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EXPERIMENTAL STUDY OF TWO FALLOW FIELD TREATMENT INFLUENCE METHODS ON SOIL MOISTURE DYNAMICS

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The yield of any crop depends on soil moisture. One of the moisture conservation technological methods is fallow in the form of soil mulch with a layer not exceeding a thickness of 5–6 cm. To create this, a harrow utilizing special working devices was designed. This paper presents the results obtained on the dynamics of changes in soil moisture in a fallow field treated with a new harrowing unit compared to a serial cultivator operating at a depth higher than 6 cm. It was observed that the soil moisture in the harrowed area of the fallow field was 1.4 times higher, while the moisture reserves were 2.2 times higher in contrast to the field with the agrotechnical environment, treated with the sweeps of a serial cultivator. The actual soil tillage depth uniformity reached with the new harrowing unit is higher in comparison to that of the basic cultivator unit because, according to the *F*-test, the dispersion of fluctuations in the field tillage depth by the former (0.64 cm^2) is significantly less than that for the latter (3.24 cm^2).

Keywords: harrowing; cultivation; soil depth; soil moisture accumulation

Meeting the food requirements of an ever-increasing population is a pressing challenge for every country around the globe. Soil degradation has a negative impact on food security by reducing the cultivated land areas, while at the same time the world population is predicted to increase to 9.2 billion in 2050 (Meena et al., 2019; Telak et al., 2021).

The major factors are salinization, erosion, depletion of nutrients due to exhaustive agricultural practices and contamination with toxic metal ions and agrochemicals, reducing soil microbe activity (Wolny-Koładka et al., 2022; Mitchell-Forsytk et al., 2021).

According to J. Liebig's law, the yield of any crop is limited by the factor (moisture, heat, light, air, etc.) that is at a minimum, which is especially true for soil moisture (Donaldson et al., 2001; Zsembeli et al., 2019; Ruan et al., 2021).

It has been established that this parameter significantly affects the emission of C-CO_2 from the soil, directly affecting root and microbial activity and indirectly on the soil's physicochemical properties (Ruan et al., 2021; Tuba et al., 2021). The positive effect of soil organic matter (SOM) on the physical, chemical and biological soil properties has already been well described. A high SOM level is related to improved soil properties resulting in higher water infiltration and nutrient accessibility (Novák et al., 2021). If the SOM amount is insufficient, the crop sowing may be delayed to a later date, which is undesirable. In the case of winter crops, it is generally postponed until spring (Zsembeli et al., 2019; Korenko et al., 2021).

One of the technological methods for preserving moisture in the soil is fallow utilization (Wolny-Koładka et al., 2022), which is efficient only if applied correctly. Research shows that fallow treatment can ensure precipitation storage in soil up to 75%. According to Riar et al. (2010), the rest of the moisture evaporates from the soil. As noted by Pimentel and Burgess (2013), erosion degrades the land, which means it can support fewer plants that can absorb the climate-warming carbon dioxide. Soils themselves could potentially sequester enough greenhouse gases (GHG) in a year equal to approx. 5% of all annual human-origin GHG emissions. Better land management can help keep soils intact to grow more carbon-absorbing vegetation. It should be noted that the decrease in moisture evaporation is associated with the issue of moisture separation in the soil due to heat. Along with the employment of grain crops mulch (Meena et al., 2019; Telak et al., 2021), chemical treatment of weeds utilizing herbicides (Smith and Young, 2000), a relatively common method for moisture evaporation reduction during fallowing is the use of mechanical mulch (Kollárová et al.; 2015, Weninger et al., 2020).

Periodic maintenance of the upper soil layer by mulch can almost wholly neutralize its capillarity, creating an environment that separates the moisture and the relatively cold soil layer from the dry and warm ground air. Ultimately, moisture evaporation from the uncultivated soil layer is significantly reduced (Weninger et al., 2020).

Agricultural machines aggregated with different working devices create a soil layer with a destroyed capillary system.



