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Mode of moistening ordinary chernozem using the "no-till" technology

Abstract. Studies of the influence of different technologies of conventional chernozem cultivation on the reserves of productive moisture for the cultivation of maize over grain and winter wheat in the Steppe zone of Ukraine were carried out. The parameters of productive moisture in the technology of growing field crops using "no-till" soil treatment in relation to shelf ploughing were determined. It was established that the "no-till" system substantially reduces moisture loss due to unproductive evaporation with a high coefficient of precipitation assimilation and provides reliable protection of the soil from erosion. If the soil surface is covered close to 100% in the summer under maize, the reserves of productive moisture in the root layer are over 1.5 times higher than the corresponding reserves under conventional technology; in the absence of mulch, the moistening regime for no-till technologies is more intense compared to the conventional one. The mode of moistening the soil under winter wheat over maize for silage is preferable according to the "no-till" technology, but

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there was no substantial difference between the variants on average for 3 years. In a winter with little snow, the height of the snow cover was 3.2 times higher with the "no-till" technology with mulch compared to the conventional technology. It was found that a prerequisite for growing crops without tillage in the zone of insufficient moisture is the creation of a powerful layer of mulch due to the non-commodity share of the crop, which stays on the soil surface in crushed form. Projective mulch coverage of 100% or close to this level is the key to the widespread introduction of technologies for growing without tillage in arid Steppe conditions

Keywords: reserves of productive moisture, ordinary chernozem, maize over grain, winter wheat, "no-till" system

RELEVANCE

Growing maize in the steppe is a risky endeavour. A.H. Shevchenko (1996) classifies the level of favourability of the natural and climatic resources of this zone for the cultivation of most crops, including maize, as unfavourable. V.V. Medvedev *et al.*, based on numerous studies in various soil and climatic zones, consider the Steppe, including the Donbas, to be an acceptable zone for growing maize, but suboptimal (Medvedev, 1997). The primary limiting factor of the yield level is moisture reserves, which are insufficient for optimal growth and development of maize.

It is the preservation and rational use of moisture that is one of the principal tasks of steppe agriculture. Therefore, investigating the regime of chernozem hydration in the development and implementation of innovative technologies for growing agricultural crops is a mandatory condition.

Such studies are especially necessary in the areas of water and wind erosion, which include the Donetsk region, since fluctuations in soil moisture reserves cause not only a substantial change in crop yields, but also a noticeable erosion resistance of the soil.

The most effective technique for accumulating and preserving moisture is mulching the soil surface with plant remains (Bulyhin *et al.*, 2016).

The "no-till" system allows successfully applying this method during the cultivation of all agricultural crops and maize specifically. The study by V.V. Medvedev and others has shown that the soils of Ukraine are generally favourable for the introduction of minimal and no-till cultivation. Soils were classified according to the possibility of applying minimal and no tillage by classes and area: I – optimal (8.46% or 2.54 mln ha); II – favourable (40.57% or 12.17 mln ha); III – satisfactory (41.2% or 12.36 mln ha). Along with reducing costs for soil cultivation, increasing its fertility, their use contributes to the additional accumulation of moisture by 30-50 mm, which ensures stable harvests, especially in conditions of severe droughts, which are most inherent in the Steppe zone (Kosolap & Krotinov, 2011).

ANALYSIS OF RECENT STUDIES AND PUBLICATIONS

The transition to the no-till system is not just a replacement of the tillage system, but factually a new farming system. In the world, the area on which this system is used is approximately 105 mln ha, of which 87 mln ha are in the USA, Canada, Brazil, Argentina, and Australia, and annually the area under such a system grows by approximately 1 mln ha. In Europe, including its eastern part, the volume of implementation of no-till technology is 2.5-3% of the global application (Medvediev *et al.*, 2017; Bulyhin *et al.*, 2019).

Considerable attention of Ukrainian scientists is devoted to the search for optimal soil cultivation systems, their adaptation to the cultivation of various agricultural crops in the conditions of changing climatic conditions, which substantially determine the level of productivity.

It was found that the use of minimal and no tillage of ordinary chernozem for the cultivation

of maize for silage provided the highest reserves of productive moisture in a metre-thick soil during the growing season compared to ploughing, and the indicators of deflation resistance increased considerably (Pikovska, 2020).

