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Investigation of the Formation of Productive Moisture Reserves in the Thickness of Chernozem under the Forest-Steppe Conditions

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ABSTRACT

In this research paper analysis of the dynamics of the moisture content of the soil layer of chernozem and the accumulation of productive moisture reserves in its thickness was carried out, based on a set of data from 1947 to 2022. The change in the moisture regime within the periodically leaching water regime of the central part of the Left Bank Forest-Steppe of Ukraine has been analyzed. The analysis was performed under the crops: winter wheat, spring barley, corn for grain and silage, sugar beet, sunflower in crop rotations of various types to a depth of 0–100 cm to 0–300 cm. The purpose of the research was to establish the features of the formation of reserves of productive moisture in the chernozem thickness in a seasonal dimension upon the dynamics of climatic parameters against the background of their intra-century climatic variability for the conditions of the left bank part of the central Forest-Steppe of Ukraine. The generally accepted research methods were used: field, laboratory, mathematical, statistical and comparative calculation. Based on the conducted research, the following results were obtained. In order to form a non-flushing humidification regime, it is necessary to accumulate 117–135 mm in the thickness of 0–100 cm, which will correspond to a reserve in the thickness of 0–200 cm – 117–167 mm. For periodic flushing water regime 160–165 mm of moisture should be accumulated in the 0–100 cm thickness, which will provide a moisture reserve of 300 mm in the 0–200 cm thickness. The flushing water regime is formed with a moisture reserve in the thickness of 0–100 cm in the amount of 175 mm, which provides a moisture reserve in the thicknesses of 0–150 cm and 0–200 cm – 250 mm and 315 mm, which corresponds to the reserve of NV-VRK, and the thickness of 0–300 cm is saturated with moisture in an amount of more than 400 mm (HB-VK). Calculation of the paired correlation coefficients showed that an inverse strong correlation ($R > -0.70$) was found between the amount of precipitation for November – March and the supply of moisture to the meter layer of soil ($R > -0.70$), and the consumption of moisture from the soil for April – July correlated with the precipitation for November – March at the level of direct strong correlation ($R \geq 0.70$). The relationship with the moisture consumption from the moisture potential for April – August was at the level of an inverse strong correlation ($R < 0.70$), i.e. the higher the amount of precipitation during the autumn-winter-spring period (cold period), the less moisture is recorded in a meter-thick layer, the greater its consumption in April-July from the soil and the smaller consumption of moisture potential in April-August. The zone of the central Forest-Steppe is characterized by a periodically leaching water regime, when an average of 165 mm of moisture accumulates in a meter-thick chernozem, and therefore gravitates towards the values of the moisture reserve in the non-flushing water regime, which exceeds its value by 25 mm, which is a stable trend of aridization of soil conditions in spring period. The conditions of moistening chernozems, formed in a long-term time interval under the present climatic conditions of the central part of the Left Bank Forest-Steppe, cannot be shifted under the influence of agrotechnical influences beyond the parameters of the non-leaching or periodically leaching water conditions in the agrocenosis. There is manifested the process of the self-regulation stability of the Forest-Steppe zone against active aridization and the "attack" of the Steppe on the Forest-Steppe.

Keywords: productive moisture reserve, volatility, precipitation of the cold period, moisture index (indiator), factor analysis, climate, correlation, Left Bank Forest-Steppe.

INTRODUCTION

In the family of soils of a non-leaching and periodically leaching type of the water regime, typical chernozems of the Forest Steppe zone are the most optimally moistened since they do not have the disadvantages of soils of the leaching regime and the disadvantages of soils of the non-flushing mode of moisture, which contributes to the manifestation of the chernozem type of soil formation The formation of the water mode of chernozems in agrocenoses is determined primarily by changes in the nature of consumption by the crops of different depth and volume in the structure of the root system in agrocenoses. The water balance of chernozems in agrocenoses is formed at a lower level, compared to virgin chernozems [Ivanov et al., 2013]. In agrocenoses a consequence of "aridization" of chernozems is manifested – a lesser supply of soil moisture to the chernozem thickness than is possible under the particular climatic conditions. In chernozems of agrocenoses the water conditions are formed in two opposite directions: the total volume of moisture is reduced and, at the same time, the moisture of the lower horizons is not completely consumed, but accumulates in a long-term cycle [Kukharchuk et al., 2017].

The change in the hydrological profile of the chernozem decreases from the chernozem in the Forest-Steppe to a chernozem in the southern part of the Forest-Steppe zone, and the Northern Steppe, which is manifested in a decrease in the degree of stability of hydrological profiles relative to weather conditions: in virgin chernozems, the layer-by-layer moisture reserves for the dry and wet years deviate from the norm by 35%, in chernozems of the Forest-Steppe – by 10–15%, and under the present climatic conditions of global warming, deviations can reach up to 25–30%, or more, especially in the dry and acutely dry years [Medvedev et al., 2011; Demydenko, 2021; Lebedeva et al., 2013; Bazykina and Boyko, 2008; Kuznetsova, 2013, Lebedeva, 2002; Lebedeva, 2004].

In the Forest-Steppe the virgin chernozems and chernozems of agrocenoses differ in the nature of moisture consumption during the growing season: in th virgin analogues there is a gradual and consistent consumption of moisture from spring to autumn, as the drying front deepens deeper into the profile, and in the hydrological profile of chernozem in agrocenoses there are three zones with differently directed, relatively natural chernozems, the dynamics of soil moisture: the upper half meter is characterized by an unstable actively variable water regime, the middle part of the profile, corresponding to the accumulative carbonate horizon, is drier in all seasons, and the lower part of the profile is always, even in the dry years, wetter than in the virgin soils. [Demydenko, 2023; Belolipsky and Bulygin, 2009; Belolipsky and Polulyakh, 2015].

A negative change in the water-physical properties naturally leads to a decrease in the income items of the water balance of chernozems in agrocenoses and the moisture-releasing capacity of the agrohorizon, in which the bulk of the roots of agricultural crops are concentrated [Medvedev et al., 2013; Medvedev, 2013; Medvedev and Plisko, 2014; Kovalev et al., 2023]. The lack of atmospheric precipitation and the active physical evaporation of the soil moisture is facilitated by the low water permeability of the arable layer, which is close to critical (about 50 $mm \cdot h^{-1}$) and does not sufficiently ensure the absorption of moisture from the soil, the absorption of moisture from the cold period of the year in the spring and moisture from the intense rainfalls during the growing season of agrocenosis crops [Voytovik et al., 2023; Medvedev et al., 2012; Medvedev, 2017; Kramarev and Bandura 2023; Medvedev et al., 2013]. An important feature of the moisture supply to crops in agrocenoses during the growing season, associated with changes in the water-physical properties, is manifested in the sharply changing nature of the moistening of the arable layer: relatively short periods of water logging, when there are no cracks, occupied by air in the thickness of 0–30 cm, repeatedly alternating with periods of complete drying [Medvedev et al., 2013; Batey, 2009; Zabrodskyi et al., 2021; Medvedev and Bigun, 2013; Demydenko and Velychko, 2013; Armindo and Wendroth, 2016; Bacher et al., 2019; Khan et al., 2013; Hallett et al., 2013; Nichols and Samson-Liebig, 2011; Nichols and Toro, 2010; Lanying et al., 2006; Tang et al., 2010; Feiziene et al., 2007]. In the works of Mikhailovich et al. [Chendev et al., 2012] and Ciric et al. [Mihailovich et al., 2016] it was found that typical chernozems turned out to be more sensitive to climatic parameters (air temperature and amount of precipitation) than soils with an increased level of moisture (Fluvisols, Gleysols and Vertisols). Chernozems have higher values, characterizing the evaporation of soil moisture from the profile and its internal soil migration [Purton et al., 2015; Routschek et al., 2014; Demydenko and Shapoval, 2015; Demydenko, 2023].