Fig. 1 Harrowing machine-tractor unit

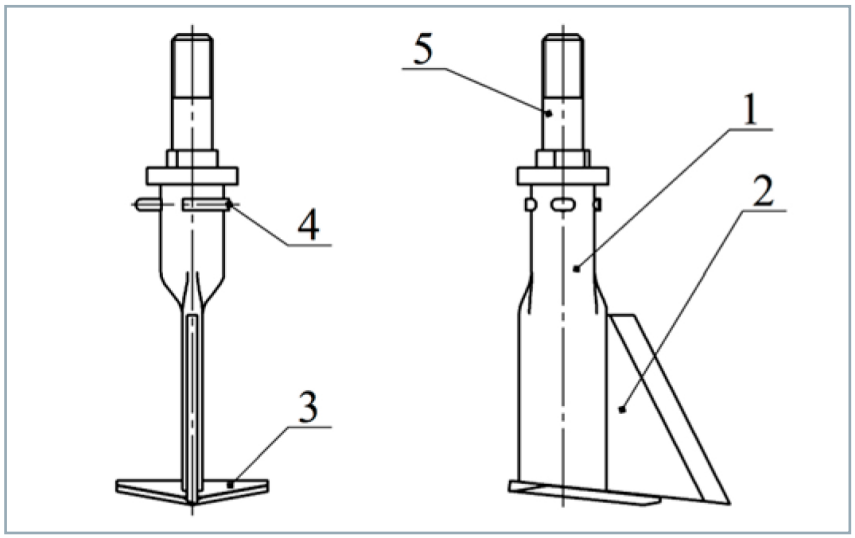


Fig. 2 Harrow's front tooth
1 – tooth's lower part; 2 – vertical segment; 3 – horizontal segment; 4 – cotter pin; 5 – tooth's top part

They are often produced in V-shaped blades with an operating width of 46 cm or more (Rédl and Findura, 2021). Furthermore, Mühlbachová et al. (2022) observed that tillage practices and varying construction of the devices employed have an impact on CO_2 emissions as well.

As practice shows, the movement stability of such machines in the longitudinal-vertical plane is ensured at a tillage depth of at least 10 cm. At the same time, the geometry of their working devices is such that, firstly, it causes the mixing of the soil in this layer, and secondly, it causes the soil to rise from a depth of 10 cm to the daytime surface of the field. As a result, both factors lead to intense soil drying in the cultivated layer.

Adamchuk et al. (2020) established that the highest intensity of moisture evaporation occurs in the soil layer up to 4–5 cm. This result found its practical application in the fallow treatment technology performed by applying a new harrow design (Bulgakov et al., 2020b), which provides systematic loosening of the soil to a depth of no more than 5 cm.

Currently, the movement dynamic of this machine in the longitudinally vertical plane has been studied (Bulgakov et al., 2020a). Ultimately, this made it possible to select such values of harrow design parameters, which can provide the technological process implementation with the specified agrotechnical requirements. Firstly, this concerns the movement stability of this machine in terms of the depth of cultivation.

The purpose of this paper is to present the results on the dynamics of changes in soil moisture in a fallow field at different depths of its cultivation over a longer period (more than 3 months). Additionally, selected quality indicators of the new harrow unit are presented.

Material and methods

The research compares a new harrowing machine-tractor unit (MTU) with a serial cultivator KPS-8. The new harrowing MTU (Fig. 1) was aggregated with an MTZ-892 tractor (Belarus) with dual rear tires and a BP-9 mounted harrow (Ukraine). The operating width of this unit is 8.3 m.

Each of the 9 harrow sections was equipped with 20 tines with horizontal triangular segments with an angle of 5°, ensuring teeth penetration into the soil to a depth of 5–6 cm.

The teeth in the harrow's front row and the horizontal ones had vertically mounted segments (item 2 in Fig. 2).

The conventional MTU (Fig. 3) comprises a tractor HTZ-17221 (Kharkiv, Ukraine) and a mounted cultivator KPS-8 (Ukraine) with an operating width of 8.4 m.

Each of the 8 cultivator sections of this unit was equipped with sweeps and bar harrows. The working devices of each section were adjusted to a tillage depth of 12 cm. Based on the preliminary research, it was found that the working bodies of this type are not sufficiently stable in the longitudinal-vertical plane with a smaller installation depth. In addition, wet soil is significantly emerging from the soil horizon to the daytime field surface. And since such results are unacceptable in terms of moisture loss reduction during fallow cultivation, the movement mode of the cultivator machine-tractor HTZ-17221 unit with a depth of the fallow field treatment of less than 12 cm was not opted.

To eliminate the influence of the subjective factor, the same machine operator worked alternately on both tillage units – conventional and new.

Field measurements were carried out at one of the fallow fields of the Zaporizhzhia region (Ukraine). Soil characteristics were as follows: medium



Fig. 3 Cultivating machine-tractor unit

loamy soil with a humus content of 2.6% in a layer of 0–20 cm, which contained total nitrogen – 21.2, phosphorus – 38.5, and potassium – 295.0 mg per kg of soil. Field capacity was 21–22%, and wilting point moisture was 9%.