The advantage of shallow cultivation with slitting to a depth of 38-40 cm over shelf ploughing for growing maize over grain in the growing conditions of southern Ukraine is evidenced by the data of R.A. Vozhehova *et al.* (2019) and V.Kh. Kiver *et al.* (2019), which established a high efficiency of minimization of tillage and fertilization on ordinary chernozems for maize grain production.

The widespread use of chemicals, the elevated energy saturation of conventional technologies can cause environmental pollution, the development of erosion processes, and increase costs per unit of production. Therefore, one of the main areas of eliminating or mitigating these adverse factors is to reduce the anthropogenic load and switch to less expensive technologies with maximum use of plant growing by-products.

NSC "Institute of Agriculture of the National Academy of Agrarian Sciences" (2015) developed resource-saving technologies for growing maize over grain and winter wheat according to the no-till system, which achieves the highest return on spent resources with the obtained products, renews soil fertility.

The advantage of "no-till" technology in preserving soil fertility and, specifically, soil moisture, which determines the productivity of crops, is also evidenced by data obtained by foreign researchers. R. Derpsh, A. Calagari (1992) established that during shelf cultivation in the arable layer, moisture loss amounted to 18.3 mm, during no tillage – 4.1 mm, and the subsoil layer lost 9.7 mm and 3.5 mm, respectively. An analysis of numerous studies on no-tillage by Y. Li, Z. Li, S. Cui & Q. Zhang (2020) showed that it is climatic conditions that determine its effectiveness, and therefore research on such tillage systems is important, especially in arid zones.

The purpose of this study was a systematic investigation of sowing seeds without tillage, which is the basis of the "no-till" technology of growing crops in the understanding of American scientists.

MATERIALS AND METHODS

The study was conducted in the conditions of a stationary field experiment, established on the territory of the experimental farm of the Donetsk region, on ordinary low-humus light loamy chernozem. The repetition of the experiment was threefold. The area of the sown plot was 1.7 ha, the accounting plot area was 100 m^2. The research was conducted in a 9-field crop rotation, entering the crop rotation was carried out with four fields. Furthermore, separate options include the unchanged sowing of maize over grain (monoculture) with a natural projective coverage and the option of monoculture of maize with an artificially created 100% projective coverage of the soil surface with a layer of mulch, which is obtained from crushed maize stalks. The obtained data were subjected to statistical processing according to the variance method (Dospekhov, 1985), and analysed by non-parametric statistics using quantile analysis (Blahoveshchenskyi, Samsonova, Dmitriev, 1987).

RESULTS AND DISCUSSION

Under crops in crop rotation, the projected coverage of the soil surface with plant residues did not exceed 25%, it was insufficient for a substantial increase in moisture in the soil, and therefore under the "no-till" technology, the moisture reserves were slightly higher compared to theconventional technology (Table 1).

Table 1. Dynamics of productive moisture reserves when growing maize over grain (average for 3 years)

Variants	Soil layers, cm	Stock, mm				
		Exit from winter	Sowing	Sprouts	Flowering	Harvesting
Shelf ploughing – control	0-20 0-50 0-100 0-150	35 91 168 233	33 80 143 207	33 71 140 198	15 36 76 127	16 39 75 118
"No-till"	0-20 0-50 0-100 0-150	41 98 176 244	37 84 150 212	29 73 131 185	17 39 80 129	18 42 77 119

Only before sowing, the moisture reserves under the "no-till" technology of growing monoculture maize over grain were substantially higher than under the conventional technology, and even then, only in the 0-50 cm soil layer. Furthermore, during germination, the moisture reserves in the soil layer of 0-20 cm using "no-till" technology were substantially less than using conventional one (shelf ploughing). In general, the sowing-germination period turned out to be critical for the "no-till" technology with a small amount of plant residues on the soil surface. This was most pronounced in May 2011, when the reserves of available moisture at the time of germination of monoculture maize over grain using "no-till" technology were only 8 mm in a 0-10 cm layer, which is too insufficient. At the same time, through sowing to a depth of 5 cm, maize seeds were found in the over-dried upper layer of soil. Currently, the shoots of monoculture maize over grain using conventional technology have risen by 100%, while using "zero" technology – only by 60%. maize – a monoculture over grain under "no-till" technology – rose only on June 9 and continued to fall behind in development.

