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Long-Term Dynamics of the Spring Moisture Reserves with Various Methods of Processing Typical Chernozem

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ABSTRACT

In this work there are studied the peculiarities of formation of the reserves of productive moisture in a meter–thick layer of chernozem in a long–term dimension using various methods of soil cultivation and agroclimatic indicators under the conditions of the left bank part of the central Forest–Steppe of Ukraine. In the work there used generally accepted research methods: the field, laboratory, mathematical statistics, comparative calculations. Based on the conducted research, the following results were obtained. In the period from 1977–1982 to 2020–2024 the amount of precipitation during the cold period of the year (November–February) increased by 71 mm, and for the period November–March – by 64 mm. In the months of the cold period of the year the amount of precipitation increased most of all: in November (+15 mm), December (+28 mm), February (+38 mm) relative to the norm. The average monthly air temperature in the period November–February in 2020–2024 was above 0 °C, while according to the norm of observations the average monthly air temperature was –1.3 °C. In the period from 1977 to 2024 the increase in average daily air temperature occurred according to trustworthy trends. A direct correlation was established between the amount of precipitation during the cold period of the year (November–February) and the average monthly air temperature at the level of $R = 0.73–0.75$, and with precipitation for the period November–March the correlation weakened to an average level of $R = 0.63–0.70$. During the shallow non–moldboard cultivation in 2020–2024 the accumulated moisture was by 16 mm less, in contrast to the deep non–moldboard cultivation. A direct correlation was found between the moisture reserves in the 0–50 cm layer and the average daily air temperature for the periods November–February and November–March: $R = 0.74–0.76 \pm 0.02$, $R^2 = 0.54–0.58$ (ploughing), $R = 0.70–0.71 \pm 0.02$, $R^2 = 0.49–0.50$ (moldboardless tillage) and $R = 0.49–0.52 \pm 0.02$, $R^2 = 0.24–0.27$ (small mouldboardless tillage). The relationship between the amount of atmospheric precipitation and the reserves of productive moisture in a meter–thick layer, regardless of the processing method, was at the level of direct correlation of the average level, and the formation of spring reserves of productive moisture in a meter-thick layer, regardless of the processing method, over 46 years of observations took place according a downward trend. For ploughing the intensity of the decrease in the moisture reserve was 2.1 times higher compared to the non–moldboard cultiation, which made it possible to form a higher moisture reserve by 8–10 mm.

Keywords: soil cultivation, normalized moisture supply, precipitation, productive moisture, mouistre indicator, cold period of the year, excess, asymmetry.

INTRODUCTION

The soil moisture and the moisture of atmospheric precipitation is the main resource for the growth of agricultural crops, and it is the fundamental factor determining the productivity of agricultural crops. The availability of information about the conditions of the soil moisture reserves is a prerequisite for optimizing both the structure of the crop rotation and soil cultivation in the crop growing technologies [Kovalenko et al., 2014; Tkachuk, 2011; Litovchenko, 2011; Kovalenko et al., 2015; Kovalenko et al., 2016; Kovalenko et al., 2019; Achasov et al., 2015].

Cultivation in itself does not enrich the soil environment with the energy material for reproduction of the fertility of chernozems; however, the agrophysical parameters of the soil depend on it, determining the moisture accumulation capacity in the spring, the air and thermal conditions of the soil climate, the introduction degree and depth of the plant residues, which is reflected in the dynamics and ratio synthesis and mineralization of humus, the formation of available forms of nutrients and their absorption by agricultural crops [Pykhtin, 2017; Kyryushin, 2019].

Chernozems as the main productive resource of agriculture have long been under conditions that differ significantly from the optimal ones in which chernozems should be formed, and therefore they are prone to degradation [Krupenikov, 2008]. The main reason is the inconsistency of the technologies, used with the principles of natural formation of chernozems [Baibekov, 2018]. This discrepancy refers to the basic soil cultivation, which is associated with the destruction of turf and litter, leading to increasing agrophysical degradation of chernozems in agrocenoses [Pykhtin, 2017; Demidenko, 2013; Kuznetsova, 2013]. The choice of a system for processing chernozems has always been the most controversial and relevant in the process of agricultural practice in the Forest–Steppe of Ukraine. Endless doubt about the need for deep processing with the turnover of the layer are reflected in the need to minimize the processing of chernozems, aimed at reducing the depth and number of treatments [Romanov et al., 2018].

Over the past decades the most balanced cultivation system for chernozems is a differentiated one, consisting of various combinations of the ploughing techniques and non–moldboard cultivation [Sayko and Malienko, 2004]. The problems of deterioration of the agrophysical properties, after abandoning intensive cultivation, are solved by periodical use of ploughing for the most demanding crops [Gordienko, 2004; Medvedev and Laktionova, 2007; Cherkasov and Pykhtin, 2006]. On the other hand, there are substantiated facts about the advisability of minimizing cultivation on chernozems, which are characterized by high agrophysical parameters, relative to the optimal values, for growing most crops [Kurachenko et al., 2010].

One of the most realistic directions for solving the problem of the chernozem degradation is further improvement of the soil cultivation technology by reducing the production costs, and, therefore, the resource-saving technologies for basic soil cultivation are becoming widespread, due to which it is possible to achieve further adaptation of the agricultural crops to complex modern natural and climatic conditions, which allows maintaining agroecological balance in agrocenoses [Akulov, 2004].