In the field research process, the moisture content of treated soil was repeated ten times at a depth of 6 cm. The measurements were carried out 8 times in 2021: 1 – 14. 3. 2021; 2 – 29. 3. 2021; 3 – 12. 4. 2021; 4 – 27. 4. 2021; 5 – 15. 5. 2021; 6 – 29. 5. 2021; 7 – 14. 6. 2021; 8 – 30. 6. 2021.

The kit developed was used for measuring the soil moisture content (Fig. 4). Its operation principle is based on the changes in the dielectric permeability of the soil, depending on its moisture content.

A piston for soil compaction was mounted on the top cover of the kit to exclude soil compaction's influence on moisture. Its electronic recording part was located on the lower cover of the device.

The process of working with the kit started with placing a dose of soil in the device glass. Then it was compacted by a piston, and its moisture (%) value was displayed on the device. The kit measurement error did not exceed 1%.

A method described by Nadykto et al. (2020) was utilized to determine the soil bulk density. This parameter was measured ten times at 6–12 cm soil depth.

Two parameters were evaluated to quantify the work quality of the compared MTUs: i) the probability of maintaining the permissible technological value for fluctuations in the operating depth (*P*, %); ii) the deviation frequency of the actual tillage depth value from the given level (ω, m^{-1}). The former was determined based on the method described by Bulgakov et al. (2020b). The latter parameter was calculated as follows:

$$\omega = \frac{n \cdot \exp\left(-\frac{\Delta^2}{2\sigma^2}\right)}{2\sum(\tau_{i+1} - \tau_i)} \quad (1)$$

where: n – number of the intersection points by the normalized correlation function of the abscissa axis; Δ – permissible value for fluctuations in the depth of the fallow field treatment (±cm); σ – standard deviation of the soil depth treatment (±cm); τ_i, τ_{i+1} – successive abscissa values at points where the normalized correlation function takes zero values

The tillage depth performed by both compared MTUs was measured along the diagonal of the site in two

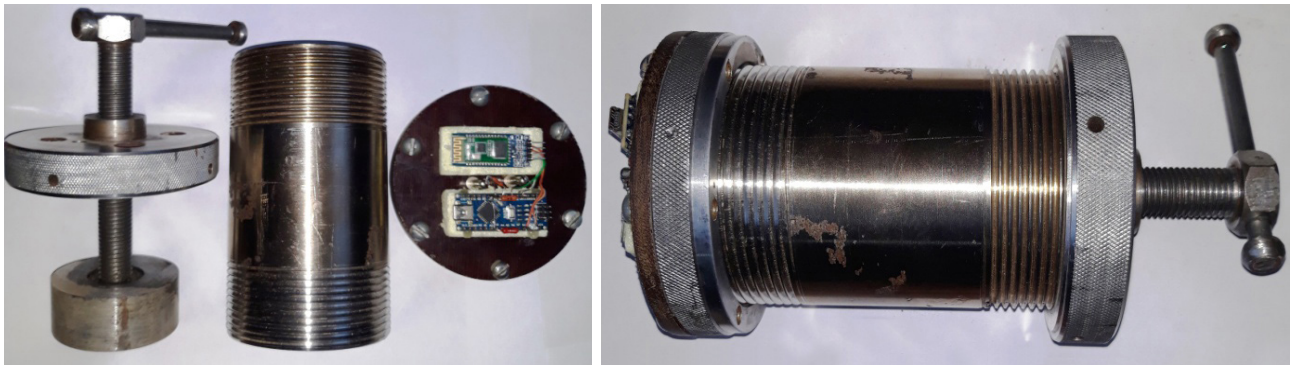


Fig. 4 Soil moisture content measuring kit



Fig. 5 Device for tillage depth measuring

repetitions. The number of measurements of this parameter was 300 in each repetition. The measurement step for this parameter was 0.2 m.

To determine the tillage depth, a device (Fig. 5) designed based on an ultrasonic sensor HC-SR04 (China), and an Arduino UNO board (Italy) was employed. The error in tillage depth measuring did not exceed 0.5 cm. With each change in depth, the HC-SR04 ultrasonic sensor detected the signal reflection from the UNO board.

Results and discussion

Observation of soil moisture content, measured at the same depth (6 cm) in treated field areas showed that soil moisture contents in both agrotechnical environments gradually decreased from the initial value of 28% (Fig. 6).

The moisture contents observed in treated areas under compared conditions were the same after the first cultivation and amounted to 28% (stage 1, Fig. 6).

