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DETERMINING THE INFLUENCE OF STRUCTURAL AND TECHNOLOGICAL PARAMETERS OF STRIP TILLAGE ON SUNFLOWER VEGETATION

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The object of this study is the process of strip tillage, its effect on soil moisture in the strip, and subsequent vegetation of sunflower plants. At the same time, the task to increase the efficiency of strip tillage was solved.

It has been established that the rational values of the structural and technological parameters of the strip tillage section in terms of fuel consumption depend on the speed of movement of the unit, the depth and width of the tilled strip of soil. One section of the unit was used for the research. The studies were conducted using the Box-Benkin three-factor experiment design. It was established that the rational values of the structural and technological parameters of strip tillage in terms of fuel consumption have the following values: the depth of strip tillage h=20–25 cm, the width of strip tillage b=20–25 cm, the speed of the unit from 7.5 to 11 km/hours. In this case, the actual fuel consumption ranged from 4.2 to 6.3 l/ha.

It was also established that an increase in the width and depth of the strip cultivation leads to an increase in moisture loss in it. The highest value of soil moisture occurs at the minimum values of the depth and width of the strip cultivation, and the lowest at their maximum values. The influence of the width of the cultivated strip on the height of sunflower plants is more significant than the influence of the depth of tillage. This applies both to the range of changes in the height of sunflower plants (12.4–13.6 cm compared to 12.5–13.1 cm) and the intensity of the impact. The greatest influence on the height of sunflower plants is exerted by the magnitude of the transverse displacement of the axis of the row of plants. The intensity of this influence is approximately the same as the depth of tillage, and the range of changes in the height of sunflower plants is 11.7–14 cm.

Research results could be used in the design of units for strip tillage and sowing units

Keywords: fuel consumption, tillage depth, sowing line, tillage width, movement speed

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1. Introduction

Mechanical tillage is the most important component in the system of agrotechnical measures for the production of plant products. It serves to destroy surface soil compaction, owing to which the physical condition of the soil changes, promoting more intensive root growth. However, the specified effect is temporary, and the impact on the hydraulic characteristics of the soil should be objectively evaluated in order to effectively target the technology of its cultivation [1]. For example, moderately deep tillage, unlike surface tillage, significantly improves its physical-chemical properties, enhancing the antioxidant capacity of leaves and roots, while contributing to an increase in crop yield in general [2].

In order to determine the optimal set of tillage tools, the primary task is to determine the content of nutrients in the soil [3]. It is also necessary to take into account the variety of the cultivated crop, its resistance to nutrient deficiency, the expected yield, the chemical and physical properties of the fertilizers used, and the recommended method of their application.

The degree of solubility of the substance in the soil, the mobility of the nutrient and the intensity of its weathering belong to the most important chemical and physical properties of nutrients, which are taken into account when devising soil cultivation technology. In particular, nitrogen, for example, is characterized by a high degree of mobility, the ability to move in space, and a high intensity of weathering, which is largely manifested in the process of plowing. In turn, phosphorus and potassium are less mobile substances, so they are evenly distributed near the root growth zone of plants [4].

Modern tillage technologies do not provide for spreading fertilizers on the soil surface because of their low efficiency. With such methods of applying fertilizers, there is a significant loss of nutrients due to weathering and leaching since the distance from the point of application of fertilizers to the roots of plants significantly affects the intensity of plant growth [5]. It is recommended to apply each type of fertilizer separately to the depth regulated for it. This can be implemented by using systems of precision agriculture [6], which makes it possible to provide the plant with the necessary nutrients throughout the growing season. Depending on the type of soil and the needs of the plant, nitrogen fertilizers can be applied to a depth of 10...15 cm, phosphorus – 15...20 cm, potassium – 20...25 cm.

Although in modern science there are enough scientific works on the application of Strip-till and No-till tillage technologies, there are still certain scientific issues that need to be researched. In particular, depending on the type of agricultural crop, soil and climate zone, the content of nutrients in the soil, it is necessary to establish rational values of the structural and technological parameters of soil cultivation. This will make it possible to improve the efficiency of the tillage process, reduce fuel consumption and harmful effects on the environment, as well as increase the yield of agricultural crops.

2. Literature review and problem statement

According to studies [4, 6], strip-till includes pre-sowing soil cultivation with strips 15–20 cm wide and 15–20 cm deep, where rows of agricultural crops alternate with rows of uncultivated soil. This type of tillage belongs to the group of soil protection technologies, which, unlike plowing, do not involve turning over the soil layers. At the same time, more than 30 % of nutrient residues remain on the soil surface. Strip tillage combines the advantages of classic soil tillage (warming and drying of the soil) with the possibility of protecting the soil from drying out, since only a strip 15–20 cm wide, into which the seed is sown, is subject to tillage.

The authors of work [7] note that in modern tillage, the Strip-till technology is a reasonable replacement for No-till zero tillage (only the sowing strip is subject to processing with the formation of a low ridge). At the same time, about 33 % of the area remains uncultivated. This technology is used for soybeans and row crops (beets, sunflowers, corn). Strip-till technology, in contrast to No-till, has significant ecological, agronomic, and economic advantages. Using the Strip-till technology, it is possible to eliminate some problems related to soil and climatic conditions, namely: soil compaction; high contamination of the soil with weeds; low organic content, which is the cause of poor soil fertility; short growing season. Despite the advantages of the Strip-till technology, the authors of paper [7] recommend investigating the physical condition of the soil after its application and establishing rational values of the structural and technological parameters of tillage for a certain crop depending on the soil and climatic conditions.

The study of the physical properties of loams (temperature, humidity, compaction) after carrying out three types of tillage, namely by No-till, Strip-till, and chisel plow technologies, is reported in [8]. The use of strip tillage contributed to an increase in the temperature of the surface layer of the soil (by 1.2...1.4 °C) and an increase in the crop germination index compared to zero tillage and tillage with a chisel plow. The moisture content in the soil profile with the specified three cultivation technologies was higher than the normative values of the moisture content required for plant vegetation. However, at the depth of 0–30 and 0–120 cm, changes in soil moisture content were more significant under strip tillage and chisel plow tillage compared to No-till technology. The greatest changes in soil moisture content occurred between post-emergence tillage and soil loosening. The authors note that strip tillage, similar to plowing with a chisel plow, helps increase the germination of plants, and compared to the No-till technology, it preserves moisture in the soil more effectively. However, in work [8], there are no studies on the influence of structural and technological parameters of soil cultivation according to the specified technologies on the yield of agricultural crops.