Considering the experience of 2011, a micro-field experiment was created with 100% coverage of maize plant residues and in 2013 the authors received data on moisture reserves under the maize monoculture for grain with 100% projected coverage (Table 2).

Table 2. Dynamics of reserves of productive moisture when growing maize over grain, 2013

Variants	Soil layers, cm	Stock, mm			
		Exit from winter	Sowing	Flowering	Harvesting
Shelf ploughing – control	0-20 0-50 0-100 0-150	34 92 174 222	38 93 170 229	7 29 69 118	1 7 14 36

Table 2. Continued

Variants	Soil layers, cm	Stock, mm			
		Exit from winter	Sowing	Flowering	Harvesting
"No-till", projective coverage – 100%	0-20 0-50 0-100 0-150	42 109 193 259	44 108 186 238	23 66 132 174	5 15 31 62

2013 was a dry year, and therefore the difference between the variants was striking. In almost every soil layer, at each selection period, the moisture reserves under mulch were substantially higher compared to conventional technology. Additionally, the moisture reserves under the "no-till" technology with a projective mulch coverage < 30% at the end of winter were insignificantly lower compared to the projective mulch coverage of 100%; however, in the subsequent sampling periods, the moisture reserves under the "no-till" technology with a small amount of mulch were significantly smaller (see Table 1). During flowering (in the period critical for maize), the reserves of moisture in the soil for "no-till" technology with mulch exceeded the reserves for other technologies in the 0-20 cm soil layer by 3.2 times, in the 0-50 cm soil layer – by 2, 3 times, in the 0-100 cm layer – by 1.9 times, and in the 0-150 cm layer – by 1.5 times. N.F. Tsupenko (1990) compiled a scale for evaluating the suitability of productive moisture reserves for maize based on generalized data (Table 3).

Table 3. Scale for assessing the compliance of productive moisture reserves in the soil with the requirements of maize in different growing seasons

Soil layer, cm	Phases of plant development	Stock, mm	Assessment of moisture reserves
0-20	Sowing – seedlings	< 10	Insufficient
		11-20	Satisfactory
		21-30 >	Good
0-20	Flowering	<10	Insufficient
		11-20	Satisfactory
		21-30 >	Good
0-50	Flowering	< 20	Insufficient
		30-50	Satisfactory
		60-70	Optimal

Consequently, the initial conditions for maize growth and development were equal (Figs. 1 and 2). But in July, when, according to M.I. Volodarskii, maize needs the largest amount of available moisture, its median reserves according to conventional technology (comparable data were obtained using "no-till" technology for 25% coverage of the soil surface with plant remains) were insufficient both in the soil layer 0-20 cm (Fig. 1) and in the 0-50 cm layer (Fig. 2).

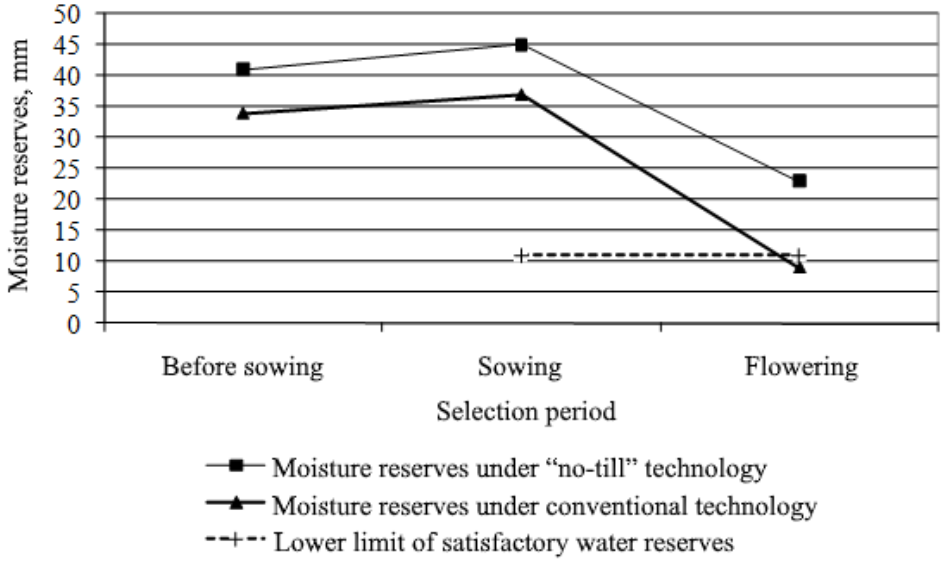

Figure 1. Median values of productive moisture reserves in the 0-20 cm layer under maize over grain