Changing the depth of the main cultivation has a strong effect upon the chernozem fertility. As a rule, less cultivated chernozems require deeper cultivation [Buyankin et al., 2004], and, as the level of cultivation increases and agrophysical properties improve, the sensitivity of chernozem to intensive cultivation weakens, and the fertility of chernozem with minimization of processing becomes higher than with conventional deep cultivation [Buyankin et al., 2004; Nikolaev et al., 2015; Goryanin and Chudanov, 2017].

In modern agricultural production the resource–saving technologies (combined, minimal, zero) are used, in which special attention should be paid to the agrophysical factors of the chernozem fertility. The soil density is the main indicator of the physical state of the chernozem for growing crops [Solodovnikov et al., 2015; Romanov et al., 2018; Samofalova et al., 2013].

Favorable agrophysical properties are the basis and necessary condition for achieving the potential fertility of the chernozem in order to obtain high yields of agricultural crops, and the creation and maintenance of optimal structure of the arable layer of soil and soil thickness, using various tillage systems, is an urgent task of modern agriculture in terms of enhancing the moisture accumulation and moisture retaining ability of the chernozem [Jordan and Gil, 2010; Modak et al., 2020; Nandan et al., 2019; Copec et al., 2015; Castellini et al., 2019; Lampurlanes et al., 2016; Zhang et al., 2015; Kaminsky and Gangur, 2018; Sokyrko, 2011; Demydenko, 2021; Demydenko, 2023].

Thus it becomes relevant to carry out a comprehensive analysis of the obtained data in a long–term dimension (48 years) regarding the spring moisture accumulation using various methods of processing and agroclimatic indicators in agrocenoses of the central part of the left bank forest–steppe agrolandscape, as well as normalization of the processes of formation of reserves of productive moisture in the thickness of chernozem under the influence of changing climatic conditions factors and conditions and processing methods.

The purpose of the rsearch is to establish the peculiarities of formation of productive moisture reserves in a meter-thick layer of chernozem in a long-term dimension by various methods of soil cultivation for the conditions of the left bank part of the central Forest–Steppe of Ukraine.

MATERIALS AND METHODS

The investigations were conducted in the central part of the left-bank Forest–Steppe of Ukraine in a long-term stationary experiment of the Drabovsky experimental field of the Cherkassy State Agricultural Experimental Station of the National Scientific Centre "Institute of Agriculture of the National Academy of Agrarian Sciences". The soil is a typical low-humus, coarse-silty, light–loamy chernozem with a humus content of 3.8–4.2%, the content of mobile phosphorus is 120–140 mg per 1000 g of soil, mobile potassium is 80–100 mg per 1000 g of soil, pH H_2O = 6.8–7.0. The size of the sown plot is 162 m^2, and the registration plot is 100 m^2.

The investigations were conducted from 1976 to 2024 in a multifactorial stationary experiment of the Cherkassy State Experimental Station of the National Scientific Centre "Institute of Agriculture of the National Academy of Agrarian Sciences". There were studied two types of 5-field crop rotations in the experiment: A: perennial grasses – winter wheat – sugar beets – corn (maize) – barley + perennial grasses (cereals – up to 60%, technical – up to 20%; perennial grasses – up to 20%); B: Peas – winter wheat – sugar beets – corn (maize) for grain – corn (maize) for grain (cereals – up to 60%, technical – up to 20 %; legumes – up to 20%).

The fertilizer system: 6.0 t $(ha)^{-1}$ by-products; $N_{31}P_{33}K_{41}$ (medium dose); $N_{62}P_{66}K_{82}$ (double dose) per 1 ha of crop rotation area. By 1999 6 t $(ha)^{-1}$ of manure was applied, and from 2000 to 2022, 6–7 t $(ha)^{-1}$ by-products were applied.

Basic processing methods

Ploughing the soil at various depths (22–25 cm) for all crops; no-moldboard tillage (22–25 cm) for all crops; shallow tillage (8–12 cm) for all crops. In both experiments the repetition was threefold. The present period of research of the water mode was based on: Soil quality – determination of soil water content as a volume fraction on the basis of known dry bulk density – gravimetric method. [DSTU ISO 16586:2005, 2008]. The soil quality – soil moisture and unsaturated zone [ISO 15709:2002, 2002].

The humidification conditions are determined by L.S. Kelchevskaya like this [Baisholanov et al., 2017]: at $\eta > 1.3$ – excessively wet; $\eta = 1.3–1.1$ – wet; $\eta = 1.1–0.9$ – optimal; $\eta = 0.9–0.7$ – slightly arid; $\eta = 0.7–0.5$ – moderately arid; $\eta = 0.5–0.3$ – arid and at $\eta < 0.3$ dry. A complex indicator for assessing the level of the moisture supply is the ratio of the actual reserves of the productive moisture to their optimal value, namely 85% of the productive reserves of the moisture from NV in the calculated soil layer. The analysis was applied to archival data from the reports of the spring moisture reserves at the level with their current determinations in a metre layer of chernozem and agroclimatic parameters for 1976–2024 according to official data from the Cherkassy Regional Center for Hydrometeorology and the weather station of the Drabovsky experimental field.