Such studies are reported in [9]. The dependent factor was the yield of agricultural crops. The variables are the technology of protective tillage, agrotechnical measures, climatic conditions, and physical properties of the soil. Strip-till, No-till, and classic tillage technologies were used during the research. It is noted that the use of Strip-till technology contributed to an increase in crop yield compared to other tillage technologies. In particular, when applying the Strip-till technology, the yield was 4.81 % higher compared to the No-till technology. With repeated tillage, the yield of grain crops and straw using the Strip-till technology was 7.66 % and 7.60 % higher in comparison with the No-till technology. On all soil types, including neutral soil, the use of Strip-till technology increased the yield of crops by 5.68 % compared to classic tillage and by 11.63 % compared to No-till technology. It was noted that the use of Strip-till technology was more effective in yielding crops in cooler climate zones with an average annual temperature below 10 °C. Under these conditions, crop yield increased by 3.64 % compared to No-till technology. Significance analysis revealed that tillage technology and air temperature are the key factors affecting the yield of agricultural crops.

The results of more thorough studies with a larger number of variable parameters are given in [10]. The authors evaluated the influence of strip, minimum and zero tillage on the quality of the seedbed, soil damage by weeds, and the yield of corn. The research period is from the moment of establishment of the crop to harvesting. The conditions are sandy-loamy soil with high levels of fertility and water supply for the crop. Strip cultivation was carried out by a passive tool attached to a seeder, the speed of which was 6 km/h. According to the results of the experiments, the highest seedlings, minimal soil contamination by weeds, significant plant density, biomass growth, and grain yield occurred with strip tillage.

The results of work [11] complement the study reported in [10]. The purpose of [11] was to determine the degree of infiltration, moisture content in the soil, the degree of disease of the root system of plants, and the population of nematodes over 12 years (the number of soil treatments was 16). At the same time, the following schemes were used:

a) four crop rotations (monocultures and corn and wheat crop rotations);

b) two tillage technologies – Strip-till and No-till;

c) two technologies for handling plant residues – working out and removal.

The best results were obtained with the use of Strip-till technology, crop rotation, and incorporation of plant residues into the soil. At the same time, diseases of the root system of plants had a smaller effect on crop yield compared to infiltration and the presence of available moisture in the soil. Although this research has good results that can be applied to the cultivation of other agricultural crops, it is incomplete. The paper did not examine the level of soil salinity, although this indicator is extremely important for growing crops in arid regions.

This issue was studied in [12], in which the dynamics of water and salt in the soil were studied using the method of numerical modeling; the results were confirmed experimentally. The degree of water absorption by the roots of a monoculture of sugar beet, cotton, and intermediate crops in an arid climatic zone was also investigated. Biochar and drip irrigation were used to minimize moisture loss in the soil. It was noted that the use of biochar intensified the soil's ability to accumulate moisture and salts, which contributed to an increase in the yield of the studied crops. The results of the study also have practical value for arid and semi-arid climatic zones. However, the issue of the suitability of using the results in the Strip-till soil cultivation technology requires further research.

Works [7–12] confirmed the positive influence of Strip-till technology on the chemical and physical properties of the soil and the yield of agricultural crops. However, the authors did not investigate the significance of the structural and technological parameters of soil cultivation in none of these works, which helped achieve the specified results. Partial influence of structural and technological parameters of tillage on the vegetation of agricultural crops is given in [13–18].

In order to evaluate the performance of the deep loosener, the authors of [13] measured the traction force of the unit, the specific resistance of the soil, studied the profile of the treated soil, and the size of the soil fractions. The deep loosener processed the soil at five depths – 10 cm, 15 cm, 20 cm, 25 cm, and 30 cm. The best physical characteristics of the soil corresponded to the loosening depth of 20 cm. The height, width, area of the processed soil profile, and the average diameter of the blocks were 16.3 cm, 42.2 cm, 0.0305 m^2 and 28.77 cm, respectively. Specific resistance at this depth was minimal and amounted to 62 kN/m^2. When the tillage depth increased to 30 cm, the values of these parameters decreased by 36.8 %, 26.1 %, 12.1 %, and 33.54 %, respectively. The specific resistance at the loosening depth of 30 cm was 195 kN/m^2, which is 214.5 % more than at the depth of 20 cm. The overall effect on soil structuring caused by tillage shows that the highest quality of the topsoil and the efficiency of energy use took place when cultivating the soil to a depth of 20 cm.

The influence of the method of deep loosening and one-time full-layer application of fertilizers on the preparation of the sowing belt, suitable for the growth and development of seeds, is described in study [14]. In order to effectively implement the technological operation of one-time full-layer application of fertilizers, the structure of the subsoil blade adapted to the corn planter was designed. The authors modeled an experiment in which the dependent factor was the coefficient of variation of the uniformity of fertilizer application, and the working speed of the blade and the depth of cultivation were influencing factors. With the help of the Design-Expert program, the response surfaces were analyzed to obtain the optimal combination of working parameters, which were: working speed – 3.81 m/s, processing depth – 25.22 cm. The results of field experiments showed that with optimal parameters of the work process and of the construction of the subsoil shovel, the coefficient of variation of the uniformity of fertilizer application was 41.05 %, 24.11 %, 20.31 %, and 14.63 %. The relative error between the experimental value and the theoretical optimization value was 10.89 %, 4.06 %, 2.37 %, and 3.10 %, respectively. The results of the study make it possible to significantly reduce the time and money spent on expensive experimental research and to obtain optimal structural and technological parameters of the soil cultivation process. However, the results are not generalized, although the method of calculating parameters could be applied for modeling soil tillage processes for growing other crops.

