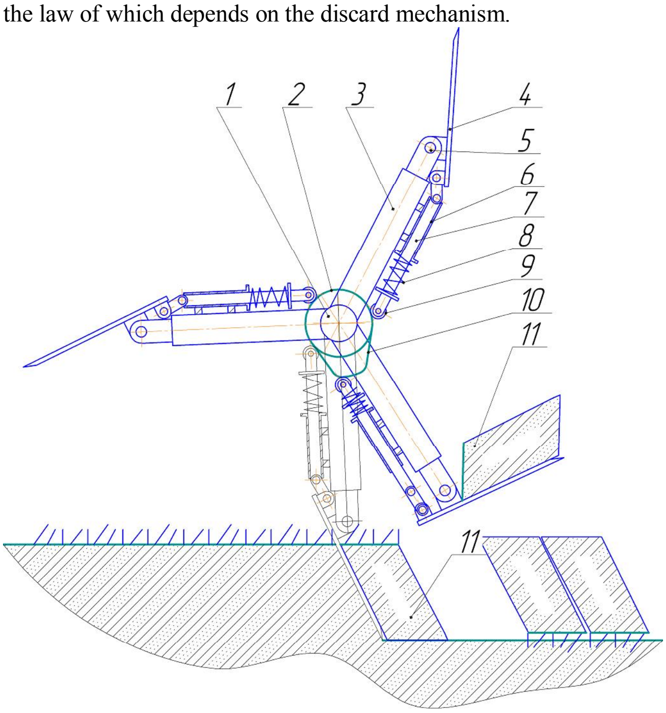

Fig. 2. Technological scheme and principle of operation of the mining working body: 1 - drive shaft; 2 - balm; 3 - rack; 4 - scapula (working body); 5 - a finger; 6 - housing; 7 - pusher; 8 - spring; 9 - roller; 10 - eccentric; 11 - a piece of soil

It is established that the process of soil rejection begins at a rotor speed of 50 min-1. This allowed to justify the maximum speed of rotation of the rotor, at which the specified condition is met [18].

The angle of inclination of the working body that ensures the movement of the formation depends on the moment of rejection. It is established that the required height of the formation up to the moment of tilting depends on the rotor speed, depth of processing and the number of working bodies in one section and is in the range of 0.1 ... 0.45 m [18].

As a result of the analysis of earlier researches of tools with rotary working bodies (Vasilenko P.M., Dalin A.D., Dokin B.D., and others) it is established that one of the main indicators of an operating mode is a relation between circular and translational speeds. [13,18, 19].

As a result of studying the dependence of the angle of the blades, providing the movement of the formation on the surface of the working body, from their position on the trajectory, it was found that the smallest value ($5 \ldots 7^0$) is the angle of inclination after turning the blade deepening. When lifting the formation from the bottom of the furrow to a certain height, the required angle of the blades increases, reaching a value of $28 \ldots 30^0$ when overturning the formation at a height of 0.20…0.25 m.

To ensure the separation of the formation from the working body, the angle of overturning of the blades during design should take at least 35… 40^0. And to ensure complete inversion of the arable layer - about 180^0.

Analysis of the influence of the moment of the beginning of overturning of the formation on the amount of displacement to the side, which is determined by the width of the open furrow, shows that the smallest displacement occurs when overturning it at a distance from the bottom of the furrow close to the depth of processing (0.20… 0.25 m). from the initial position equal to 225… 240^0.

To find the parameter of the digging device that most affects the force acting on the shovel, we compare the value of the torque that occurs during digging. The results of the calculations are presented in Figure 2.4.

We will change the value of the rotor radius from 0.4… 0.6 m with a step of 0.05 m, the digging step from 0.15… 0.25 m with a step of 0.025 m, the working depth from 0.2… 0.3 m with a step of 0.025 m and the rotational frequency from 40… 60 min-1 with step 5 min^{-1}