The topicality of the investigation lies in the fact that, in order to deepen the fundamental understanding of the impact of global climate change upon the development and functioning of agrocenoses, it is necessary to conduct a comprehensive analysis of the available long-term data on the state of the moisture conditions of chernozems, especially on the formation of the spring wet reserves, within the non-flushing and periodically leaching water mode, and the nature of the formation of the spring moisture reserves of chernozems in agrocenoses is an indicator of the response to synoptic changes in the composition of the climatic factors in the central part of the Left Bank Forest-Steppe of Ukraine. It is important to make complex analysis of the obtained data in a long-term dimension (76 years) regarding the moisture accumulation on chernozems and climatic 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 factors and conditions.

Purpose of the study establishment of peculiarities of the formation of reserves of productive moisture in the thickness of chernozem in a seasonal dimension in the dynamics of climatic parameters against the background of their intra-century climatic variability for the conditions of the left bank part of the central Forest-Steppe of Ukraine.

MATERIALS AND METHODS

The research was 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 NSC (Institute of Agriculture of the National Academy of Sciences).

Geographically the research was implemented in the Middle Dnieper-Seim agro-soil district, covering the lands of the Kyiv, Poltava, Sumy, Chernigov and Cherkassy regions. The experiment was laid in the Drabovsky agro-soil region of the forest-steppe zone of the Left Bank lowland province, the northern subprovince on typical low-humus light loamy silt chernozems.

Analysis of the dynamics of the soil moisture and accumulation of the productive moisture reserves in the chernozem layer was conducted, based on a set of data from 1947 to 2022 (field research by I.G. Zakharchenko, Yu.T. Beskrovny, I.S. Shapoval), based on the materials from scientific research reports by Drabovskaya experimental station and Drabovsky experimental field of the Cherkasy State Agricultural Experimental Station. The change in the moisture conditions within the periodically leaching water of the central part of the Left Bank Forest-Steppe of Ukraine has been analyzed at the NSC (Institute of Agriculture of the National Academy of Sciences). Specifications were determined for the crops (winter wheat, spring barley, corn for grain and silage, sugar beet, sunflower) in the crop rotations of various types to a depth of 0–100 cm to 0–300 cm. There were analyzed the primary initial data about the moisture content as a percentage of weight to the dry soil. Long-term data on the moisture content of typical chernozem are unique data since observations throughout all years of observation, starting from 1947 to 2022, were and are done according to the unified methodology, and the determination of the soil moisture was based on the method of thermostat-gravity drying. Samples were taken with a drill to a depth from 0–100 cm to 0–300 cm in the layers of every 10 cm. The repetition when taking samples up to 0–100 cm is fourfold, and in the lower horizons – twofold.

The present period of the water condition research was based on: DSTU ISO 16586:2005. The quality of soil. Determination of the volumetric moisture of soil by the known packing density on the dry mass. The graviometric method. (ISO 16586:2003, IDT); DSTU ISO 15709:2004 The quality of soil. The soil moisture and unsaturated zone. Definition, designation and theory. (ISO 15709:2002, IDT). The frequency of observations of the moisture condition is during the warm period of the year, from March to November, once a month.

There were analyzed the data of meteorological parameters, obtained at the weather station of the Drabovsky experimental field [Demydenko and Shapoval, 2015]. The complex of weather data is presented by year on a monthly basis: the amount of precipitation, the average monthly air temperature, the sum of active and efficient temperatures and the calculated HTC indicator according to Selyaninov on a monthly basis. The assessment of climate parameters was based on the methodological principles of earlier publications [Demydenko, 2023b].

The results of the field research were subjected to statistical processing by the method of analysis of variance according, using statistical methods: dispersion, factorial and nonparametric statistics. The research results were summarized using the "STATISTICA-10" program.

RESULTS AND DISCUSSION

As it is commonly mistakenly believed, the water mode and the moistening mode of chernozems are synonymous. However, there are practically no investigations that through our actions and technological influences (soil cultivation, application of mineral and organic fertilizers, introduction of intensive crop rotations, etc.) we have an opportunity to change the water mode of chernozems in the central part of the Left Bank Forest-Steppe to the parameters when the water mode changes its zonal parameters. Under contemporary climatic conditions the moisture conditions of chernozems in the long-term time dimension determine the water conditions of the agricultural landscape, which is ultimately difficult to shift beyond the parameters of the non-leaching or periodically leaching water mode in the agrocenosis. There is a process of self-regulation of the stability of the Forest-Steppe zone against active aridization and the "attack" of the Steppe upon the Forest-Steppe [Feiziene et al., 2007].

Under the water mode should be understood a totality of all the phenomena of the flow of atmospheric moisture into the thickness of the chernozem, its movement, changes in the physical state and flows from the soil of the Forest-Steppe agrolandscape [Medvedev et al., 2011].

The moistening mode is a change in the elements of the water balance in the zone of vital activity of the root systems of the agricultural crop species of an agrophytocenosis within a certain type of water mode (non-flushing or periodically leaching) [Medvedev et al., 2011].

The moisture mode, in the most general terms, consists of the influx of moisture (precipitation, surface and soil inflow, condensation moisture, and so on) and its consumption (evaporation from the underlying surface, surface and underground runoff, transpiration of plants, and so on). The moisture mode of specific agrophytocenoses and their typological associations (phytocenoses) depends on many indirect local causes (relief conditions, soil, vegetation itself).

The reserve of the productive moisture in November for the period 1947–2023 averaged about 62 mm, and the median was 10 mm less. The amplitude range of the moisture reserve was 128 mm, and the normalized range was 24.5 mm (50%) and 33 mm (10%). At the same time the moisture reserve along the median tended to a greater extent to $L_{0.25}$ = 44 mm, which indicates a decrease in the moisture reserve in the meter layer of soil from 1947 to 2023. The coefficient of variation was 54.4%, which corresponds to a very high level of variation. The variability of the moisture reserves in the meter-thick soil layer in November exceeded the variability of precipitation 2.3 times. The amount of precipitation for April – August during the observation period averaged 257 mm, and beyond the median the average value of precipitation was 9 mm higher, and the amount of precipitation itself at the median tended to a greater extent towards the upper typical value, which is associated with their increasing amount since 1947 to 2023 (Table 1).