The authors of paper [15] established the influence of the parameters of the equipment elements for strip tillage (seeder coulter, row cleaner) on the amount of traction force and diesel fuel consumption. The specified parameters were determined by changing the angle of inclination of the rakes (10°, 15°, 22.5°), the depth of immersion of the plowshares (0, 100, 200 mm) and the working speed (1.3, 1.9, 2.5 m/s). It was found that increasing the speed of movement and the depth of immersion of the coulter significantly increased the consumption of diesel fuel and CO_2 emissions of the tractor. At the same time, increasing the front angle between the wiper disks had almost no effect on fuel consumption and CO_2 emissions.

Usually, to assess the force interaction of tillage working bodies with the soil, the traction resistance generated by the tillage unit is measured. However, the traction resistance of tillage implements does not take into account the force interaction with the soil of the tractor running system and other costs for creating traction force [15, 16]. In this regard, such an indicator as fuel consumption is often accepted as a criterion for evaluating the energy interaction of the machine-tractor unit with the soil [17]. This indicator, in contrast to the traction resistance, makes it possible to proceed directly to the economic evaluation of the technological operation or the production of agricultural products in general [18].

The research results reported in [19] supplement the results obtained by the authors of [13–15]. In [19], the results of a field experiment on the influence of the geometric parameters of the flat-cutting working bodies of the tillage tool on the efficiency of cutting and loosening loam with a high moisture content are given. The variable parameters of the working bodies were the angle of inclination of the rake to the horizontal (30, 60, and 90°), the width of the grip (75 and 150 mm), and the depth of cultivation (100, 150, and 200 mm). The cross-sectional area of the treated soil layer did not change with the angle of attack, but a significant increase in thrust with increasing angle led to a decrease in soil cutting efficiency. The degree of soil loosening was lower at 60° rake angle than at 30 or 90° and was higher at greater tillage depth. Also, increasing the ratio of tillage depth to grip width increased the degree of loosening. As a result, the best design of the tool, which provided high cutting efficiency and excellent loosening of the soil, had an angle of inclination of the rake to the horizontal of about 30°. At the same time, the ratio of the depth of processing to the width of the capture was 2. The disadvantage of the work is the lack of results of the study on the hydrothermal regime, which has a significant impact on the yield of crops.

A solution to this problem is given in [20]. The authors investigated the influence of strip tillage width (20 cm, 30 cm, 40 cm) on the hydrothermal regime and soil structure in the strip of the seedbed and the area between the seedbeds covered with straw. As a result of the field experiment, the authors of the study did not notice a significant difference in the soil structure at all three widths of strip cultivation. As for the hydrothermal mode, higher soil temperature and humidity occurred at a strip tillage width of 30 cm, so this strip tillage width is recommended for use by farmers in a temperate climate zone.

In works [13, 14, 19, 20], the issue of energy consumption for the strip tillage process, which was partially solved in [21], remained unresolved. The authors made a quantitative assessment of the effect of three strip widths on individual physical properties of the soil, seed germination, sunflower yield, and estimated fuel consumption for the process. A mechanized in-row rotary harrow equipped with C-shaped blades was used to cultivate strips with a width of 37.5, 30, and 22.5 cm. The speed of the tractor was 5.4 km/h, the depth of cultivation was 10 cm. A pneumatic seeder was used for sowing with a row spacing of 75 cm. According to the results of the study, the soil temperature increased with an increase in the width of the strips, while the moisture content in the soil decreased. The similarity of sunflower seeds ranged from 67 to 93 %, with a value of 67 % corresponding to a strip width of 22.5 cm. Seed yield increased with increasing strip width and was 4.4, 4.1, and 3.9 million/ha for strips with a width of 37,5, 30, and 22.5 cm, respectively. Although the seed yield was the lowest at the 22.5 cm strip width, the fuel efficiency of the tractor was the highest. Also, with a strip width of 22.5 cm, the soil retained more moisture, compared to strip widths of 30 and 37.5 cm. The results have practical application under the conditions of a sharply continental climate.

Features of the application of Strip-till technology on the territory of Ukraine are given in works [22–26].

In particular, in [22], the authors substantiated the agronomic requirements for the quality indicators of strip tillage. These requirements are as follows: the height of individual ridges or the depth of grooves is up to 5 cm, the transverse unevenness of the treated strip is no more than 15 %, the lumpiness of the treated soil (the number of lumps with a diameter of more than 50 mm) is up to 10 %. In the same work, a wide range of structural and technological parameters of the unit for strip tillage is specified. Thus, the speed of movement of the unit can range from 4 to 10 km/h, the depth of cultivation from 20 to 40 cm, the depth of fertilizer application from 10 to 30 cm, the width of the processed strip from 20 to 40 cm. A wide range of structural and technological parameters of the unit for strip cultivation soil needs additional research to determine more specific values of these parameters for specific crops.

The authors of work [23] experimentally determined that the section of the unit for strip tillage ensures the minimum transverse unevenness of the treated strip in the range of 8 to 15 % with the width of the treated strip in the range of 22 to 38 cm, the distance from the soil loosener to the axis of the cutting discs is 50 cm. With an increase in the depth of cultivation, the transverse unevenness increases in direct proportion, which requires additional soil cultivation and, accordingly, an increase in the costs associated with it.

In work [24], the authors proposed to implement the Strip-till technology to use a combined unit that includes a tractor, a front disc harrow, and a chisel plow installed behind the tractor. That made it possible to implement the single-pass Strip-till technology, which significantly reduced the cost of tillage. According to the results of the study, at an average speed of movement of the combined unit of 2.1 m/s, the emission frequency of the average value of soil loosening depth exceeding ±2 cm was only 0.29 s or 0.05 Hz. At least 95 % of the dispersion of non-linear oscillations of loose strips was in the frequency range of 0...0.25 m^{-1}, and the value of the dispersion itself was insignificant and amounted to 1.08 cm^2. The results meet the requirements for non-linearity of row crops in terms of dispersion and frequency of oscillations.