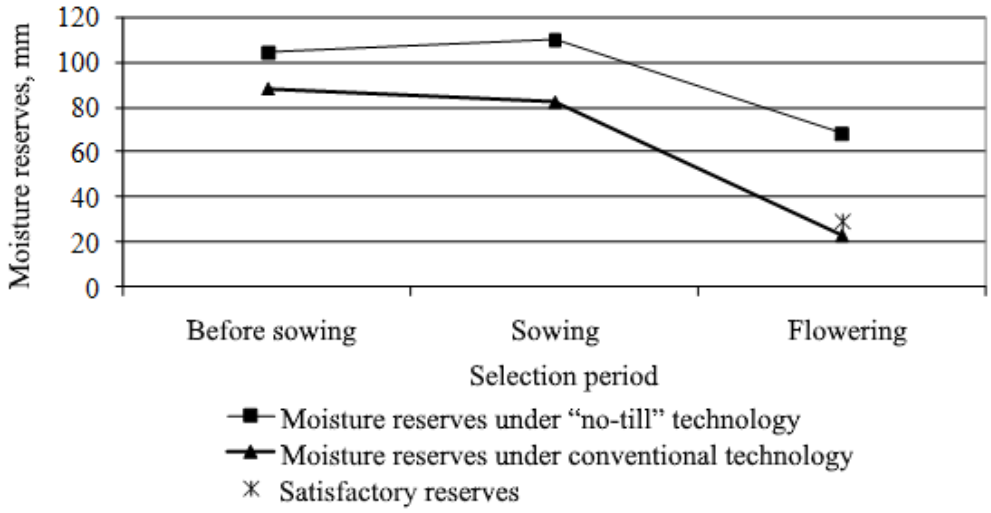

Figure 2. Median values of productive moisture reserves in the 0-50 cm layer under maize over grain

The authors of this study deliberately took the median values because they are statistically "more stable" than the average. When using "no-till" technology with 100% mulch coverage during flowering, available moisture reserves were optimal, both in the 0-20 cm soil layer and in the 0-50 cm soil layer.

The use of mulch, admittedly, is prescribed over a fairly long period of time, as a result of which it is possible to accumulate moisture in the deep layers of the soil from year to year. A certain trend was already visible in 2013. Thus, the average moisture content of the soil layer when using conventional technology in a 100-150 cm layer at the time of exit from winter was 21%, and when using no-till – 23.5%.

It is known that mulch, by lowering the temperature on the soil surface and separating the soil surface from the atmosphere, sharply reduces the intensity of steam entering the air from the soil surface, reduces unproductive evaporation of water from the soil. However, the question arises as to how the soil surface retains moisture without a mulch of plant residues. On June 3, 2013, in the seedling phase of maize under the "no-till" technology, the authors of this study noticed that the upper, 0-3 cm layer of the soil is much looser than the rest of the soil. B.H. Rozanov claims that soils with a heavy granulometric composition have a tendency to self-mulching. The authors of the present study believe that this is precisely what happened. According to V.V. Medvediev (1988), the differentiation of the upper layer of the soil by density (the upper loose layer changes to a denser one at 5--10 cm) helps to reduce evaporation, increases the condensation of moisture vapour, while at the same time there are no substantial additional obstacles to the entry of atmospheric moisture into soil. Clearly, mulch created by fine soil is not as effective as mulch created by plant residues. In the flowering phase, when using the "no-till" technology without mulch and when using the conventional technology, the humidity in the 0-3 cm layer was 8% and 7%, respectively, and 13% against 10% in the 3-10 cm layer, while when using the "no-till" technology with 100% coverage with plant remains – 18% in the 0-3 cm layer and 23% in the 3-10 cm layer.