Generalization of indicators of the chernozem moisture mode, climatic parameters, and the calculations of the research results were carried out by applying the method of analysis of variance, using the STATISTICA–10 program and non–parametric statistical methods, the correlation, factor and the cluster analysis.

RESULTS

An analysis of the amount of atmospheric precipitation in November 2020–2024 showed that the excess above the norm was 15 mm. In certain observation periods (1st, 4th, 5th) the excess of precipitation above the normal averaged 2.3 mm, and below the normal – 4.7 mm. In December the amount of precipitation exceeding the norm was observed: 1 (+17 mm), 4 (+7.0 mm) and 7 (+28 mm) (Figure 1).

In the 3rd and 6th observation periods, precipitation fell below normal by 15 mm. In January the amount of precipitation that exceeded the norm was observed in periods 4 and 6, and in other periods the amount of precipitation was less than normal. In February, in the 4th and 5th observation periods, the amount of precipitation exceeded the norm by an average of 15 mm, in the 6th observation period

(2020–2024) the excess of precipitation above the norm was 2–4 mm, and in other observation periods the precipitation fell below the normal: in the 7th period (2020–2024), precipitation fell below the normal by 7–10 mm (Figure 1).

On average, for November–February in the 1st, 4th, 5th and 7th periods of precipitation, precipitation fell above normal by 22 mm (1st, 4th, 5th), and in the 7th period (2020–2024), the excess of precipitation above the norm was 71 mm. During November – March, in the 1st, 4th, 5th, 7th observation periods, the amount of precipitation exceeded the norm by 20 mm (1st, 4th, 5th periods), and in the 7th period (2020–2024) the excess above the norm was 64 mm. Over the period November – February – March, the trends in the exponential equations of atmospheric precipitation dynamics for 1977–2024 were increasing (Figure 2).

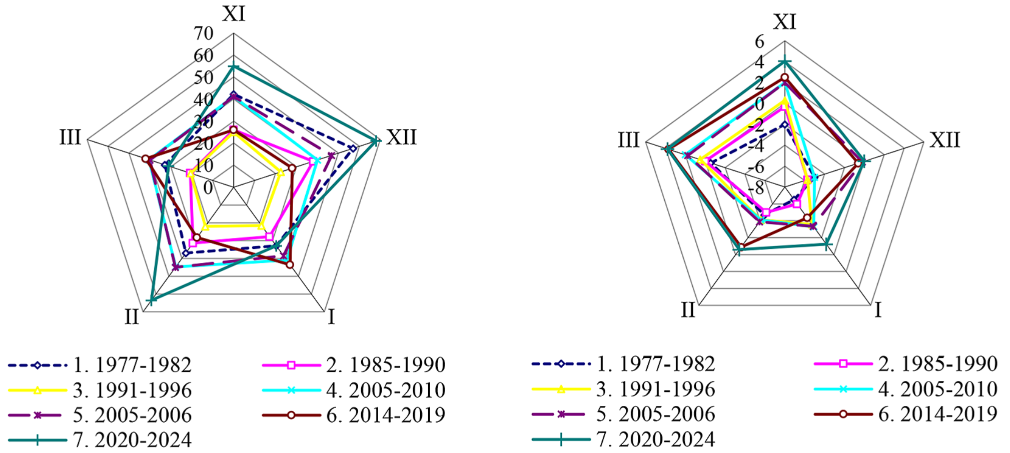

Figure 1. Dynamics of agroclimatic parameters of the cold period of the year for 1977–2024: (a) – the amount of precipitation that exceeded the norm; (b) – average monthly air temperature