Studies on the effect of changing the kinematic parameters of the vertical milling adapter on the nature of the movement of the particles of the working medium are reported in [25]. Operating conditions of the adapter are as follows: angular speed – from 50 min^{-1} to 250 min^{-1}; speed of translational movement – 1.2...3.2 m/s. According to the results of the research, the influence of the parameters of the vertical milling adapter on the quality indicators of soil cultivation was established. The maximum content of 77.5 % of fractions with an optimal diameter of 0.001...0.005 m and 0.005...0.01 m in the treated layer was reached at an angular speed of rotation of the adapter disks of 26.5 s^{-1}. At the same time, the speed of translational movement was 2.2 m/s. The optimal value of the soil density of 1.2...1.25 g/cm^3 was achieved at an angular speed of rotation of the adapter disks of 14...16 s^{-1}. The maximum content of plant residues of 79 % of the optimal size of 0.005...0.03 m was achieved at a rotational speed of the adapter disks of 26.5 s^{-1} and a translational speed of 1.2 m/s. The results show that using a vertical milling adapter, it is possible to achieve a high quality of the technological process of strip tillage, which provides optimal conditions for the development of cultivated plants.

In [26], the structural and technological parameters of the developed strip tillage section are substantiated. It has been proven that the position of the working body on the section rack affects the quality of fertilizer application and the traction resistance of the tool. To increase the yield of crops, it is recommended to ensure volumetric intra-soil application of fertilizers to the depth of the treatment layer. The working body allows for the main cultivation of the soil on a strip 15–25 cm wide. At the same time, reducing the cultivated area of the field by up to 30 % makes it possible to significantly reduce energy costs.

In work [27], unlike [22–26], the authors not only substantiated the structural and technological parameters of the Strip-till technology but were also able to summarize them and present the corresponding mathematical model. It makes it possible, based on the results of the assessment of the main parameters of the machine-tractor unit, to determine and set the optimal composition and operating modes of the tillage unit for Strip-till technology. Mathematical dependences make it possible to analyze the application of traction units based on energy means with various parameters during soil cultivation in relation to real operating conditions. This, of course, speeds up design calculations and makes it possible to reduce the number of expensive practical studies.

There are also studies that substantiate the high environmental and economic indicators of Strip-till technology [28–30]. In particular, paper [28] lists a number of factors that determine the choice of a farming system, taking into account economic, ecological, techno-energy and social factors. The features of various farming systems, including Strip-till, were considered, which made it possible to assess their energy and resource efficiency in rural areas. Each farming system was evaluated for resource and energy saving with the aim of their practical use. It has been established that the use of Strip-till technology saves resources and energy, increases the productivity of agricultural machinery, and reduces the burden on the environment. This contributes to the energy efficiency of rural areas and their long-term development. Also, when using the Strip-till technology under the conditions of Ukraine [29], it was proved that this technology of soil cultivation has economic feasibility due to the increase in the yield of corn grain by 16–18.5 % compared to plowing.

Most of the literature on Strip-till technology is related to field experiments conducted in the north of the USA, Canada, Turkey, partly in European countries, and in Ukraine. However, the research results should be confirmed for other soil and climatic zones, preferably using sunflower as a test crop since it is one of the most widespread in the world. Also, in the scientific literature, there are only a few works on the estimation of fuel consumption during strip tillage, but none of them is related to the cultivation of sunflower. Therefore, it is expedient to study the impact of structural and technological parameters of strip tillage on sunflower vegetation using modern methods and measuring tools.

3. The aim and objectives of the study

The purpose of our study is to determine the influence of the structural and technological parameters of strip tillage on fuel consumption and the height of sunflower plants during the growing season. This will make it possible to improve the quality of tillage and sunflower sowing by determining the rational design parameters of strip tillage.

To achieve the goal, the following tasks were set:

– to determine the influence of the width and depth of strip tillage and the speed of movement of the unit on fuel consumption during strip tillage;

– to determine the influence of the width and depth of the cultivation of the strip and the transverse displacement of the row of sunflower plants from the middle of the processed strip on the height of the sunflower plants.

4. The study materials and methods

The object of our study is the process of strip tillage and its effect on sunflower vegetation.

The research hypothesis assumes that fuel consumption and the height of sunflower plants during the growing season are determined by rational design and technological parameters of strip tillage. During the research, the values of the structural and technological parameters of the strip tillage unit had deterministic values and were set at the levels specified by the experiment plan. Stochastic values of technological and measured parameters were processed by methods of mathematical statistics, and their values were determined by methods of planning multivariate experiments.

To carry out research on the determination of parameters and regimes of strip tillage, an assembly was used, the structural and technological scheme of which is shown in Fig. 1.

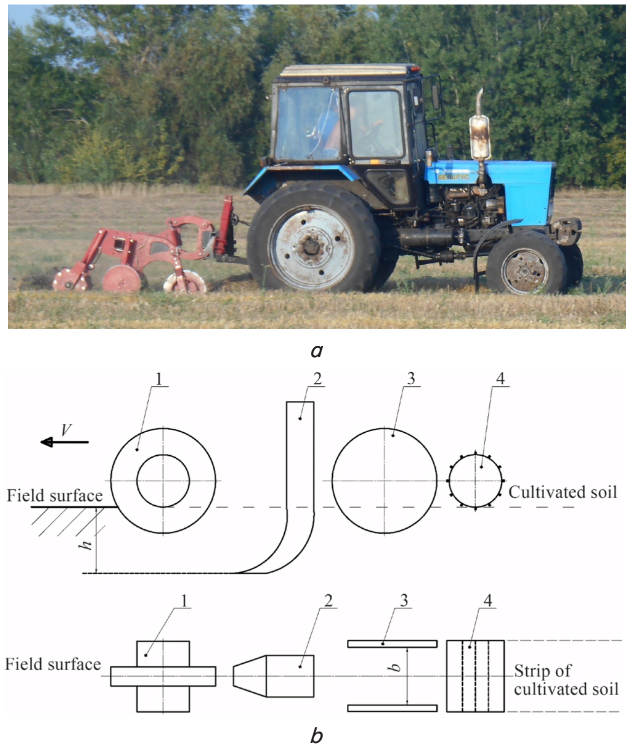

Fig. 1. Experimental unit for strip tillage: *a* – general view; *b* – structural and technological scheme of the unit section for strip tillage: 1 – front cutting disk; 2 – deep softener; 3 – cutting disks; 4 – grinding roller; *b* – strip processing width, cm; *h* – the depth of strip processing, cm; *V* – speed of movement of the experimental unit

A uniform section of the field without slopes or protrusions was chosen for the research. The length of this section was divided into three zones. The first zone was used to accelerate the tractor and ensure a stable operating mode. The next 100 m were used for research. The last zone served for braking, meeting the generally accepted requirements for such experiments.