Since the natural process of moisture evaporation from the soil can only be slowed down, this result is quite logical. As expected, the intensity of this process differed in the harrowed (curve 1, Fig. 6) and cultivated (curve 2, Fig. 6) areas. Cases of a particular increase in soil moisture content at certain stages of its study were not a result of the measurement error of this indicator but arose due to slight precipitation in the year's corresponding period.

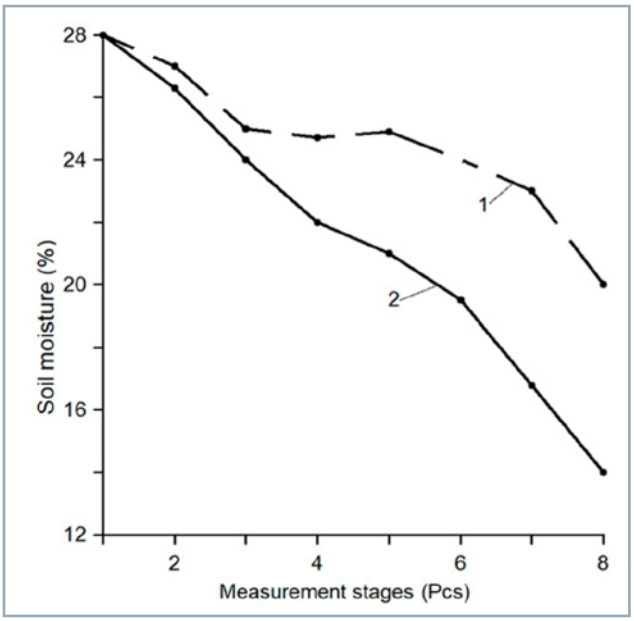


Fig. 6 Soil moisture contents in the harrowed (1) and cultivated (2) field areas by stages 1–8

Stages 1–2 and 2–3 were characterised by a gradual decrease in soil moisture in both conditions. However, in stages 2–3 and 3–4, the difference between soil moisture contents grew more rapidly. The following might have caused this – at the beginning of the research, there were two layers of the cultivated soil: one was loosened to a depth of up to 6 cm, and the second was up to 12 cm. During the subsequent treatment of the fallow area, the cultivator sweep of the base machine, operating at twice the depth than the working devices of the newly developed machine, brought moist soil to the daytime soil surface. As a result, after each subsequent stage of cultivation, there was less moisture at the estimated depth of 6 cm (curve 2, Fig. 6). Simultaneously, moist soil removal was almost absent in harrowing sections. As a result, at stage 4 (Fig. 6), the efficiency of moisture conservation due to using a new machine-tractor unit reached the first (in this particular case) maximum. A further increase in soil moisture in stages 4–5 (Fig. 6) was due to precipitation, approximately occurring at stage 4. After this rainfall, soil cultivation was carried out in both parts of the field in stages 4–5.

In principle, it is easy to see that the intensity of soil moisture increased in the harrowed area (stage 5, Fig. 6). This can be explained by the fact that the working devices of the new tillage machine practically did not transfer the moist soil up to the field surface. At the same time, the soil mulch they produced quickly passed the moisture from precipitation to the uncultivated (capillary) horizon and minimized the losses in productive moisture.

Consequently, at the end of observation (stage 8, Fig. 6), the soil moisture content in the area with the fallow field treatment by the new harrowing machine was 1.4 times higher than in the area treated by the KPS-8 serial machine.

The dynamics of changes in soil bulk density in the studied areas were also different, both qualitatively and quantitatively (Fig. 7).

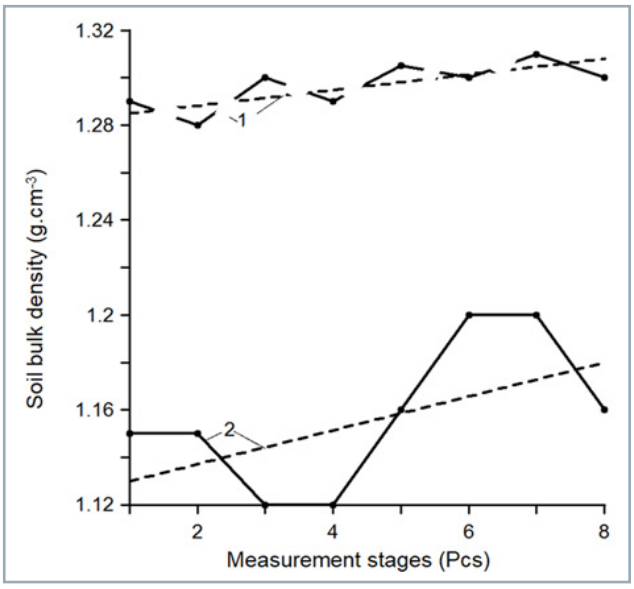


Fig. 7 Soil bulk density dynamics changes in the harrowed (1) and cultivated (2) field areas by stages 1–8