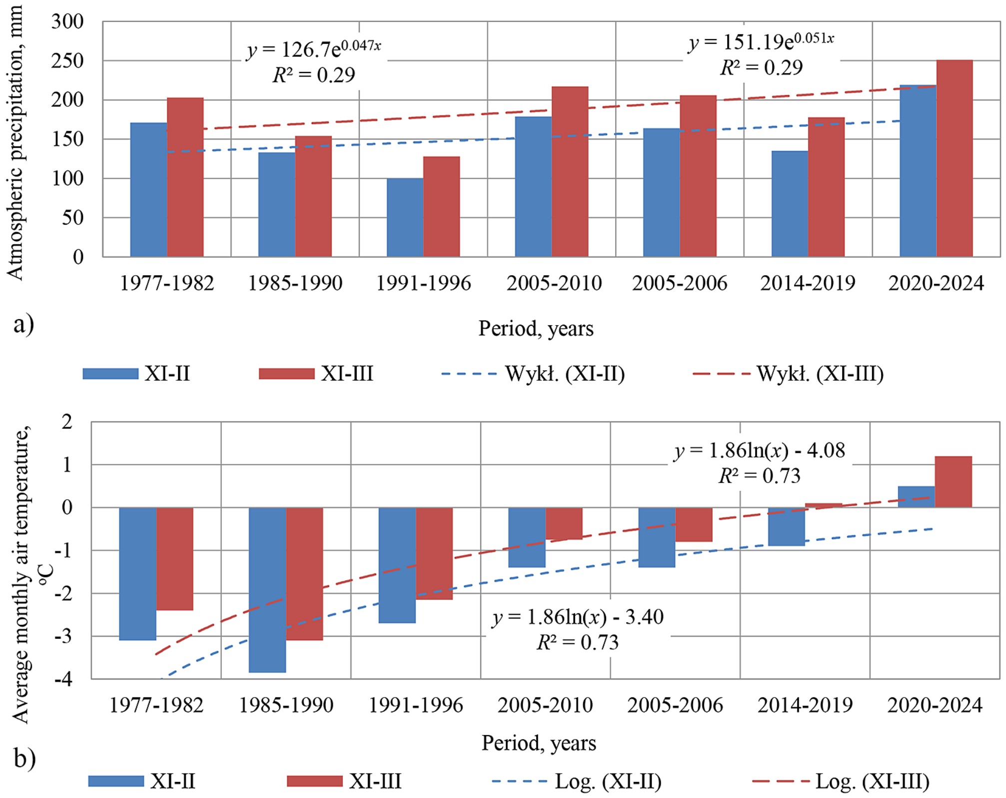

Figure 2. Dynamics of the agroclimatic indicators in November–February and November–March for 1974–2024: (a) – the amount of precipitation; (b) – the average monthly air temperatures

The average monthly air temperature in November, in the 1st, 4th, 5th and 6th observation periods, was above 0 °C and, on average, 0.3 °C below normal, and for the 7th observation period (2020–2024) the temperature air exceeded the norm by +1.4 °C. In December an increase in the negative air temperatures from the 1st observation period to the 7th by 3.1 °C was recorded, and, compared to the 2nd observation period, the air temperature increased by 3.5 °C, the excess of air temperature in the 7th observation period, in relation to the norm, was 1.7 °C. In January the established pattern of increasing negative temperatures persisted against a lower background of negative temperatures. The increase in negative temperatures from the 1st period (–6.5 °C) to the 7th period (–1.36 °C) was 5.1 °C. If from the 3rd period to the 5th period the average monthly air temperature was –3.5 °C, which corresponds to the norm, then in the 6th period there was a decrease in the air temperature by –1.1 °C, which was above the norm by –1.02 °C.

In the 7th observation period (2020–2024), the average monthly air temperature was 2.1 °C above normal. In February the established pattern persisted against a higher background of negative temperatures: in the 6th period (2014–2019), the average monthly negative air temperature exceeded the norm by 1.5 °C, and in the 7th observation period (2020–2024) it exceeded the norm was 1.9 °C, and relative to the 2nd period the excess of air temperature was 4.5 °C. In March there was a steady upward trend in the average monthly air temperature, which increased by +3.4 °C relative to the 1st and 3rd periods in the 7th observation period (2020–2024), and the excess relative to the norm was +1.5 °C.

In the period November–February and November–March, stable, reliable trends in increasing negative temperatures during the cold period of the year were established (Figure 2). In the period 2020–2024, the average monthly air temperature had values above 0 °C (0.5 °C and 1.2 °C), and in relation to the 1st and 2nd observation periods there was an increase in negative temperatures, which in the period November – February the temperatures were above the normal by 0.5 °C, and for the period November – March acquired values above 0 °C (6th, 7th observation periods).

During the observation period a direct correlation was established between the amount of precipitation in November – March and the amount of precipitation in November, December and February: $R = 0.87–0.96 \pm 0.02$; $R^2 = 0.75–0.92$. The correlation between the amount of average monthly precipitation in January, February, March and the average monthly air temperature in December was at the level of $R = 0.70–0.75 \pm 0.02$; $R^2 = 0.49–0.56$ and average monthly precipitation with air temperature in March ($R = 0.58–0.69 \pm 0.02$; $R^2 = 0.33–0.48$). In general, a direct correlation at an average level ($R = 0.63–0.71 \pm 0.02$; $R^2 = 0.40–0.50$), as with precipitation for February and March.

In the initial observation period (1977–1982) the reserves of the productive moisture in the soil layer, regardless of the method of soil processing, were 182–187 mm. The moisture reserve in the 0–50 cm thickness was 100–105 mm, and in the 50–100 cm thickness it was 77–79 mm with non–moldboard tillage at various depths and 12 mm more ploughing. The ratio of the moisture reserves at half-thicknesses was 1.2 to 1 during ploughing, 1.4 to 1 during deep non-moldboard tillage, and 1.3 to 1 during shallow non-moldboard tillage. The moisture index was $\eta = 1.26–1.29$, which corresponded to the humid conditions regardless of the tillage method (Figure 3).

In the periods 1985–1990 and 2005–2010, during ploughing, the reserve of the productive moisture in 0–100 cm the soil thickness decreased to 145 mm, and the reserves for half–thickness were 72–84 mm (0–50 cm) and 61–72 mm (50–100 cm) at a ratio of 1.01–1.4 to 1.

With no–moldboard tillage, the moisture reserve in a meter–thick layer decreased to 143 mm, with reserves in thicknesses of 0–50 cm and 50–100 cm – 83 mm and 60 mm, respectively, with a ratio of 1.4 to 1. In 2005–2010 the moisture reserve in a metre-thick layer was 8 mm higher than during ploughing, and the reserves in half-thickness were 76 mm and 75 mm with a ratio of 1 to 1. With shallow, non-moldboard tillage the moisture reserves in a metre– thick layer for 1985–1990 and 2005–2010 were 140–145 mm, while the reserves in the half-metre thick layers were 71–75 mm (0–50 cm) and 62–72 mm (50–100 cm) with the ratio of reserves in the half–thicknesses being 1.01–1.2 to 1.