The plan of a three-factor experiment using the Box-Benkin method was used for the research. The homogeneity of variance in the experimental data was assessed using the Cochrane test, and the adequacy of the obtained regression equation was checked using the Fisher test.

Fuel consumption, G (l/ha), was the criterion for evaluating the energy parameters of strip tillage. Variable factors of field tests were chosen as follows (Table 1):

– b – strip processing width, cm;

– h – depth of strip processing, cm;

– V – unit movement speed, km/h.

– S – transverse displacement of the row of sunflower plants from the middle of the processed strip.

The width of the strip was provided by changing the distance between cutting disks 3 (Fig. 1). The strip processing depth was set by changing the position of deep loosener 2 (Fig. 2) relative to the section frame for strip processing. The speed of movement of the unit was ensured by changing the position of the fuel supply rail of the fuel pump.

Table 1

Field test variables

Factor	Level of factor variance			Variance interval
	–1	0	+1	
b (cm)	20	25	30	5.0
h (cm)	15	20	25	5.0
V (km/h)	4	7.5	11	3.5
S (cm)	0	7.5	15	7.5

Fuel consumption was determined by draining the remaining fuel from an additional measuring tank mounted parallel to the main fuel system. Fuel from the main tank was used for idling, acceleration, and braking, and from an additional metering tank for the experimental run. Switching between fuel systems was carried out by three-position taps.

The height of sunflower plants, *S* (cm), was the criterion for evaluating the intensity of vegetation after sowing on treated strips of soil. In addition to the width and depth of strip cultivation, indicated in Table 1, the transverse displacement of the row of sunflower plants from the middle of the processed strip was chosen as an additional variable factor.

24 plots with a width of 2.5 m and a length of 30 m each were formed in the field for conducting research. To exclude the competition of sunflower plants in rows, seeds were sown in a strip according to the scheme shown in Fig. 2.

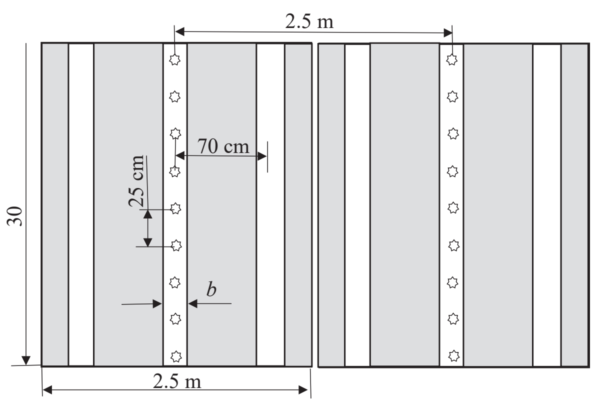

Fig. 2. A fragment of a field diagram with two adjacent sections

The seeds were sown manually using a special template (rail) with a length of 3 m. Holes with a diameter of 10 mm were drilled along the template with a step of 25 cm. In one version, the template (i.e., the rail) was placed in the middle of the processed strip, and in the other, according to the experiment scheme (Table 1), it was shifted by 15 cm in the transverse direction. The sowing bed of each seed was created by plunging a wooden punch into the holes of the template to a depth of 6 cm. The final stage of the process of sowing sunflower seeds was their manual sprinkling with soil.

After germination, the height of each plant was measured. The number of measured plants of each repetition is at least 100. Measurements were performed with a ruler with an error of ±0.5 mm.

Before conducting the experiment and at the time of measuring the height of the sunflower plants, the soil moisture in each strip was recorded. For these purposes, a device created on the basis of Arduino Uno (Italy) was used, which allows an error of measuring soil moisture at the level of ±0.4 % (Fig. 3). The number of measurements of this parameter in each strip is at least 50. Based on the results of the measurements, the average values of soil moisture were calculated, as well as the smallest significant difference (LSD05) between these values at a statistical significance level of 0.05.

Fig. 3. Soil moisture measurement kit

The results of field experiments were processed in the Microsoft Excel software environment.

5. Results of investigating the impact of structural and technological parameters of strip tillage on sunflower vegetation

5. 1. Influence of structural and technological parameters of strip tillage on fuel consumption

After processing a part of the field with the experimental unit, the formed strips were visually evaluated according to the quality of processing and conditionally divided into three groups (Fig. 4): processed qualitatively (experiment No. 1, 8, 9, 11), processed relatively qualitatively (No. 4, 6, 7, 12, 13, 14, 15), and poorly processed (No. 2, 3, 5, 10).

a *b* *c*

Fig. 4. Samples of treated strips according to visual assessment data: *a* – a strip of soil treated with high quality; *b* – a strip of soil processed relatively qualitatively; *c* – a strip of soil treated poorly

After completion of field studies and processing of experimental data, a regression equation was derived, on the basis of which an analysis of structural and technological parameters of strip tillage was carried out. The equation that establishes the value of fuel consumption during strip tillage in relation to the width and depth of strip tillage and the speed of movement of the unit takes the following form:

$$G = 79.0881 - 5.9131 \cdot b - 0.8428 \cdot h + 0.2583 \cdot V + 0.1629 \cdot b^2 + 0.0526 \cdot h^2 + 0.0087 \cdot V^2 - 0.0547 \cdot bh + 0.0167 \cdot bV - 0.0533 \cdot hV, \quad (1)$$

where G is fuel consumption, l/ha; b – width of the processed strip, cm; h is the depth of the processed strip, cm; V – unit speed, km/h.

The Cochrane criterion for the obtained experimental data was $G=0.04$ and was less than its tabular value $G_T=0.335$ with a confidence probability of 95 %. This testifies to the homogeneity of variance in the experimental data. Fisher's criterion at a confidence level of 95 % was $F=1.36$ and was smaller than its tabular value $F_T=2.53$, which indicates the adequacy of our regression equation.