It is known that in the chernozem zone of insufficient moisture, the productive moisture in the soil is the first limiting factor in the yield level of agricultural crops. Using evidence from 2013, it can be argued that mulch practically solves the problem of a guaranteed high maize yield in conditions of insufficient moisture in the chernozem zone.

In addition, there is a tendency for changes in some characteristics of the soil climate. A.A. Shulgin (1972) gives a quantitative description of the amplitude of soil moisture reserves in a metre-long soil layer during the warm period (the so-called moisture turnover): uniform – under 50 mm, uneven – 50–100 mm, very uneven – over 100 mm. Evidently, at least up to and including flowering, the amplitude of soil moisture reserves under the "no-till" technology with mulch was considered uneven – 61 mm, and under the conventional technology, as very uneven – 105 mm.

The mode of moistening the soil under winter wheat for maize over grain is preferable when using "no-till" technology, but there was no substantial difference between the options on average for 3 years (Table 4).

Table 4. Dynamics of productive moisture reserves for winter wheat cultivation (average for 3 years)

Variants	Soil layers, cm	Stock, mm			
		Sowing	Restoration of vegetation	Flowering	Harvesting
Shelf ploughing – control	0-20	12	25	16	18
	0-50	35	64	34	34
	0-100	73	116	65	48
	0-150	116	173	111	78

Table 4. Continued

Variants	Soil layers, cm	Stock, mm			
		Sowing	Restoration of vegetation	Flowering	Harvesting
"No-till"	0-20	19	25	21	18
	0-50	44	66	41	35
	0-100	83	119	76	53
	0-150	129	175	119	81

This can be explained by the contrasting weather conditions in 2011 compared to 2012 and 2013. Considering each year separately, it turns out that in 2011, during sowing, reserves of available moisture in the 0-20 cm layer when using "no-till" technology amounted to 39 mm, against 29 mm when using the conventional one. During sowing in 2012, the moisture reserves using the "no-till" technology were 2.4 times higher compared to conventional technology, respectively, 12 mm against 5 mm. In 2013, the driest year at this point, the moisture reserves for both technologies were practically the same: 3 mm for the conventional one, 5 mm for the "no-till" one. Thus, when sowing winter wheat using "no-till" technology, the starting conditions are better than upon using conventional technology. The fact is that the "no-till" technology contributes to more efficient consumption of moisture for physical evaporation, and therefore the highest content of moisture is stable in the soil during sowing. Both in 2012 and 2013, using the "no-till" technology, full shoots were observed in the autumn, while upon using the conventional technology, only in the spring of the following year.

It is known that in the Steppe zone, moisture accumulation occurs during the cold period of the year. In winter, precipitation falls in the form of snow, sleet (snow with rain) and rain. The average snow cover height is 6-11 cm. Due to frequent thaws, the snow cover is unstable. The value of the hydrothermal coefficient for Donbas (0.8-0.9) shows that evaporation in the warm period of the year exceeds this amount. Therefore, in the practice of agriculture, it is necessary to apply all methods of moisture accumulation in the autumn and winter period.

During ploughing, due to the uneven "corrugated" surface, the snow is blown off the ridges, and the surface of the soil without plant remains freezes and prevents the infiltration of water into the soil. The presence of a mulch layer on the surface of the soil also affects its hydrothermal regime in winter, reducing soil freezing and creating more favourable conditions for replenishing water reserves during snow melting, during thaws and in spring, and considerably reduces the risk of water erosion. On February 24, 2013, the soil temperature in the 0-5 cm and 0-10 cm layers upon using the "no-till" technology with mulch was the same and equal to +1.5°C. Using conventional technology – -1.5°C in the 0-5 cm layer and -0.7°C in the 0-10 cm layer.

Apart from affecting the freezing of the soil, mulch, by increasing the aerodynamic roughness of the surface, retains and accumulates snow, protecting it from wind blowing. This is especially evident in low-snow winters, in heavy-snow winters without blizzard redistribution of snow, the difference in its reserves on the field slightly decreases (Table 5).