The amplitude range of precipitation for November – March was 145 mm, and the normalized A_H = 49 mm (beyond the 50% significance level). During the observation period the average amount of precipitation was about 191 mm, and its amount beyond the median was by 4 mm more. Amplitude range A_H = 129 mm. The coefficient of variation exceeded 20%, indicating insignificant variability. The average reserve of productive moisture in the meter layer of soil in April was about 156 mm, and the median value was about 158 mm. The amplitude range was 58 mm. The normalized range was 20 mm (50%) and 35 mm (10%), which is close to the normalized range of the moisture reserves of 0–100 cm in November.

The coefficient of variation of the moisture reserves in April was at the level of 10%, and, compared to the variation of reserves in November, it was 5.3 times less. The variation in precipitation in November – March was 2.3 times higher than the existing reserves of the productive moisture in April. On average, during the cold period of the year, the soil accumulated about 94 mm of moisture from the atmospheric precipitation, and beyond the median–5 mm more.

The moisture accumulation in the soil tended to a greater extent towards the upper typical value ($L_{0.25}$ = 105 mm) indicating that the less moisture was accumulated before entering winter, the greater the amount of moisture from precipitation was absorbed by the soil layer in spring, which is

Table 1. Typification of the atmospheric precipitation, reserves and consumption of the productive moisture from the soil for 1947–2023

Parameters	Mean	Median	Amplitude range		Normalized range				Coefficient of variations
			Min	Max	$L_{0.25}$	$L_{0.75}$	$L_{0.10}$	$L_{0.95}$	
Precipitation, mm									
XI – III	190.6	195.0	121.0	266.0	160.5	209.0	128.0	257.0	23.2
IV – VIII	257.2	266.0	200.0	292.0	239.5	277.0	218.0	285.0	11.0
Reserve of the productive moisture in 0–100 cm, mm:									
XI – November	61.6	51.5	32.0	160.0	44.0	68.5	42.0	75.0	54.4
IV – April	155.7	157.5	130.0	188.0	145.0	165.0	135.0	170.0	10.3
Moisture that entered the soil in spring	93.9	99.0	26.0	118.0	91.5	105.0	80.0	115.0	25.3
P_t	421.1	419.5	362.0	473.0	405.5	442.0	388.0	457.0	7.3
VII – July	50.1	45.5	25.0	81.0	39.0	63.0	35.0	70.0	32.8
Moisture consumption from soil, mm									
IV – VII	–105	–105	–125	–90.0	–108	–99.5	–122	–99.0	9.3
IV – VIII from P_t, mm	362.7	376.0	307.0	391.0	340.5	384.0	317.0	389.0	8.4
Evaporation, mm	428.4	392.5	325.0	561.0	385.0	507.5	350.0	535.0	18.2
$K_{Z.V}$	1.02	1.02	0.75	1.41	0.88	1.13	0.77	1.22	18.56

Note: $K_{Z.V}$ – moisture coefficient; P_t – moisture potential – moisture reserve in April in a meter layer of soil + precipitation for April – August (mm).

more characteristic of earlier observation periods, while in 2020–2023 the pattern was reversed. The amplitude range of the moisture input into a meter-long thickness was 92 mm, and the normalized range was 13 mm (50%), and 35 mm (10%) with a coefficient of variation of more than 25%, which indicates a high level of variation.

The average potential moisture reserve (reserve in April in a meter layer of soil + precipitation for April – August) was 421 mm, and the median was about 420 mm. The amplitude range was 111 mm, and the normalized range was 36 mm (50%) and 69 mm (10%). The moisture potential along the median was more inclined to $L_{0.25}$ = 405.5, which indicates a steady downward trend in its level from 1947 to 2023. The coefficient of variation of the moisture potential was 7.3%, which is 3.5 times lower in variability than the variability of the productive moisture accumulation in April, indicating a high level of stabilization of the growing season conditions by precipitation in April – August (Table 1).

The reserve of the productive moisture in a meter-thick layer in July during the observation period was about 50 mm, and behind the median it was 5 mm less, which caused the value to decline to $L_{0.25}$ = 39 mm, indicating a decrease in the amount of moisture in the meter-long soil layer in July from 1947 by 2023. The amplitude of the moisture reserve in July was 56 mm, and the normalized range was 24 mm (50%) and 35 mm (10%). The coefficient of variation in the formation of the moisture reserves in the 0–100 cm layer in July exceeded 30%, which indicates a high level of variability, exceeding the variability in April by 3.2 times, and was 1.65 times less relative to November.

The consumption of the productive moisture reserves from a meter-thick soil layer for April–July, according to the average and median, was 105 mm. The consumption of moisture from the soil, according to both statistical indicators, tended to the upper typical value ($L_{0.75}$ = 122 mm), which indicates intensive consumption of moisture from the soil over the entire observation period. The amplitude range of moisture consumption from the soil was Δ_a = 35 mm, and the normalized one was $\Delta_н$ = 8.5 mm (50%) and $\Delta_н$ = 23 mm (10%). The coefficient of variation in the consumption of the productive moisture reserves was less than 10%, which indicates a constant increase in the moisture consumption from the soil thickness over time.

The average consumption of the moisture potential for April – August was 363 mm, and, according to the median, it was 13 mm more. The median flow rate tended to the upper typical value $L_{0.75}$ = –384 mm, which indicates an increase in the moisture potential flow rate from 1947 to 2023. The amplitude range of the moisture consumption was Δ_a = 84 mm, and the normalized range was $\Delta_{н}$ = 43 mm (50%) and $\Delta_{н}$ = 72 mm (10%). The closeness of the flow rate at $\Delta_{(10\%)}$ to the amplitude range indicates the stability of this parameter, reflected by the coefficient of variation, which, being less than 10%, was 1.2 times lower than the moisture flow from the soil.

The average evaporation for April–August was 428 mm, and in terms of amplitude the evaporation reached a maximum value of 561 mm; the minimum value is 325 mm. The amplitude range was Δ_{a} = 236 mm. The normalized range of evaporation was $\Delta_{н}$ = 122 mm (50%), and $\Delta_{н}$ = 185 mm (10%), and the coefficient of variation of evaporation was 18.2%. The median value of evaporation tended to a greater extent towards the upper typical value ($L_{0.75}$ = 507.5 mm), which indicates an increase in evaporation from 1947 to 2023.

The average value of the moisture coefficient ($K_{sv'}$) was at the level of $K_{sv'}$ = 1.02 (optimal humidity), and the median value of $K_{sv'}$ = 0.98, which tended more toward the lower typical value ($L_{0.25}$ = 0.88) or increasing drought conditions. Amplitude range $\Delta_{kz(a)}$ = 0.66, and normalized $\Delta_{н/р}$ = 0.25 (50%) and $\Delta_{н/р}$ = 0.45 (10%). In addition, the coefficient of variation $K_{sv'}$ amounted to 18.6%, which indicates a progressive increase in drought conditions over the observation period from 1947 to 2023.