The dependence of fuel consumption on the depth of strip cultivation h, the width of strip cultivation b, and the speed of movement of the experimental unit V is shown in Fig. 5–7.

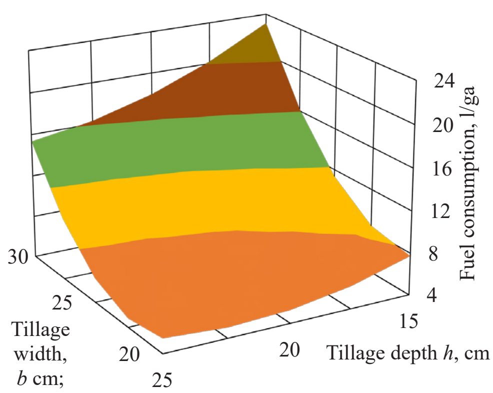

Fig. 5. Dependence of fuel consumption on the width of the strip processing b and the depth of the strip processing h at the speed of the experimental unit $V=7.5$ km/h

The graphical dependence at $V=7.5$ km/h shows (Fig. 5) that with the depth of strip cultivation $h=15$ cm, the value of fuel consumption will be the largest at all values of strip width b, which is unacceptable.

The dependence of fuel consumption on the speed of movement of the experimental unit V and the width of the strip processing b at the depth of the strip processing $h=20$ cm is shown in Fig. 6.

The graphical dependence shows that when the speed of movement increases from 4 to 11 km/h, there is a direct downward dependence, which is characterized by a decrease in resistance and an increase in the quality of processing.

The dependence of fuel consumption on the speed of movement of the experimental unit V and the depth of cultivation of the strip h at the width of the cultivation of the strip $b=25$ cm is shown in Fig. 7.

The graphic dependence shows that with an increase in the depth of the strip cultivation at all experimental speeds, the value of fuel consumption decreases.

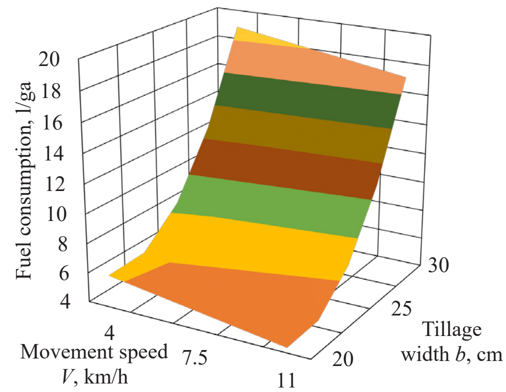

Fig. 6. Dependence of fuel consumption on the width of the strip cultivation b and the speed of movement of the experimental unit V at the depth of strip cultivation $h=20$ cm

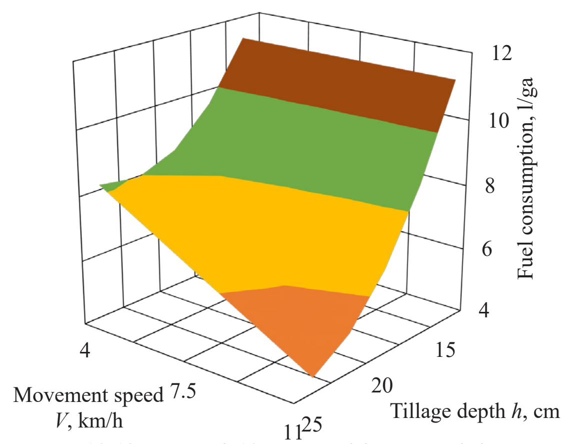

Fig. 7. Dependence of fuel consumption on the depth of strip cultivation h and the speed of movement of the experimental unit V at the width of strip cultivation $b=25$ cm

5. 2. Influence of structural and technological parameters of strip tillage on the height of sunflower plants

The results of soil moisture determination in the strip at the time of measuring the height of sunflower plants are shown in Fig. 8.

The equation for the regression of the height of sunflower plants from the width and depth of the tilled strip and the transverse displacement of the row of sunflower plants from the middle of the tilled strip is as follows:

$$H = 18.554 - 0.1268b - 0.0692h - 0.0679S - 0.0034bS - 0.0000411bhS, \quad (2)$$

where H is the height of sunflower plants, cm; b – width of the processed strip; h is the depth of the processed strip; S is the transverse displacement of the row of sunflower plants from the middle of the processed strip.

Graphical interpretation of process (2) is shown in Fig. 9–11.

Therefore, in the process of sowing row crops using the one-step strip-till and two-step strip-till technologies, it is necessary to ensure that the deviation of the axis of the row of plants from the middle of the loosened strip is as small as possible.

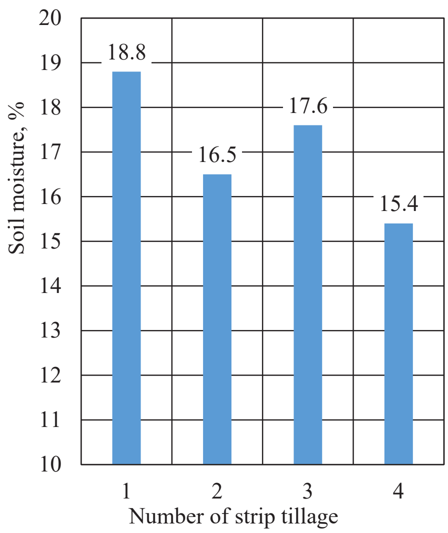

Fig. 8. Soil moisture in the strip with different parameters of strip cultivation:1 – b_{min}, h_{min}; 2 – b_{max}, h_{min}; 3 – b_{min}, h_{max}; 4 – b_{max}, h_{max}