Table 5. Snow cover thickness in various hydrothermal winter conditions, cm

Crop	Technology	February 2, 2011	February 2, 2013
Winter wheat	Conventional	25.8	13.3
	No-till	25.8	7.7

Table 5. Continued

Crop	Technology	February 2, 2011	February 2, 2013
Maize – monoculture	Conventional	24.7	8.2
	No-till (projective coverage < 30%)	24.7	16.1
	No-till (projective coverage > 85%) No-till	-	26.1
Stubble of winter wheat (predecessor for sunflower	Conventional	24.7	8.1
	No-till	24.7	6.2
$LSD_{0.05}$ S_x%		2.8 4.9	

As this table suggests, in the snowy winter of 2011, the height of the snow cover was almost the same for all technologies. In a winter with little snow, the advantage of "no-till" technology was evident. This is especially noticeable for the use of "no-till" technology with mulch, where the height of the snow cover was 3.2 times higher compared to the conventional technology. The "no-till" technology of growing corn without mulch also contributed to the accumulation of snow cover – twice as much as the conventional technology.

The relatively small height of the snow cover on the stubble of winter wheat is explained by the low cut of the straw during wheat harvesting. However, when using conventional technology, the surface area without snow occupied up to 15%, and when using "no-till" technology, 100% snow coverage of the soil surface was noted for all cultures.

CONCLUSIONS

In the world and in Ukraine, the use of agrotechnical techniques is becoming increasingly important. These techniques ensure a substantial reduction of moisture loss caused by unproductive evaporation with a high rate of assimilation of (melt) water and rain, which, among other things, provides reliable protection of the soil from erosion.

The "no-till" technology most fully meets these requirements with 100% or close to this level of projective covering with mulch from plant residues, which is considered a prerequisite for the wide implementation of cultivation technologies without tillage in the arid conditions of the Steppe.

If the soil surface is covered close to 100% in the summer under maize, the reserves of productive moisture in the root layer are over 1.5 times higher than the corresponding reserves when using conventional technology; in the absence of mulch, the moistening regime when using no-till technologies is more intense compared to the conventional technology.

The mode of moistening the soil under winter wheat over maize for silage is preferable when using the "no-till" technology, but there was no substantial difference between the variants on average for 3 years.

In a winter with little snow, the height of the snow cover was 3.2 times higher when using the "no-till" technology with mulch compared to the conventional technology.

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Режим зволоження чорнозему звичайного за технології «no-till»

Анотація. Проведені дослідження впливу різних технологій обробітку чорнозему звичайного на запаси продуктивної вологи за вирощування кукурудзи на зерно та пшениці озимої у степовій зоні України Визначені параметри продуктивної вологи при технології вирощування польових культур за «нульового обробітку» ґрунту («*No-till*») щодо полицевої оранки. Встановлено, що система «*No-till*» сприяє суттєвому зменшенню втрат вологи на непродуктивне випаровування за високого коефіцієнта засвоєння атмосферних опадів, забезпечує надійний захист ґрунту від ерозії. У разі вкриття поверхні ґрунту близькому до 100 % влітку під кукурудзою запаси продуктивної вологи в кореневмісному шарі в 1,5 і більше рази перевищують відповідні запаси за традиційної технології; у разі відсутності мульчі режим зволоження за технології без обробітку ґрунту складається більш напружений у порівнянні з традиційною. Режим зволоження ґрунту під озимою пшеницею по кукурудзі на силос кращий за «нульовою» технологією, але суттєвої різниці між варіантами в середньому за 3 роки не виявлено. У малосніжну зиму за «нульової» технології з мульчею висота снігового покриву була в 3,2 рази вищою у порівнянні з традиційною технологією. Виявлено, що обов'язковою умовою вирощування культур без обробітку ґрунту в зоні недостатнього зволоження є створення потужного шару мульчі завдяки нетоварній частці врожаю культур, яка в подрібненому вигляді залишається на поверхні ґрунту. Проєктивне покриття мульчею у 100 % або близьким до цього рівня є запорукою широкого впровадження технологій вирощування без обробітку ґрунту в посушливих умовах Степу

Ключові слова: запаси продуктивної вологи; чорнозем звичайний; кукурудза на зерно; пшениця озима; система «*No-till*»