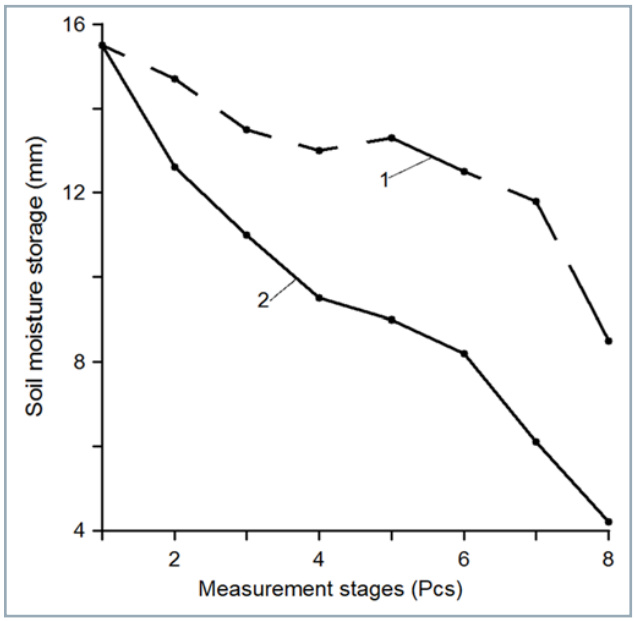


Fig. 8 Productive moisture reserve in the harrowed (1) and cultivated (2) field areas by stages 1–8

According to the research methodology, soil bulk density was measured in the harrowed agrotechnical environment at 6–12 cm depth. And since a harrow did not loosen it, the soil bulk density value was 1.28–1.31 g·cm^{-3} (curve 1, Fig. 7). Generally, this indicator was characterized by small fluctuations with certain uptrends.

In the fallow field area cultivated by the KPS-8 cultivator, the soil density was recorded at the same depth, i.e., 6–12 cm. However, since this soil layer was constantly loosened, the average soil bulk density was lower, i.e., 1.12–1.20 g·cm^{-3} (curve 2, Fig. 7).

A characteristic feature of this process was the growing intensity of average soil bulk density value. The approximation straight line steepness for this option (dashed line 2, Fig. 7) was much stronger than for the option of changing a similar approximation straight line (dashed line 1, Fig. 7) for the soil harrowing with a newly developed machine.

As a result, it is evident that the fallow field treatment utilizing a new machine causes a more significant reserve of productive moisture in the treated agrotechnical environment (Fig. 8). By soil moisture storage is meant the actual water reserve in the soil at a given depth horizon (mm).

Although the value of this moisture reserve gradually decreased over time, it was constantly much larger than in the harrowed area. This increase from 1.15 times (stage 2, Fig. 8) progressed to exceed 2.2 times (stage 8, Fig. 8). Similar results were obtained by Mühlbachová et al. (2022), who achieved an increase in value up to 1.7-fold. In areas with scarce rainfall, soil conservation technologies are vital, as other types of technology cause soil desertification (Ruan et al., 2021).

From the point of view of providing potential conditions for obtaining guaranteed germination of agricultural winter crops in the period after their sowing, even despite the absence of autumn (pre-sowing) precipitation, such a result is desirable and entirely satisfactory. Moreover, its efficiency is not lower than that of measures provided by "dry farming" systems (Cheng and Liu, 2014).

It should be emphasized that for such a technological process as fallow care, agrotechnical requirements for tolerance of fluctuations at the tillage depth have not been officially formulated in Ukraine or any other country. Taking this into account for further analysis, it was assumed that to ensure minimal moisture loss during fallow harrowing, the fluctuation value should not exceed $\Delta = \pm 1$ cm. This is half the similar indicator established in Ukraine for ploughing.