During the observation period (1947–2023), the moisture indicator for November averaged P_z = 0.42, and the median P_z = 0.35, with an amplitude range $\Delta_{pz(a)}$ = 0.90 and normalized $\Delta_{pz(n)}$ = 0.16 (50%) and $\Delta_{pz(n)}$ = 0.23 (10%) with a high level of the coefficient of variation exceeding 50%. The average value of P_z in April was P_z = 1.05, which corresponds to optimal moisture. By the amplitude range $\Delta_{pz(a)}$ = 0.71, while the normalized range at the 50% and 10% significance level was at the level of $\Delta_{pz(n)}$ = 0.12 and $\Delta_{pz(n)}$ = 0.42, respectively, with a level of variation of the indicator of 17.5%, which indicates a stable level of P_z in April for the entire observation period with a weak tendency towards a decrease in P_z in the period 2010–2023 (Table 2).

On average, the humidity indicator in July was 1.23 times lower than the value in November, and in relation to April, P_3 was 3.1 times lower. The amplitude range was $\Delta_{pz(n)}$ = 0.38, and the normalized $\Delta_{pz(n)}$ = 0.16 (50%) and $\Delta_{pz(n)}$ = 0.25 (10%) with an increase in the coefficient of variation to 32.9%, which indicates a rapid increase in aridization in the meter-long thickness soils in July (Table 2).

Table 2. Typification of climatic parameters of the conditions for the formation of the humidity mode for 1947–2023

Parameters	Mean	Median	Amplitude range		Normalized range				Coefficient of variations
			Min	Max	$L_{0.25}$	$L_{0.75}$	$L_{0.10}$	$L_{0.95}$	
					50% significance level		10% significance level		
Humidity index, P_z									
*P_z for XI	0.42	0.35	0.21	1.11	0.30	0.46	0.28	0.51	56.01
P_z for IV	1.05	1.10	0.65	1.36	1.01	1.13	0.79	1.21	17.48
P_z VII	0.34	0.31	0.17	0.55	0.27	0.43	0.24	0.48	32.92
**D_v XI	0.59	0.65	0.00	0.81	0.54	0.70	0.49	0.72	35.04
D_v VII	0.66	0.69	0.45	0.83	0.57	0.73	0.52	0.76	17.02
Average daily air temperature, t °C									
IV–V	12.3	12.1	10.4	14.5	11.5	13.2	11.2	14.3	10.2
V–VIII	19.9	19.9	16.7	22.0	19.3	21.2	18.5	21.6	7.40
IV–VIII	16.27	15.90	14.60	18.00	15.40	17.35	15.10	18.00	7.19
Sum of active temperatures									
IV–V	766	753	685	875	705	829	695	875	9.35
V–VIII	1857	1837	1702	2025	1771	1959	1720	2000	5.93
IV–VIII	2610	2553	2355	2955	2473	2760	2405	2860	7.20
Hydrothermal moisture indicator (HTC according to Selyaninov)									
IV–V	1.00	0.95	0.65	1.51	0.79	1.19	0.69	1.29	26.3
IV–VIII	0.99	1.00	0.76	1.21	0.91	1.09	0.79	1.13	13.5
VI–VIII	0.97	1.06	0.61	1.18	0.78	1.13	0.66	1.15	21.2

Note: *P_z – moisture indicator; **D_v – moisture deficit, mm.

The average moisture deficit coefficient (D_v) in November was $D_v = 0.59$ with a median value of $D_v = 0.65$, which indicates that the D_v indicator in November was close to the upper typical value, and a high range in the amplitude and normalized values was associated with a high value of the coefficient of variation exceeding 30%. The moisture deficit coefficient in July was $D_v = 0.66$, and with a median value of $D_v = 0.69$, which tended towards the upper typical value, and the level of amplitude and normalized value corresponding to D_v in November provided a coefficient of variation of 17%, which indicates the formation of drier conditions in the soil in July (Table 2).

The normalized HTC parameter, according to Selyaninov, shows that in the period April–May over the observation period (75 years) it was HTC = 1.0, and behind the median HTC = 0.95, which was more inclined to the lower typical value and the formation of arid conditions. According to the amplitude range, the spring period was characterized by excessively moist conditions (GTC > 1.5) to arid (GTC = 0.79) with amplitude range $\Delta_{GTC(a)} = 0.86$. The normalized range was $\Delta_{GTC(n)} = 0.40$ (50%) and $\Delta_{HTC(n)} = 0.60$ (10%) with a coefficient of variation of more than 25%, which indicates high variability and an increase in high droughts, especially since 2010. The average HTC value for the summer period was HTC = 0.97 with an amplitude range $\Delta_{GTC(a)} = 0.57$ and a normalized range $\Delta_{GTC(n)} = 0.35$ (50%) and $\Delta_{GTC(n)} = 0.49$ (10%) with a coefficient of variation of more than 20%, which is 1.2 times lower. On average for April–August, HTC = 0.99 with an amplitude range $\Delta_{HTC(a)} = 0.45$. The HTC (State Customs Committee) indicators for the minimum value of the spring and summer periods were HTC = 0.61–0.76 (dry conditions), and with a normalized range according to $L_{0.1}$ and $L_{0.25}$, HTC = 0.78–0.91 and HTC = 0.66–0.79, which corresponds to arid and acutely arid conditions. The indicator of hydrothermal conditions for the summer period had a coefficient of variation of 13.5%, which indicates the stability of the prevailing conditions for 1947–2023 with a persistent tendency of increasing the dry conditions in the summer period.

It was established that between the amount of moisture in a meter thick layer in November and the reserve in April the lower the moisture reserve before entering winter, the higher its reserve in April and July (R = 0.78–0.84). A direct correlation was established between the April soil moisture reserves and the July moisture reserves (R = +0.82).

A direct correlation was established between the precipitation for April–August and the consumption of moisture potential for this period (R = 0.95). A direct correlation was found between the reserves of the productive moisture in November and April and the moisture indicators (R = 0.65–0.84), and an inverse strong correlation with the moisture deficiency (R = –0.80–0.84). The moisture reserve in the soil in July correlated with P_z in November by a direct strong correlation R = +0.83, in April R = +0.65, and in July at the level of direct functional connection.