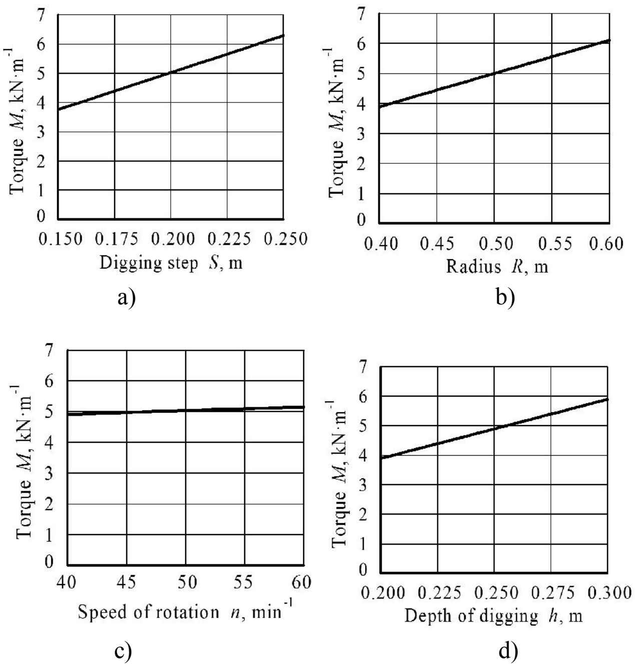

Fig. 3. Torque change schedule depending on:
a) digging step *S*; b) radius of the rotor *R*; c) speed of rotation *n*; d) processing depths *h*

As can be seen from the graphs in fig. 3, the rotational frequency has almost no effect on the torque when digging by a rotary digger (Fig. 3c), and other parameters change the torque linearly, with almost the same speed (Fig. 3 a, b, d).

In fig. 3d we see that with increasing depth of processing the value of torque increases linearly, but observing the digging process we can see that the value of torque with increasing depth of processing will first increase, and then at a depth of 25… 30 cm will decrease, reaching values close to oscillation frequency when rotating the rotor at idle. This phenomenon is explained by the increase in the time of interaction of the working bodies with the soil, at which the soil begins to act as a damper [20].

The power consumed for digging increases with the depth of processing, and the specific power consumed per unit volume decreases and at a depth of 25… 30 cm almost does not change its value. The analysis of the process research allows to substantiate the optimal depth of processing 25… 30 cm.

In the study of the influence of the magnitude and speed of feed on the change in power expended on digging, it was found that with increasing feed torque and power will increase. Moreover, when increasing the feed rate by 4.7 times leads to an increase in power consumption by 4.2 times.

Analysis of the change in specific power shows that at a feed rate greater than 0.4 m · s^{-1} it practically does not decrease. This allows to justify the optimal feed rate equal to 0.3… 0.4 m · s^{-1}, which is provided when feeding to one working body 0.15… 0.20 m.

Studies of the digger's work process show that there is a significant uneven load in the process of work. The reason for this is the constructive and technological scheme of digging machines. To reduce the load peaks, when designing digging machines, their sections should be installed so that in the process of work they provide overlapping of the load phases. Using the methods of physical modeling it is established that the work of shovels with overlapping is provided when installing them at an angle of 35… 50^0, while the minimum number of shovels on one digging machine is 9. With more shovels on one machine increases the coefficient of simultaneous shovel work. Increasing this coefficient leads to a decrease in the value of the fundamental oscillation frequency.

4. Conclusions

1. The main tillage is an energy-intensive process. Therefore, attention should be paid to combined tools, or the development of machines that reduce the number of technological operations.
2. To perform the main technological processes use general-purpose tools: plowing, flat-cutting, chiselling, cultivation, grinding, harrowing, milling, mechanical digging. The most promising for deep tillage is the digger in terms of both energy and agronomic indicators (reduction of compaction, preservation and restoration of water and air balance, preservation of humus, preservation of biomass).
3. Rotary diggers with rotational movement of working bodies are more effective in comparison with diggers having oscillating movement of working bodies.