During the periods 1991–1996, 1997–2001, 2014–2019 and 2020–2024 the moisture reserve in a metre layer during ploughing was within the range of 157–160 mm, with the reserves in the half-metre thicknesses being 80–87 mm (0–50 cm) and 71–76 mm (50–100 cm) with a

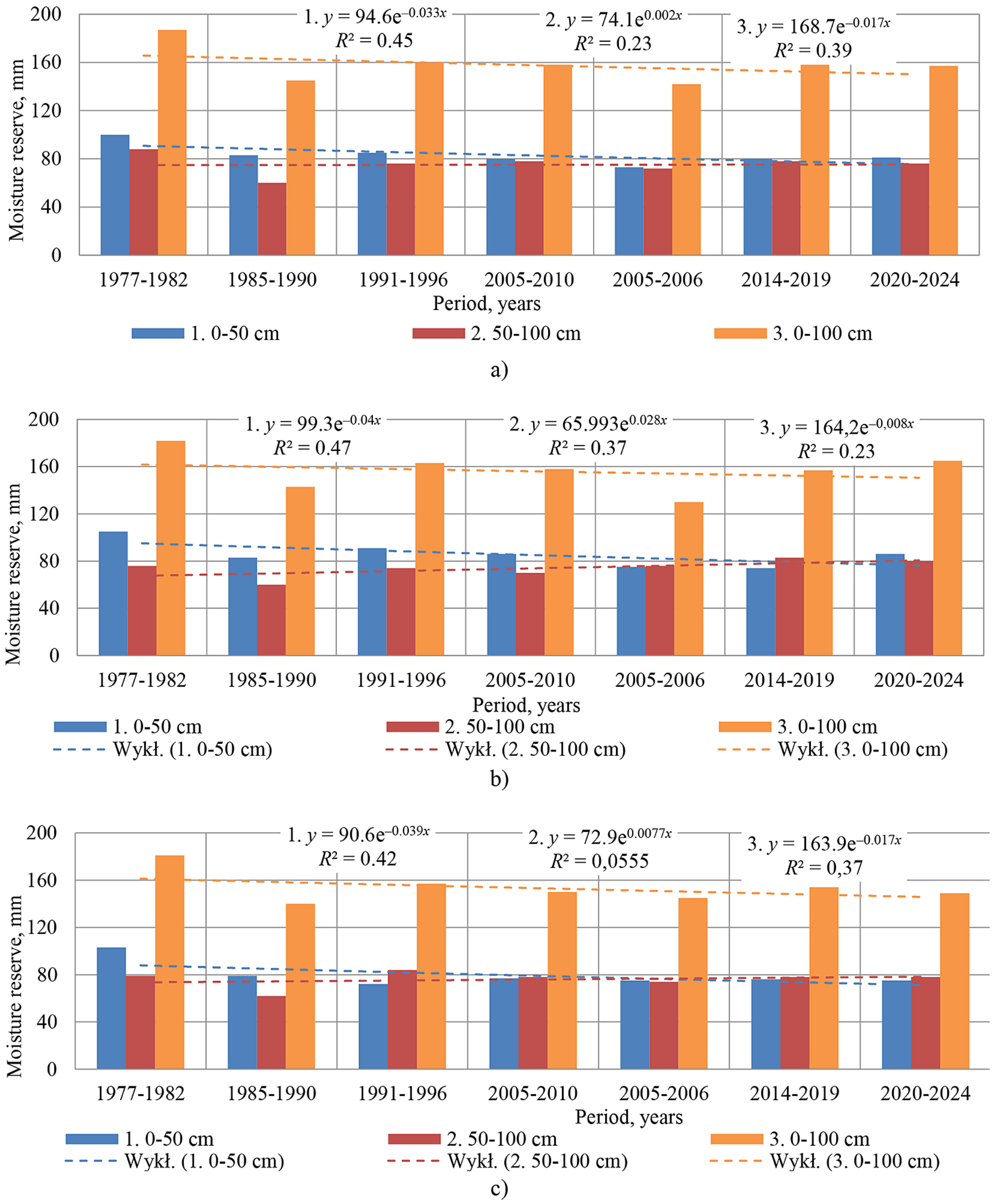

Figure 3. Dynamics of the productive moisture reserves for various cultivation methods in 1977–2024: (a) ploughing; (b) non–moldboard tillage; c – non-moldboard fine tillage

reserve ratio of 1.12–1.14 to 1. During the non–moldboard tillage in the periods indicated above, the moisture reserves in a metre-thick thickness were 155–165 mm with a moisture ratio in half-thickness of 1.2 to 1. During the shallow, non-moldboard tillage in the indicated research periods the high moisture reserves reached 150–156 mm with layer-by-layer reserves of 71–73 mm (0–50 cm) and 77–85 mm (50–100 cm) with a reserve ratio of 0.9 to 1.

In the period 2020–2024 the moisture reserve when ploughing the soil was 157 mm, with non–moldboard tillage – 165 mm (+8 mm) and 150 mm with shallow non-moldboard tillage, which is 7 mm and 15 mm less relative to ploughing and non-moldboard tillage. The difference in the moisture reserves in the metre-thick layer between the initial and the final periods was: 30 mm (ploughing), 17 mm (non-moldboard tillage) and 32 mm (fine non-moldboard tillage). At a half-thickness of 0–50 cm, the difference in moisture reserve was 19 mm, 25 mm and 30 mm, and in the thickness of 50–100 cm, the difference was

–17 mm, +3 mm and –2 mm, respectively, according to the tillage.