The correlation between the humidity indicators in July and April was at the level of direct average correlation, and between P_z in November and July, the correlation was at the level of direct strong correlation (R = +0.83). The relationship between the soil moisture deficit and P_z

Table 3. Matrix of paired correlation coefficients between the parameters of input and output of the atmospheric moisture and the soil moisture

Parameters	Precipitation for November-March, mm	November, mm	April, mm	Receipts for November-April, mm	Precipitation for April-August	July, mm	Soil consumption for April-July, mm	Consumption for April-August according to potential,mm
Precipitation for XI–III, mm	1.00	–	–	**–0.74**	**–0.58**	–	**0.77**	**–0.78**
*November (0–100 cm), mm		1.00	**0.78**	**–0.91**	–	**0.84**	–	–
*April (0–100 cm), mm			1.00		–	**0.82**	–	–
Moisture intake for X–IV, mm				1.00	**–**	**–0.64**	–	**0.62**
Precipitation April-August IV–VIII, mm					1.00	**–**	–	**0.95**
*July (0–100 cm), mm						1.00	–	–
Consumption for I–VII from soil, mm							1.00	–
Consumption I–VIII from Пт, mm								1.00

Note: *moisture reserve in the soil, mm.

for November – July, was reversed at the level of strong correlation: $R = 0.65 – 0.87$ (Table 4).

The calculation showed that correlations were found between the evaporation and thermal climate indicators. With SCC (IV – VIII) and SCC (VI – VIII) at the inverse average correlation level ($R = 0.74–0.96$). The relationship between the moisture evaporation for April – August and the humidification coefficient was at the level of an inverse strong correlation ($R = –0.91$), (Table 5).

The block of thermal indicators (the average monthly air temperature and the sum of active temperatures) across observation periods correlated with each other at the level of direct correlations ($R = 0.86–0.99$), and the K_{sv} indicator had correlations with the block of thermal indicators at the level of strong inverse correlation ($R = –0.83–0.91$). The relationship between the moisture index (K_{sv}) and SCC for the spring-summer period was at the level of direct strong correlation ($R = 0.68–0.72$) (Table 5).

The factor analysis showed that using factor F_1 as the main component, according to a direct strong correlation, forming a direct functional connection, the moisture reserve in November, April, July and P_z for the indicated months and the moisture coefficient were linked. According to the inverse correlation the indicators of the moisture deficit in November and July, the evaporation and temperature indicators were linked to F_1: the average daily temperature in April – May (t, °C) and April – August (t, °C), and the sum of the active temperatures for June – August and April – August. The indicated directional parameters are inversely functional in nature. The ratio of the backward and forward connections is 1 to 1, which is the most weighted (Table 6).

According to factor F_2, by direct correlation, the link to the factor was precipitation for November – March, and by inverse correlation, the link to factor F_2 was with the indicators: the precipitation receipt for November – April, precipitation for April – August, the moisture consumption April – September, SCC for April – August. The link by F_3 and F_4 was a direct correlation between the moisture potential and the moisture consumption for April – July. In total, there were 14 direct and reverse connections for F_1, 6 for F_2, and 3 for F_3 and F_4. A total of 23 connections with a ratio of the forward and the backward connections of 0.76 to 1. Factors F_1 and F_2 account for 37% and 33% of the total variance, and F_3 and F_4 account for

Table 4. Matrix of paired correlation coefficients between the moisture indicators and the soil moisture deficit

Climatic parameters	P_z for XI	P_z for IV	P_z VII	D_v XI	D_v VII
P_z for XI	1.00	**0.63**	**0.83**	**-0.96**	**-0.83**
P_z for IV		1.00	**0.65**	**-0.66**	**-0.65**
P_z VII			1.00	**-0.87**	**-0.95**
XI				1.00	**0.87**
D_V VII					1.00

Note: P_z – moisture indicator; D_v – indicator of moisture deficiency.

Table 5. Matrix of paired correlation coefficients between the climatic parameters of the atmospheric soil moisture supply and consumption

Parameters	Volatility, mm	State Customs Committee (IV–VIII)	State Customs Committee (VI–VIII)	April–May, T°	Summary T°, April–May	T°, June–August	Summary T°, June–August	T° April–August	Summary T°, April-August	K_{sv}
Volatility, mm	1.00	**–0.64**	**–0.66**	**0.91**	**0.74**	**0.87**	**0.96**	**0.96**	**0.95**	**–0.91**
SCC (IV–VIII)		1.00	**0.86**	**–**	**–**	**–0.60**	**–0.59**	-	-	**0.72**
SCC (VI–VIII)			1.00	**–**	**–**	**–0.63**	**–0.66**	**–0.61**	**–0.58**	**0.68**
April-May, T°				1.00	0.69	**0.86**	**0.89**	**0.97**	**0.97**	**–0.77**
Summary T° for IV–V					1.00	**–**	**0.66**	**0.68**	**0.72**	**–**
T° for VI–VIII						1.00	**0.93**	**0.92**	**0.90**	**–0.83**
Summary T° for VI–VIII							1.00	**0.97**	**0.96**	**–0.91**
T° April-August								1.00	**0.99**	**–0.86**
Summary T° for IV–VIII									1.00	**–0.86**
K_{sv}										1.00

Table 6. Factor load of the water regime formation parameters

Parameters	Factor – 1	Factor – 2	Factor – 3	Factor – 4
Precipitation for November–March, mm	0.02	**0.81**	– 0.38	0.35
November, mm	**0.73**	0.64	– 0.02	0.01
April, mm	**0.78**	0.30	0.43	– 0.29
Inflow for November–April, mm	– 0.52	**– 0.72**	0.33	– 0.20
Precipitation for April–August, mm	– 0.11	**– 0.71**	0.40	0.50
Precipitation + moisture reserve in April, (potential)	0.00	– 0.15	**0.87**	0.05
July, mm	**0.71**	0.56	0.38	0.15
Soil consumption for April–July, mm	– 0.08	0.45	– 0.08	**0.72**
Consumption for April–August according to potential	– 0.08	**– 0.80**	0.39	0.23
P_z for XI	**0.73**	0.65	– 0.02	– 0.01
P_z for IV	**0.70**	0.16	0.40	– 0.49
P_z VII	**0.71**	0.55	0.37	0.15
D_v XI	**– 0.76**	– 0.62	– 0.02	– 0.01
D_v VII	**– 0.71**	– 0.55	– 0.37	– 0.15
Volatility, mm	**– 0.83**	0.49	0.21	– 0.08
SCC (IV–V)	0.14	0.18	– 0.10	0.63
SCC (IV–VIII)	0.30	**– 0.83**	0.24	0.38
SCC (VI–VIII)	0.31	**– 0.84**	0.20	0.06
April-May, T°	**– 0.82**	0.40	0.31	0.09
Summary T° April–May	– 0.42	0.47	0.59	– 0.08
T° June–August	– 0.67	0.60	0.18	0.10
Summary T° June–August	**– 0.77**	0.53	0.21	0.01
T° April–August	**– 0.83**	0.48	0.25	0.06
Summary T° April–August	**– 0.80**	0.49	0.27	– 0.00
K_{sv}	**0.80**	– 0.50	0.14	0.17
Expl.Var	9.33	8.19	2.93	1.98

20%, which is 90% of the total factor variance. F_1 and F_2 account for 20 indicators, which is 86% of their total number. It is the parameters, associated with F_1 and F_2 that are the main component parameters that need to be taken into account when forming a model ensuring the conditions for the formation of the soil water regime in the central Forest-Steppe of Ukraine.