5. References

1. Nadykto V. T., Koliina ta mostova systemy zemlerobstva. Monohrafiia / V. T. Nadykto, V. O. Uleksin. – Melitopol. TOV «Vydavnychyi budynok MMD». 2008. – 270 s. (in Ukrainian language).
2. Hordiienko V. P., Zemlerobstvo / Hordiienko V. P., Herkiial O. M., Opryshko V. P., K.: Vyshcha shkola 1991. – 276 s. (in Ukrainian language).
3. Zahalne zemlerobstvo: Pidruchnyk / Za red. V. O. Yeshchenka. – K.: Vyshcha osvita, 2004. – 336 s. (in Ukrainian language).
4. Noskov G. S. Teoreticheskoe issledovanie kopayuschego rabochego organa dlya obrabotki pochvyi v zaschischennom grunte // G. S. Noskov., F. M. Kanarev // Trudyi Kuban. Gos. agrar. un-ta, 2000. – Vip. 382. – s 119-123. (in Russian language).
5. Nazarenko I. I., Polchyna S. M. Nikorych V. A. Hruntoznavstvo: Pidruchnyk. — Chernivtsi: Knyhy — XXI, 2004. — 400 s. Kovda V. A. Osnovы uchenyia o pochvakh. — M.: Nauka, 1983. (in Ukrainian language).
6. Behei S. V. Ekolohichne zemlerobstvo. Pidruchnyk / S. V. Behei, I. A. Shuvar – Lviv: «Novyi Svit-2000», 2007. – 429 s. (in Ukrainian language).
7. Kyselev S. N. Obosnovanye parametrov kopanyia dlia osnovnoi obrotky pochvы v teplytsakh: avtoref. dys... d-ra tekhn. nauk. - M.: 1995. — 36 s. (in Russian language).
8. Incorporation of tracers and dozomet by rotary tillage and spading machines./ Juzwik J. // Soil and Tillage Research. – № 41. – 1997. – P. 237-248.
9. Kramarenko L. P. Silskohospodarski mashyny /Kramarenko L. P : T. 1. – Kh.: Derzhavne vydavnytstvo s.-h. literatury, 1938. – 400 s. (in Ukrainian language).

10. Omar Hattab Omar. Sposobyi osnovnoy obrabotki vyischelochennyih chernozemov v zvene sevooborota goroh-ozimaya pshenitsa: Avtoref. dis. kand. s.-h. nauk. Na pravah rukopisi, Stavropolskiy s.-h. institut. – Stavropol, 1990. (in Russian language).

11. Novikov Yu. F. Mashinyi v sisteme chelovek-mashina-zemlya. /Yu. F. Novikov, M.: Mashinostroenie, 1976, 232 p (in Russian language).

12. Ivanov P. K. Osnovnaya obrabotka pochvyi na yugo-vostoke / P. K. Ivanov//Tr. Saratov. s.-h. in-ta – Saratov, 1967. – T. 16.- 212 s. (in Russian language).

13. Dalin A.B., Rotatsionnyie gruntoobrabatyivayuschie i zemleroynyie mashinyi. / Dalin A.B., Pavlov P.V. M.: Mashgiz, 1950. - 260 s. (in Russian language).

14. Gritsyishin M. I. Issledovanie protsessa i obosnovanie parametrov kopayuschih rabochih organov dlya osnovnoy obrabotki pochvyi na sklonah i terrasah./ avtoreferat dissertatsii na soiskanie uchenoy stepeni kandidata tehnicheskih nauk. Kiev, 1972. 23 s. (in Russian language).

15. Panchenko A. N. Teoriya izmelcheniya pochv pochvoobrabatyivayuschimi orudiyami. / Panchenko A. N. Dnepropetrovsk, 1999., 140 s. (in Russian language).

16. Golovach A.A. Sanitaryi i ryihliteli pochvyi / Golovach A.A. // Urozhaynyie sotki 1998, N 4 s.26-27. (in Russian language).

17. Patent UA # 93879 MItkov V. B., IgnatEv E. I., MItkov B. V., MItkov V. O. Gruntoobrobniy robochiy organ. PublIkatsIya vIdomostey pro vidachu patentu: 27.10.2014, Byul. № 20. (in Ukrainian language).

18. Dokin B.D. Issledovanie i obosnovanie parametrov i rezhimov rabotyi propashnyih frez. / Dokin B.D. V sb. nauch. tr./Sibirskiy filial VIM. - Novosibirsk, 1964, vyip. 2, s. 203-217. (in Russian language).

19. Zhalnin E. V., Istoriya razvitiya i perspektivyi vnedreniya mostovogo rastenievodstva. /Zhalnin E. V., Mufteev R. S. //Traktoryi i selskohozyaystvennyie mashinyi, 2002, # 5. s. 23-30. (in Russian language).

20. Prymak I. D., Mekhanichnyi obrobitok gruntu v zemlerobstvi / I. D. Prymaka, Roshko V. H., Hudz V. P ta inshi – Bila Tserkva: Bilotserkivskyi DAU, 2002. – 320 s. (in Ukrainian language).