Trends of changes in the reserves of the productive moisture in the 0–50 cm layer, regardless of the treatment method, were downward and had various intensities according to the value of the regressioncoefficient in the exponential trend equations. With non-moldboard cultivation the regression coefficient was 1.2 times higher, compared to ploughing, and equal in value with the non–moldboard shallow treatment (Figure 3).

In a thickness of 50–100 cm the regression coefficients for variables in the exponential trend equations had a positive sign but with the non–moldboard tillage the value of the regression coefficient was 12.5 times higher, compared to ploughing and 3.6 times higher, compared to non–moldboard shallow tillage. The regression coefficient for shallow, non-mouldboard tillage was 3.5 times higher than the coefficient for ploughing. The most actively growing trend of the moisture changes in the thickness of 50–100 cm was during non-moldboard tillage, which ensured an increase in the moisture reserve relative to the smallest reserve in 1985–1990 by 20 mm. With ploughing and shallow non-moldboard tillage the increase in the reserve was 15 mm, which indicates that with non–mouldboard treatment, the moisture–saving ability of the soil layer increases, compared to ploughing and shallow tillage. At a thickness of 0–50 cm the increase in the supply of the productive moisture, regardless of the method of tillage (over 46 years), was: 1 mm (ploughing), 3 mm (non-moldboard tillage) and –2 mm (fine non-moldboard tillage), which indicates the stability of saturation with the productive moisture, starting from 1985–1990.

Figure 4 shows the dynamics of the moisture content index (η) according to Kelchevskaya L.S. [Baisholanov et al., 2017] of the chernozem thickness in the spring with long-term implementation of various soil tillage methods. The moisture indicator, regardless of the method of chernozem reatment, changed along a downward trend, and during all the periods of research did not decrease beyond the range of the optimal moisture (η = 1.1–0.9). It was highest in the period 1977–1982, which characterized the moisture conditions as wet (η = 1.3–1.1) regardless of the soil tillage method. In the period 1985–1990 and 2005–2010 it decreased to slightly dry conditions in the first case but in the latter case, with no-moldboard treatment, it corresponded to the optimal values of the moisture conditions (η = 1.1–0.9). In the subsequent research periods (2014–2019 and 2020–2024), η exceeded the value η = 1.0 in the first case but in the second case of observations during ploughing and shallow tillage, the soil moisture conditions were optimal (η = 1.03–1.08), then, as with the deep non–moldboard processing, η responded to the moist conditions.

When ploughing, a direct correlation was found at the level of R = 0.74–0.76 ± 0.02, R^2 = 0.55–0.58, and with the air temperature for December and January the correlation increases to R = 0.80–0.82 ± 0.02, R^2 = 0.64–0.67. Between the air temperature in February and March, and the moisture reserves in the thickness of 0–50 cm and 0–100 cm, the level of correlation weakens to R = 0.63–0.66 ± 0.02, R^2 = 0.40–0.44. The correlation between the moisture reserves in the half-thicknesses and the moisture reserves in a metre-thick thickness was at the level of R = 0.85–0.88 ± 0.02.

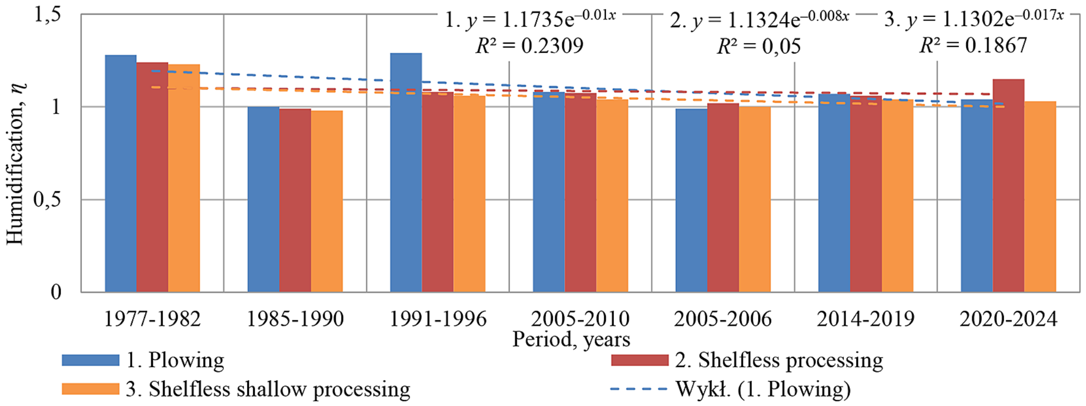

Figure 4. Dynamics of the moisture indicator of a metre-thick chernozem depending on the method of tillage for 1977–2024

With the non–mouldboard tillage the pattern of establishing correlations remained: in the 0–50 cm thickness $R = 0.70–0.71 \pm 0.02$, $R^2 = 0.49–0.50$ (for periods XI–II (*t*) and XI–III (*t*)), and the monthly correlation of the air temperature with the moisture reserves was $R = 0.65–0.78 \pm 0.02$, $R^2 = 0.43–0.61$. The moisture reserve in the metre–thick layer correlated with the reserve in the 0–50 cm layer at the level of $R = 0.87 \pm 0.02$, and in the 50–100 cm layer it weakened to an average level. In the non-mouldboard shallow tillage the established pattern of formation of correlations is weakened, and the correlation between the moisture reserve in a metre-thick layer and the moisture reserve in the half-metre layer was at the level of $R = 0.65–0.78 \pm 0.02$, $R^2 = 0.42–0.61$.