During the observation period in the thickness of 0–50 cm, the average reserve of the productive moisture was about 81 mm, and the median value was 80 mm. The normalized typical range of the moisture reserve was 21.5 mm at 50% probability and 45.0 mm at 10% probability. The median reserve tended to the average value, which indicates the stability of the moisture accumulation in the 0–50 cm soil layer. The coefficient of variation was less than 30% (Table 7).

In a thickness of 50–100 cm the moisture reserve in terms of the average and median values was almost equal, and the amplitude range was 128 mm. The normalized range at the 50% and 10% significance level was 25.5 mm and 57.5 mm, which is 1.2–1.3 times greater. In addition, the coefficient of variation was 1.3 times higher, compared to the thickness of 0–50 cm. In general, in the thickness of 0–100 cm the average moisture reserve was about 155 mm, and the median was 2.7 mm more. The normalized range at the 50% and 10% probability level was 40.3 mm and 51.5 mm, respectively, and the coefficient of variation was 25%.

In a thickness of 100–150 cm the average moisture reserve was 36.8 mm, while the median was 31.0 mm, which is 1.2 times less. The amplitude range was 62 mm, and normalized by 50%, and the 10% significance level was 43 mm and 54 mm. If the normalized range in the 0 – 50 cm thickness relative to the 50–100 cm thickness was 2.1–2.3 times less, then in the 100–150 cm thickness the reserves were 1.7 times less at a significantly lower quantitative level. Besides, the coefficient of

Table 7. Typification of layer-by-layer reserves of the productive moisture under sowing of winter wheat for 1947–2023

Thickness of the soil layer, cm	Mean	Median	Amplitude range		Normalized range				Coefficient of variations, %
			Min.	Max.	50%		10%		
					$L_{0.25}$	$L_{0.75}$	$L_{0.10}$	$L_{0.90}$	
			Δ_a = max – min		$\Delta_n = L_{0.75} - L_{0.25}$		$\Delta_n = L_{0.90} - L_{0.10}$		
0–50	80.8	80.0	11.2	231.4	70.7	92.2	60.0–	105.0	26.9
50–100	74.5	75.0	69.4	197.4	61.5	87.0	42.5	100.0	34.6
0–100	155.3	158.0	66.7	232.2	135.0	175.4	117.6	193.0	20.0
100–150	36.8	31.0	6.0	68.0	18.0	61.0	11.0	65.0	56.0
0–150	195.9	193.0	111.0	272.0	151.0	248.0	135.0	264.0	25.9
150–200	39.3	44.0	19.0	56.0	25.0	53.0	20.0	55.0	36.1
0–200	253.1	300.5	141.0	321.0	177.0	316.0	167.0	319.0	28.8
200–250	44.8	44.0	37.0	55.0	40.0	49.0	37.0	55.0	14.1
250–300	44.5	46.0	30.0	58.0	41.0	47.0	30.0	58.0	17.7
0–300	402.1	397.5	368.0	434.0	395.5	414.5	368.0	434.0	4.8

variation increases by 1.6–2.1 times relative to the thickness of 0–50 cm and 50–100 cm and indicates a large variability in the saturation with moisture of the thickness of 100–150 cm, which gives grounds to consider this thickness as indicative in the formation of the type of the water condition in different years of observation.

The average moisture reserve in the 0–150 cm thickness was 195.9 mm, and, according to the median, it was 2.6 mm less. The amplitude range reached 161 mm, and the normalized range reached 97 mm (50%) and 129 mm (10%) with a coefficient of variation of 25.9%.

The thickness of 150–200 cm accumulated on average 39.3 mm, and the median was 4.8 mm more. The normalized range at the 50% and 10% level of significance was 28 mm and 35 mm, which is 1.5 times lower than in the 100–150 cm thickness, with a coefficient of variation that was 1.6 times lower, which indicates less moisture accumulation in the 100 cm thickness–150 cm, compared to a thickness of 150–200 cm, that is, wetting of the specified thickness is limited.

On the whole, the moisture reserve in the thickness of 0–200 cm was 253 mm, while in the median it was 300 mm. The amplitude range was 180 mm, and the normalized ranges were 139 mm (50%) and 152 mm (10%). The normalized ranges in the indicated thickness account for 31% and 16% of the change in the moisture reserves relative to the 0–150 cm thickness, which indicates a decrease in the level of the moisture saturation in the 0–200 cm thickness. Enrichment by moisture occurs to 69% and 84% due to the thickness of 0–150 cm, which affected the coefficient of variation of the moisture reserve in the thickness of 0–200 cm, which was at the level of 28.8% and which corresponds to a high variation and indicates a high periodicity of saturation of this thickness soils up to 200 cm.

The average moisture reserve in the thicknesses of 200–250 cm and 250–300 cm was 44.5–44.8 mm, and the median was 44–46 mm. The amplitude range was 18% and 28%, and the normalized range was 6–9 mm (50%) and 18–28 mm (10%), which is less, on average, by 1.6 and 3.7 times relative to the amplitude and normalized range at the 50% significance level and 1.5 times less than the normalized range at a 10% significance level in a thickness of 150–200 cm. Besides that, the coefficient of variation in the thickness of 200–300 cm was 2.3 times less, which indicates a stable undersaturation of moisture in the formation.

On the whole, in the thickness of 0–300 cm the average moisture reserve was 402.1 mm, while in the median was 4.6 mm less. The amplitude range was 69 mm, which is 2.3–2.6 times less relative to the thicknesses 0–100 cm, 0–150 cm, and 0–200 cm. The normalized range at the 50% significance level was 2.1, 5.1 and 7.3 times less, and the normalized range at the 10% significance level was 1.14, 1.95 and 2.3 times less relative to thicknesses 0–100 cm, 0–150 cm and 0–200 cm. The coefficient of variation was 4.8% in the 0–300 cm thickness, which is 5.2–6.0 times less than in the 0–100 cm, 0–150 cm and 0–200 cm thicknesses and it is evidence that active moisture circulation in the soil is formed to a depth of 0–200 cm, and, in general, the moisture reserve in the 0–300 cm thickness remains relatively constant, and the variation in the total moisture reserve is determined to a greater extent by the reserves in the 0–100 cm and 0–150 cm thicknesses and to a lesser extent in the 0–200 cm thickness cm. Normalization of the moisture reserves for thicknesses of 0–100 cm, 0–150 cm, 0–200 cm and 0–300 cm allowed one to establish the pattern of formation of the moisture reserves, which are diagnostic in the formation of the moisture mode in various years of observation.

Calculation of paired correlation coefficients among the moisture reserves in the thicknesses 0–100 cm, 0–150 cm, 0–200 cm and 0–300 cm showed that the moisture reserve in the thickness 0–100 cm is determined by the moisture reserve in the thickness 0–50 cm (R = 0.81 ± 0.02, R^2 = 0.65), in the thickness 0–150 cm – moisture reserve in the thickness 0 – 50 cm and 0 – 100 cm (R = 0.79–0.94 ± 0.02, R^2 = 0.62–0.88), in the thickness 0–200 cm – reserves in the thicknesses 0–100 cm and 0–150 cm (R = 0.80–0.87 ± 0.02, R^2 = 0.64–0.75), and in the thickness 0–300 cm – reserves in the thicknesses 0–100 cm, 0–150 cm, 0–200 cm and in strata 200–250 cm and 250–300 cm (R = 0.67–0.87 ± 0.02, R^2 = 0.44–0.75) (Table 8).