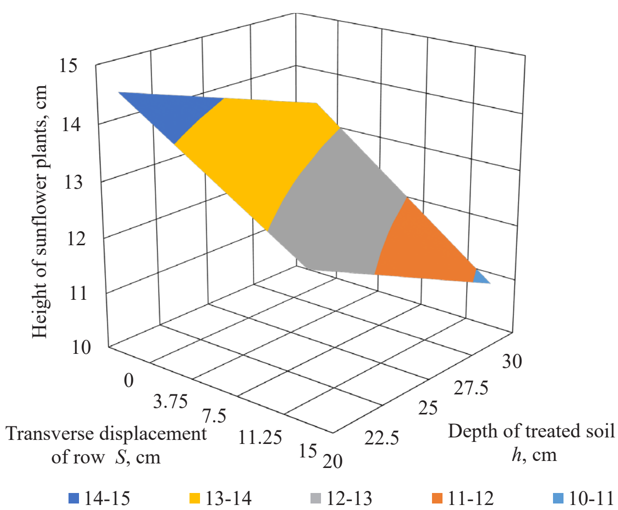

Fig. 9. Dependence of the height of sunflower plants on the deviation of the axis of the row and the depth of the treated strip of soil

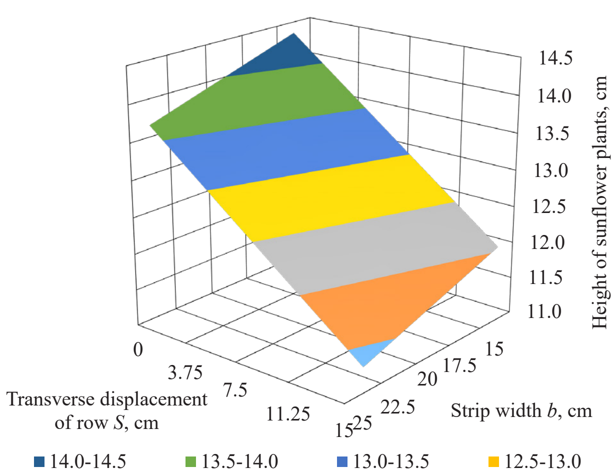

Fig. 10. Dependence of the height of sunflower plants on the width of the treated strip and the deviation of the row axis

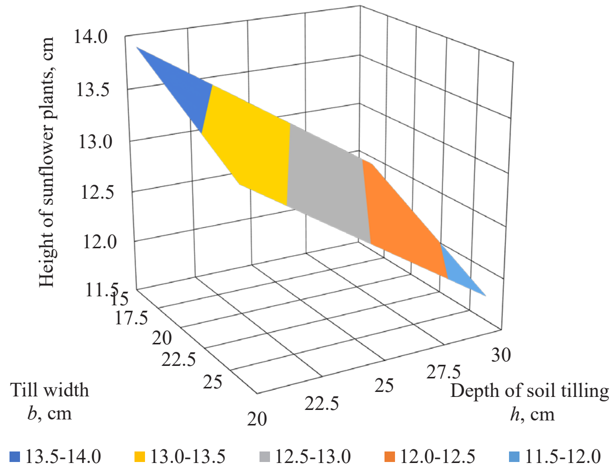

Fig. 11. Dependence of the height of sunflower plants on the width and depth of the treated strip of soil

6. Discussion of results related to the impact of structural and technological parameters of strip tillage on sunflower vegetation

It was established (Fig. 5) that at the speed of movement of the experimental unit V=7.5 km/h and the increase in the depth of cultivation of the strip h to 25 cm, the value of fuel consumption decreases. The reduction of fuel consumption is influenced by the structure of the upper layer of the soil, which is compacted and has the stubble of the previous crop, which collectively increases the resistance to cultivation. Since the deep loosener has a chisel-like shape, the compacted layer is overcome with increasing depth. Accordingly, with an increase in the speed of movement of the experimental unit, the soil accelerates more evenly along the deep loosener, which leads to a decrease in the resistance of soil cultivation and fuel consumption, respectively. The parabolic growing curve shows that the width of cultivation of the strip b from 20 to 22.5 cm with the depth of cultivation of the strip h 20–25 cm is satisfactory since these lines are close to each other at the value of fuel consumption of 4–8 l/ha. The value of the cultivation width of strip b is increasing; from 20 to 22.5 cm the canopy growth is within 4–6 l/ha, from 22.5 to 25 cm the growth angle increases to 8 l/ha, and after 25 cm it exceeds the value of 8 l/ha and increases to 16–20 l/ha. Analysis of the plot reveals that the value of fuel consumption with a width of cultivation of the strip b=30 cm with an increase in the depth of cultivation is decreasing, but it is within the range of 15.8 l/ha and above.

At the strip width b=30 cm, the value of fuel consumption is within 16–20 l/ha, which is the largest value, and the line of strip width b=20 cm has the lowest value of fuel consumption (Fig. 6). The parabolic growing curve shows that the working width of strip b from 20 to 22.5 cm is satisfactory at all speeds of movement of the experimental unit V (km/h) since these lines are close to each other in the fuel consumption value of 4–8 l/ha. The value of the cultivation width of strip b is an increasing parabola; from 20 to 22.5 cm the canopy growth is within 4–6 l/ha, from 22.5 to 25 cm the growth angle increases to 8–10 l/ha, and after 25 cm it increases up to 17–20 l/ha. Analysis of the plot reveals that the value of fuel consumption with the width of the cultivation of strip b is more than 26 cm has a constant increase, which is also due to the influence of the compacted upper layer of the soil. When the width of strip b is up to 26 cm, the cutting disks move in the zone of the structure of the upper layer of the soil (stubble) destroyed by the deep loosener, and this causes less resistance and fuel consumption. When the cultivation width of strip b is increased to 30 cm, the cutting disks already move with the stubble and when deepened by 14 cm, they destroy the structure of the upper layer, which additionally increases the total resistance of cultivation and, accordingly, fuel consumption.

It was also established (Fig. 7) that at the speed of movement of the experimental unit $V=11$ km/h, the value of fuel consumption is a smoothly decreasing curve with the smallest value at the depth of strip h from 23 to 25 cm. The line of speed of movement of the experimental unit $V=4$ km/h is especially different because when the depth of cultivation of strip h increases from 15 to 21 cm, the value of fuel consumption decreases, and starting from 24 cm, it increases. The speed line of the experimental unit $V=7.5$ km/h is between the lines 4 and 11 km/h with the beginning at the coincident point of fuel consumption of 11.372 l/ha. The line of the depth of cultivation of strip $h=15$ cm is a horizontal straight line, which is at the fuel consumption value of 11.372 l/ha and is unsatisfactory. The lines of the 20 and 25 cm tillage depth also decrease when the speed of movement of the experimental unit increases.