A normalized assessment of the average reserves of the productive moisture in the half–thickness and metre-thick chernozem showed that the moisture reserves themselves are similar during ploughing and non-moldboard tillage, while the moisture reserve during the shallow non-moldboard treatment tended to decrease by 5–6 mm. In the half-thickness of 0–50 cm the established trend remained for ploughing and non–mouldboard tillage, and in shallow tillage, a tendency towards a decrease in the supply of the productive moisture was found while in the half–thickness of 50–100 cm, the moisture reserves were the same.

The ratio of moisture reserves in the half–thickness during the non-moldboard tillage was 1.2 to 1, while during ploughing and shallow non–moldboard tillage the ratio was wider. In the thickness of 0–100 cm the oscillation coefficient during the non-moldboard treatment was at the level of $V_{os} = 25–28\%$, while during ploughing it increased to $V_{os} = 30\%$, which indicates a higher dynamic change in the moisture reserves in the spring period.

The normalized range of the moisture reserves in a metre–thick layer during ploughing and deep non–moldboard tillage was $\Delta_N = 16$ mm versus $\Delta_N = 12$ mm for shallow non–moldboard tillage. In the half–thicknesses of 0–50 cm and 50–100 cm the normalized range was the widest in the non-moldboard deep tillage: $\Delta_N = 10.0–15.8$ mm versus $\Delta_N = 7.0–7.3$ mm and $\Delta_N = 5–7$ mm during ploighing and non-moldboard shallow tillage, respectively. The coefficient of variation of the moisture reserves, regardless of the treatment method, in a thickness of 0–100 cm was $V_{var.} = 8.0–9.2\%$, and in a thickness of 0–50 cm with non-moldboard treatments $V_{var.}$ increases to 12.8–14.3%. In the thickness of 50–100 cm the variability was within the range of 9.5–10.7% (Table 1).

According to the asymmetry coefficient, regardless of the method of processing, the set of samples of the moisture reserves in spring has a left–hand slant but with the non-moldboard tillage the slant of the sample is more close to the centre of the distribution, $A_s = 1.35–1.78$ for ploughing and non–moldboard shallow tillage. In a thickness of 0–50 cm the asymmetry during ploughing and non-moldboard tillage is $A_s > 0.5$, and during shallow non-moldboard tillage $A_s = 2.44$, which

Table 1. Normalized supply of the productive moisture for various methods of soil tillage in 1977–2024

Thickness, cm	Average	Median	Amplitude range, mm		Normalized range, mm				Coefficient $V_{var.}$, %	Asymmetry	Excessc
	Mm		Min	Max	$L_{0.25}$	$L_{0.75}$	$L_{0.10}$	$L_{0.90}$			
					50 %		10 %				
Ploughing											
0–50	83.4	81.3	71.5	100.0	80.0	87.3	71.5	100	10.4	0.98	2.25
50–100	74.9	75.5	61.0	87.3	71.2	78.4	61.0	87.3	10.7	– 0.4	1.50
0–100	158	158	142	187	144	160	142	187	9.19	1.35	2.85
Non-moldboard deep tillage											
0–50	85.2	85.0	72.2	105.2	74.0	89.8	72.2	105	12.8	0.79	1.18
50–100	74.2	75.0	59.8	83.2	70.0	80.0	59.7	83.2	10.3	– 1.1	1.62
0–100	159	157	143	182	149	165	143	182	8.00	0.77	1.01
Non-moldboard shallow tillage											
0–50	78.3	74.0	71.0	103.2	73.0	78.1	71.0	103	14.3	2.44	6.14
50–100	75.5	77.0	62.0	85.2	71.6	78.8	62.0	85.2	9.52	– 0.9	2.03
0–100	153	150	139	182	144	156	139	182	8.86	1.78	3.98

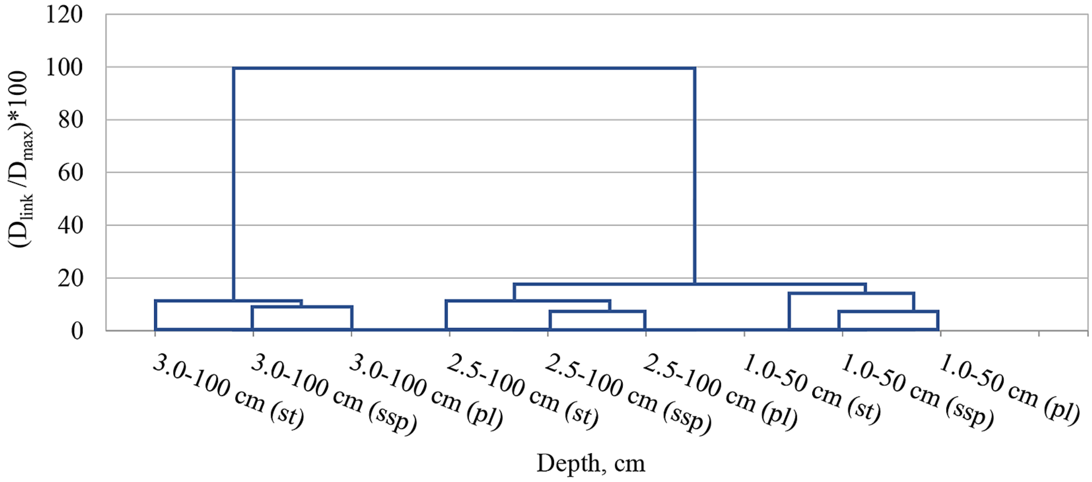

Figure 5. Clustering of the productive moisture reserves by the layers of soil thickness depending on the soil treatment