The moisture reserve in the half-thicknesses of 150–200 cm directly correlated with the moisture reserve in the thickness of 50–100 cm, and the moisture reserve in the thickness of 200–250 cm correlated with the reserve in the thickness of 0–200 cm at the level of direct strong correlation (R = 0.74 ± 0.02, R^2 = 0.54). It should be remarked that the deeper the stratum is located, where moisture is localized due to wetting, the weaker the correlation with the more superficial horizons. Thus, the correlation between the moisture reserve in the thickness of 0–100 cm and the reserve of 0–300 cm was R = 0.67 ± 0.02, and increased with depth to R = 0.80–0.87 ± 0.02, and between the reserve in the thickness of 250–300 cm and the reserve in three-meter thickness decreased to the level of R = 0.68 ± 0.02, which indicates that the decisive role in the enrichment of moisture in the 0–300 cm thickness is played by the increasing moisture reserves in the 0–150 cm, 0–200 cm and 200–300 cm thicknesses, which is a sign of through spring wetting.

The factor analysis showed that according to factor F_1, the correlation was based on moisture reserves in the thickness of 0–100 cm, 0–150 cm, 0–200 cm and 0–300 cm at the level of inverse strong correlation R = –0.87–0.96 ± 0.02, R^2 = 0.75–0.92. The moisture reserve in the 200–250 cm layer was tied to F_1 at the level of inverse strong correlation. According to factor F_2, the moisture reserves were tied at the level of inverse strong correlation (R = –0.72–0.85) with half-thicknesses of 50–100 cm and 150–200 cm. The total variance for F_1 and F_2 was 74%. According to factor F_3, the moisture reserve was tied to the thickness of 100–150 cm according to a direct strong correlation, which indicates that the thickness of 100–150 cm in terms of the moisture reserve has a functional role in the formation of the water regime, and other soil thicknesses play a self-regulating role in the formation of the water mode.

The cluster analysis made it possible to establish a relationship between the half-thicknesses (0–50 cm, 50–100 cm, 100–150 cm, 200–250 cm, 250–300 cm) and thicknesses 0–100 cm, 0–150 cm, 0–200 cm and 0–300 cm. These objects formed two clusters: half-thickness and thickness. Thus, the half-meter soil layers formed a cluster at the level of 25% similarity, and half-thicknesses of 100–150 cm, 200–250 cm, 250–300 cm formed

Table 8. Matrix of paired correlation coefficients among the layer-by-layer reserves of the productive moisture

Depth, cm	0–50 cm	50–100 cm	0–100 cm	100–150 cm	0–150 cm	150–200 cm	0–200 cm	200–250 cm	250–300 cm	0–300 cm
0–50	1.00	– 0.32	**0.81**	– 0.21	**0.79**	– 0.28	0.47	0.27	0.36	0.47
50–100		1.00	0.29	– 0.22	0.23	**0.72**	0.54	0.56	– 0.34	0.32
0–100			1.00	– 0.35	**0.94**	0.16	**0.80**	0.62	0.16	**0.67**
100–150				1.00	– 0.01	0.10	0.04	– 0.12	0.61	0.23
0–150					1.00	0.20	**0.87**	0.61	0.39	**0.80**
150–200						1.00	0.66	0.54	– 0.00	0.51
0–200							1.00	**0.74**	0.30	**0.87**
200–250								1.00	0.36	**0.85**
250–300									1.00	**0.68**
0–300										1.00

clusters at the level of 18% and 10% degree of similarity, and the unification of all half-thicknesses occurred at a level of about 29. Thicknesses of 0–100 cm, 0–150 cm, 0–200 cm and 0–300 cm were clustered with a higher degree of similarity, from 58% to 70%. Clusters of thicknesses and semi-thicknesses were clustered at a high distance from each other (> 90%) (Fig. 1).

There is a probability (10%) of the formation of a through leaching mode of water when the moisture reserve in the thickness of 0–100 cm exceeds 190 mm (> NV) at P_z = 1.33, in the thickness of 0–150 cm – 265 mm (> NV) at P_z = 1.21, 0–200 cm – 320 mm (> HB) at P_z = 1.08 and in the thickness of 0–300 cm – 435 mm (0.85% HB) at P_z = 0.98.

To determine the moisture mode within the periodically leaching water mode and the required moisture charge of the soil layer in April, the moisture supply parameters were determined (Table 9).

Mode of a very dry and arid moisture

The moisture reserves in the 0–100 cm thickness are 117–135 mm, which corresponds to 0.68–0.76% *HW* with a moisture index P_z = 0.80–0.93 (arid and slightly arid conditions). The moisture reserve ≤ *VRK*. In a thickness of 0–150 cm, the moisture reserve is 135–151 mm (< VRK); P_z = 0.61–0.69% (moderately dry conditions). In a thickness of 0 – 200 cm the moisture reserve is 167–177 mm (< VRK) or 0.48–0.51% HW at P_z = 0.56–0.60 (acute and arid conditions). The moisture reserve in the 0–300 cm thickness is 368–396 mm (0.71–0.76% HW) at P_z = 0.83–0.90. Moisture reserve < VRK.

Optimal humidification mode

The moisture reserve in the thickness of 0–100 cm is 160–165 mm at saturation of

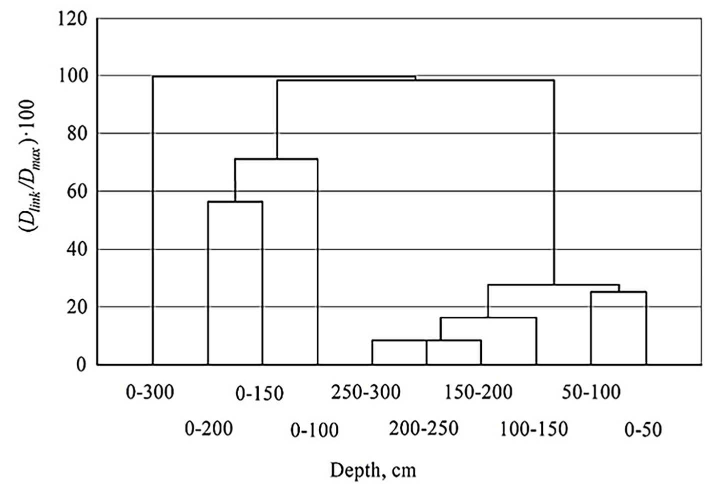

Figure 1. Clustering of the constituent horizons of the soil column within the periodically leaching modes of water