Table 1 Soil depth indicators for harrowing and cultivating units

Index	Technological operation	
	harrowing	cultivation
Mean (cm)	5.8 ±0.2	12.3 ±0.3
Dispersion (cm^2)	0.64	3.24
Standard deviation (±cm)	0.8	1.8
Coefficient of variation (%)	13.8	14.6
Probability *P* (%)	78	44
Frequency ω (m^{-1})	0.66	1.23

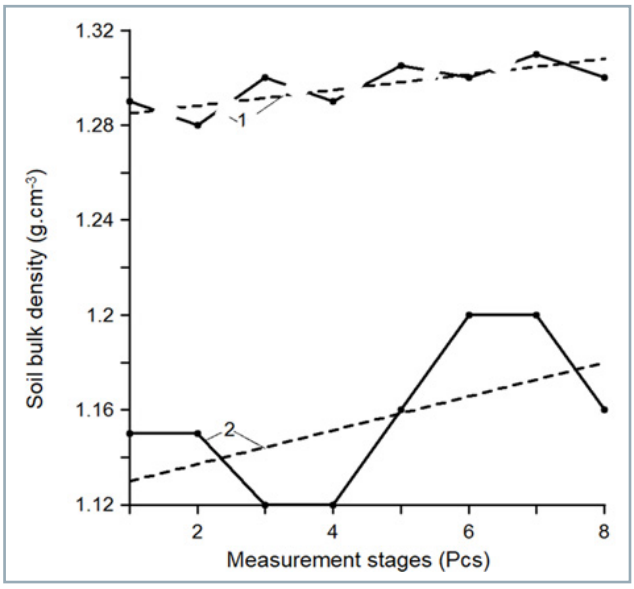


Fig. 9 Normalized correlation functions at the depth of harrowing (1) and cultivation (2)

Since $\sigma = \pm 0.8$ cm for the harrowing machine-tractor unit (Table 1), the ratio $\Delta/\sigma = 1/0.8 = 1.25$.

Based on the formula by Nadykto et al. (2020) for calculating the P-value, it follows that the probability of maintaining the new harrowing unit – with the permissible value of fluctuations at a depth of fallow field treatment at the level of $\Delta = \pm 1$ cm – is 78%.

The data analysis illustrated in Fig. 9 shows that both correlation functions cross its zero value n = 4 times. With this in mind, based on Eq. 1, $\omega = 0.66$ m^{-1}.

The probability of maintaining the permissible value $\Delta = \pm 1$ cm at $\sigma = \pm 1.8$ cm by the basic cultivator unit (Table 1) is 44%, i.e., almost 1.8 times less.

Based on Eq. 1, the value of ω, in this case, is 1.23 m^{-1}; for every 0.81 m, there was one depth fluctuation deviation of the fallow field treatment from the accepted permissible value of $\Delta = \pm 1$ cm.

It should be noted that this result is quite logical since the soil tillage depth uniformity with the new harrow unit was significantly higher than with the base one. This is backed by the *F*-test comparing the fluctuation dispersions of this parameter (3.24 cm^2 and 0.64 cm^2, Table 1). In this case, the actual value of the latter ratio of 3.24/0.64 = 5.06 was much larger than the tabular value of 1.96. Accordingly, the null hypothesis about the equality of the compared tillage depth fluctuation dispersions was rejected. This result is justified at the statistical significance level of 0.05 and the significance level of 0.01.

Conclusions

It was established that the working devices of the new harrow practically do not transfer moist soil to the field surface, and the soil mulch produced by it quickly passes the rain moisture to the untreated (capillary) horizons. Due to this, the soil moisture content in the fallow field treated by harrow for more than 3.5 months turned out to be 1.4 times higher than in the area treated by the sweeps of a serial cultivator.

In contrast to the cultivation of a fallow field, the harrowing contributed to a more significant reserve of productive moisture in the treated soil layer. Over the entire observation period, this increase progressed from 1.15 times to exceeding it by 2.2 times. In terms of providing potential conditions for obtaining guaranteed germination of winter crops, even in the absence of autumn (pre-sowing) precipitation, such a result is desirable and entirely satisfactory.

The soil tillage depth uniformity using the new harrowing unit was higher than the application of the other aggregate. Based on the *F*-test results, the fluctuation dispersion caused by the first one (0.64 cm^2) was less than the similar indicator for the second unit 3.24 cm^2 at almost any significance level.

The probability of maintaining the permissible value of fluctuations in the depth of the fallow field treatment at the level of $\Delta = \pm 1$ cm ($P = 78\%$) by the new harrow unit is greater, and the frequency of deviations from this tolerance ($\omega = 0.66$ m^{-1}) is less than the values of similar parameters ($P = 44\%$; $\omega = 1.23$ m^{-1}) for the standard cultivator.

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