indicates a left-sided asymmetry, far from the normal distribution.

Excess of sample distribution during ploughing and no-mouldboard tillage E_s < 3, and with shallow non-moldboard cultivation E_s > 3 in soil layers 0–50 cm and 0–100 cm and in the thickness of 50–100 cm E_s = 2.03, which is 1.23–1.35 times higher. That is, with shallow, non-mouldboard treatment distribution of the moisture reserves in the sample in spring has a left-sided slant with a peaked distribution, which indicates the peculiarity of relatively deep cultivation in the formation of spring reserves of productive moisture, and the most stable formation of the productive moisture reserve is during deep, non-moldboard tillage.

The correlation coefficient between the moisture reserve in the 0–100 cm thickness and the reserve in the 0–50 and 50–100 cm thickness was at the level of $R = 0.75 \pm 0.02$, $R^2 = 0.56$ and $R = 0.59 \pm 0.02$, $R^2 = 0.35$. A similar regularity was established for the deep non-mouldboard tillage: $R = 0.83 \pm 0.02$, $R^2 = 0.69$, which is at the ploughing level. In a thickness of 50–100 cm the level of correlation corresponded to the surface treatment.

Clustering of 0–100 cm thickness and half–thickness 0–50 cm and 50–100 cm by the moisture reserves during the observation period showed that the moisture reserves during ploughing and non-moldboard tillage are combined into one cluster. Thus, the reserves in the 0–50 cm thickness during ploughing and non-moldboard tillage were close at the level of 5%, while the surface treatment clustered at the level of 18%.

A similar principle of clustering of the moisture reserves in the thickness of 0–100 cm was preserved: ploughing and non-moldboard tillage (5%) were combined into one cluster, and the surface treatment was clustered at the level of 10%, which indicates a significant difference in the formation of the moisture reserves during surface treatment.

The factor analysis showed that during ploughing the formation of the moisture reserves was linked to F_1 by an inverse strong correlation (R = –0.83–0.89 ± 0.02), while during the non–moldboard treatment the reserves in the thickness of 0–50 cm and 0–100 cm were linked to F_1 by level $R = -0.75$ and $R = -0.56$, similar to the surface treatment. The moisture reserves in the thickness of 50–100 cm were linked by F_2 with a direct significant correlation of the average level $R = 0.71$, which is explained by the similarity of the soil treatments according to the method.

CONCLUSIONS

Based on the obtained results, the following conclusions can be drawn:

1. In the period from 1977–1982 to 2020–2024 the amount of precipitation during the cold period of the year (November – February) increased by 71 mm, and during the period November – March – by 64 mm. In the months of the cold period of the year the amount of precipitation increased the most: in November (+15 mm), December (+28 mm), February (+38 mm) relative to the norm.

2. An increase in the average monthly air temperature in November and March was established by 1.44 °C and 1.52 °C, respectively. The average monthly air temperature for the period November–February in 2020–2024 was above 0 °C in the period from 2014 to 2024, while, according to the norm of observations, the average monthly air temperature was –1.3 °C and –0.58 °C, respectively. In the period from 1977 to 2024 the increase in the average daily air temperature occurred according to the increase in the reliable trends.
3. A direct correlation was established between the amount of precipitation for the cold period of the year (XI–II) and the average monthly air temperature at the level of $R = 0.73–0.75$, and with precipitation for the period XI–III the correlation weakened to an average level of $R = 0.63–0.70$.
4. The formation of spring reserves of the productive moisture in a metre-thick layer of chernozem, regardless of the method of cultivation during 46 years of observations, followed a downward trend, where during ploughing the intensity of the decrease in the moisture reserve was 2.1 times higher, compared to the non-moldboard treatment, which made it possible to form a higher moisture reserve of 8–10 mm. During shallow non-moldboard tillage in 2020–2024 the moisture, accumulated less by 16 mm, compared to deep non-moldboard treatment.
5. A direct correlation was revealed between the moisture reserves in the 0–50 cm layer and the average daily air temperature for the periods November – February and November – March: $R = 0.74–0.76 \pm 0.02$, $R^2 = 0.54–0.58$ (ploughing), $R = 0.70–0.71 \pm 0.02$, $R^2 = 0.49–0.50$ (non–moldboard tillage), and $R = 0.49–0.52 \pm 0.02$, $R^2 = 0.24–0.27$ (shallow non-moldboard treatment). The relationship between the amount of the atmospheric precipitation and the reserves of the productive moisture in a metre-thick layer, regardless of the method of processing, was at the level of direct correlation of the average level.

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