Table 9. Parameters of the mode of the soil moisture within the mode of periodically leaching water of the central part of the Left Bank Forest-Steppe

Soil layer, cm	Mode of aery dry and dry humidification				Mode of optimal humidification		Wet and overly wet humidification mode			
	Insignificant soaking $L_{0.10}$		Shallow soaking $L_{0.25}$		Moderate soaking $L_{0.50}$		Deep soaking $L_{0.75}$		Through soaking $L_{0.90}$	
	10% probability		50% probability						10% probability	
	Moisture reserve, mm	% HB / P_z	Moisture reserve, mm	% HB / P_z	Moisture reserve, mm	% HB / P_z	Moisture reserve, mm	% HB / P_z	Moisture reserve, mm	% HB / P_z
0–100	117 / <ВРК	0.68 / 0.80	135 / >ВРК	0.76 / 0.93	160 / >ВРК	0.92 / 1.08	175 / НВ	1.02 / 1.20	193 / >НВ	1.12 / 1.33
0–150	135 / <ВРК	0.52 / 0.61	151 / <ВРК	0.58 / 0.69	195 / ВРК	0.75 / 0.88	250 / НВ-ВРК	0.96 / 1.13	265 / >НВ	1.03 / 1.21
0–200	167 / <ВРК	0.48 / 0.56	177 / <ВРК	0.51 / 0.60	300 / >ВРК	0.86 / 1.02	315 / НВ-ВРК	0.91 / 1.07	320 / >НВ	0.92 / 1.08
0–300	368 / <ВРК	0.71 / 0.83	396 / >ВРК	0.76 / 0.90	398 / <ВРК	0.77 / 0.90	415 / НВ-ВРК	0.80 / 0.94	435 / НВ-ВРК	0.84 / 0.98

0.90–0.92% HB at P_z = 1.05–1.08 (optimal conditions). The moisture reserve > VRK. The moisture reserve in the thickness of 0–150 cm is 250–265 mm (NV–VRK and > HB) at 7 = 1.13–1.21 (optimal conditions), which corresponds to the moisture reserve at the level of NV–VRK and > HB. Formation of moderate wetting: about 195 mm (0.75% HW) should accumulate in the thickness at P_z = 0.88 (slightly arid conditions), which corresponds to the moisture reserve during the water-cooling. In a thickness of 0–300 cm 398 mm (0.77% NV) should accumulate at P_z = 0.90, which will correspond to a reserve < VRK.

Wet and excessively wet humidification mode

The moisture reserve in the 0–100 cm soil layer is 175–193 mm with moisture saturation > 100% HB at P_z > 1.20 (humid conditions). The moisture reserve > VRK. The moisture reserve in the thickness of 0–150 cm is 250–260 mm (> NV) at P_z = 1.13–1.21 (humid conditions), which corresponds to the reserve > NV. Formation of deep and through wetting: in a thickness of 0–300 cm, the moisture should accumulate > 415 mm (NV–VRK) at P_z = 0.95–0.98 (optimal conditions), which corresponds to the moisture reserve of NV – VRK.

Formation of deep and through wetting: in a thickness of 0–300 cm, moisture should accumulate > 415 mm (NV – VRK) at P_z = 0.95–0.98 (optimal conditions), which corresponds to the moisture reserve of NV – VRK.

- the moisture reserve in the thickness of 0–100 cm at the level of 175 mm (> HB) with a moisture index P_z = 1.20;
- the moisture reserve in the thickness of 0–150 cm – 250 mm (HB – BPK 0.96% HB) at P_z = 1.13;
- the moisture reserve in the thickness of 0–200 cm is 315 mm (0.91% NV), which corresponds to P_z = 1.07, and the moisture reserve is VRK – NV;
- the moisture reserve in the thickness of 0–300 cm is 415 mm (0.80% NV) at P_z = 0.94, which corresponds to the reserve in the NV – VRK interval.
- With a small probability (10%) a type of through-wetting water mode is formed with the following parameters:
- the moisture reserve in 0–100 cm thickness > 190 mm 112% NV at P_z = 1.33;
- the moisture reserve in 0–150 cm thick – 265 mm (1.03% HW) at P_z = 1.21;
- the moisture reserve in 0–200 cm thick – 320 mm (92% MV) at P_z = 1.08;
- the moisture reserve in the thickness of 0–300 cm – 435 mm (0.85% HW) at P_z = 0.98.

The obtained data on the dynamics of climatic parameters, especially from the long-term measurements (over many years), in particular the parameters of the state of the moisture condition of chernozems, encode information about their past and present state; and obtaining this information, using the statistical analysis methods is extremely important since this information may be used to predict further dynamics of the climate change and soil moisture in the future, and, therefore, the crop yields.

CONCLUSIONS

On the whole, the obtained long-term indicators of the state of the dynamic systems under study, regarding the formation of reserves of productive moisture in the chernozem layer serve as the basis for analysis, modeling and forecasting of further development of the systems mentioned.

In order to form a non-leaching moisture mode, it is necessary to accumulate 117–135 mm in the 0–100 cm soil thickness, which will correspond to a reserve of 117–167 mm in the 0–200 cm soil thickness. For a periodic flushing water mode, 160–165 mm of moisture should be accumulated in the 0–100 cm thickness, which will provide a moisture reserve of 300 mm in the 0–200 cm thickness. The leaching water mode is formed with a moisture reserve in the thickness of 0–100 cm in the amount of 175 mm, which provides a moisture reserve in the thicknesses of 0–150 cm and 0–200 cm – 250 mm and 315 mm, that corresponds to the reserve of NV-VRK, and the thickness of 0–300 cm is saturated with moisture in an amount of more than 400 mm (HB-VK).

The leaching water regime mode is formed with a moisture reserve in the thickness of 0–100 cm in the amount of 175 mm, which provides a moisture reserve in the thicknesses of 0–150 cm and 0–200 cm – 250 mm and 315 mm, that corresponds to the reserve of NV-VRK, and the thickness of 0–300 cm is saturated with moisture in an amount of more than 400 mm (HB-VK).

Calculation of paired correlation coefficients showed that an inverse strong correlation (R > –0.70) was found between the amount of precipitation for November – March and the supply of moisture to the metre layer of soil (R > -0.70), and the consumption of moisture from the soil for April – July, correlated with the precipitation for November – March at the level direct strong correlation (I ≥ 0.70). The relationship with moisture consumption from moisture potential for April – August was at the level of inverse strong correlation (R < 0.70), i.e. The higher the amount of precipitation during the autumn-winter-spring period (the cold period), the less moisture is recorded in the metre-thick layer, the greater its consumption in April-July from the soil, and the smaller consumption of the moisture potential in April-August.

The zone of the central Forest-Steppe is characterized by a periodically leaching water mode, when an average of 165 mm of moisture accumulates in the thickness of 0–100 cm, that corresponds to the median values, and, therefore, tends to the values of the moisture reserve in a non-flushing water mode, exceeding its value by 25 mm, which is a stable trend of aridization of the soil conditions in spring.

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