So, the experiment showed that to ensure economic indicators of fuel consumption, it is necessary to use the depth of cultivation of strip $h=20–25$ cm, the width of cultivation of strip $b=20–25$ cm, and the speed of movement of the experimental unit more than 7 km/h.

The state of soil moisture in the strip was evaluated according to the procedure from [30] but in those studies, the dynamics of moisture were reflected when comparing three technologies: strip-till; no-till; plough-till. The question of the impact on this process of the depth and width of the treated strip of soil, especially the transverse displacement of the row of plants, was not considered at all.

The data on soil moisture shown in Fig. 8 are obtained with different combinations of maximum and minimum values of parameters b and h. At the same time, it was assumed a priori that the effect of the transverse displacement of the plant row axis on moisture loss within the treated strip is quite insignificant and can be neglected. Analysis of Fig. 8 reveals that the highest value of soil moisture occurs at the minimum values of parameters b and h (option 1), and the lowest at their maximum values (option 4). A pattern follows from this: the wider the treated strip of soil and the deeper it is treated, the greater the loss of moisture in it. Options 2 and 3 occupy intermediate positions. The general trend is as follows: the width of the processed strip (parameter b) causes moisture loss more than the depth of processing of the strip (parameter h). That is why the soil moisture in option 2 is greater than in option 3.

Our analysis (Fig. 9) revealed that with an increase in the depth of cultivation of the strip (h) and the amount of displacement of the axis of the sowing of the sunflower row (S), the height of the plants decreases. The intensity of these processes is different: in the case of an increase in the parameter S, it is higher, while with an increase in the offset of the row axis by 15 cm, the value of the function H decreases by 17.8 %, with an increase in the depth of processing of strip h by 10 cm – by 5.0 %.

It should be noted that the decrease in the height of sunflower plants with an increase in the depth of cultivation of the strip is quite understandable, taking into account the data on its humidity (Fig. 8). That is, the deeper the cultivation of the strip, the greater the loss of moisture and the lower the height of the plants. There is also an inversely proportional relationship between the height of sunflower plants and the lateral deviation of the row axis. This is due to the fact that, depending on the distance of the plants from the center of the treated strip, the root system comes into contact with denser layers of soil, which negatively affects the dynamics of sunflower plant development.

The analysis showed that an increase in parameters b and S also leads to a decrease in the height of the sunflower plant (Fig. 10). However, in contrast to the previous option (Fig. 9), the effect of the width of the processed strip b on the height of sunflower plants is more significant than the increase of the parameter S (mixing of the sunflower sowing line). While the change in the value of the latter from 0 to 15 cm leads to a decrease in the value of the initial parameter H by 4.0 %, the increase in the width of the treated strip from 20 to 30 cm is almost by 16.0 %.

Our analysis also revealed (Fig. 11) that the process of reducing the height H of sunflower plants is more intense when the width of the cultivated strip is reduced. The width of the processed strip b is about 2 times more influential on the function H than the depth of the processed strip h. This result follows from the analysis of Fig. 10, soil moisture losses at the maximum value of the width of the treated strip are 1.1 % greater (option 2) than similar losses at the maximum value of the depth of the strip cultivation (option 3). At the same time, it should be noted that the resulting difference in soil moisture (1.1 %) at the statistical significance level of 0.05 is significant since it is smaller than $LSD_{05}=1.0$ %.

The uniqueness of studies on the influence of structural and technological parameters of strip tillage on sunflower vegetation is determined by conducting them in a wide range of basic parameters of the unit for strip tillage. The combination of soil tillage and seeding studies and the evaluation of their joint effect on sunflower vegetation is also an element of the uniqueness of the studies. Baes on the results of our study, regression equations were built regarding fuel consumption for strip tillage and the height of sunflower plants sown in these strips. This makes it possible to ensure the advantage of the conducted research, compared to the similar one [21], in which the systemic influence of structural and technological parameters of strip tillage on sunflower vegetation was not considered.

Compared to earlier studies [22–24], our study is distinguished by a more accurate determination of the optimal depth h and width of strip cultivation b, at a speed of more than 7 km/h. In addition, it is proposed to consider strip tillage in relation to the cultivation of a specific crop, namely sunflower.

The regression equations (1) and (2) make it possible to determine the main structural and technological parameters of strip tillage, which could make it possible to design highly efficient tillage and sowing units.

Among the shortcomings of the current research is that we conducted it under certain soil and climatic conditions. They have a zonal character, and the results are limited by the conditions of the experiment in terms of humidity, initial layer-by-layer density of the soil, and weediness of the backgrounds.

Research results could be used in the design of units for strip tillage and sowing units.

7. Conclusions

1. It has been established that the rational values of the structural and technological parameters of strip tillage in terms of fuel consumption take the following values: the depth of strip tillage h=20–25 cm, the width of strip tillage b=20–25 cm, the speed of the unit from 7.5 to 11 km/h. At the same time, the actual fuel consumption will range from 4.2 to 6.3 l/ha.

2. It has been found that an increase in the width and depth of the strip cultivation leads to an increase in moisture loss in it. Transverse displacement of the axis of a row of sunflower plants has no significant effect on moisture loss. The influence of the width of the cultivated strip on the height of sunflower plants is more significant than the influence of the depth of tillage. Moreover, both in the range of changes in the height of sunflower plants (12.4–13.6 cm, compared to 12.5–13.1 cm), and the intensity of influence. The greatest influence on the height of sunflower plants is exerted by the magnitude of the transverse displacement of the axis of the row of plants. The intensity of this influence is approximately the same as the depth of tillage, and the range of changes in the height of sunflower plants is 11.7–14 cm.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study, as well as the results reported in this paper.

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Data availability

The data will be provided upon reasonable request.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

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