

Manifestation of Soil Desertification Processes in the Forest-Steppe of Ukraine Depending on their Moisture Level

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ABSTRACT:

Natural factors play an important role in the formation of soils, but under certain conditions they can cause their degradation and desertification, especially in combination with anthropogenic impact. In modern conditions, it is human activity that significantly enhances the natural processes of aridification, turning desertification into a global problem. The main natural factors are soil moisture deficiency, uneven distribution of precipitation and high evaporation intensity, the negative impact of which is exacerbated by crop rotation violations, intensive tillage and reduced use of soil protection technologies. The study was conducted on test plots within the Vinnytsia district of Vinnytsia region of Ukraine, selected based on remote sensing materials. Three main types of soils were identified: sod-podzolic, gray podzolic and podzolic chernozems, represented by sandy and sandy loam varieties. Soil moisture was determined by the gravimetric method. The results showed that desertification manifestations depend to a large extent on the seasonal dynamics of soil moisture. Spring moisture deficits prevented the formation of productive reserves for crop germination, while summer showers promoted the development of weeds. In autumn, excessive moisture created favorable conditions for the germination of winter crops, but complicated field work.

Keywords: soil, mechanical composition, moisture content, precipitation, weather conditions, available water, unavailable water

1. Introduction

Natural factors, such as climate, relief, parent rocks and biota, not only shape soils, but can also influence their degradation and desertification. These processes are closely intertwined with anthropogenic influences, including improper soil cultivation, overgrazing and deforestation. Such actions significantly accelerate erosion and fertility depletion, especially in arid regions. In the modern world, it is human activity that acts as the main factor that enhances desertification, actively influencing natural processes. At the same time, it is extremely difficult to determine the exact share of each of the factors – natural and anthropogenic – in the occurrence of soil desertification. Although climate plays a key natural role, human influence often becomes decisive in its acceleration, turning desertification from a local problem into a global challenge (Sobko et. al., 2024).

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Climate change in Europe, accompanied by rising temperatures, increasing droughts and changes in air circulation, is causing desertification, especially in the southern and eastern regions. Fertile lands are gradually becoming arid, leading to soil erosion, reduced moisture levels and general land degradation. These processes threaten agriculture, local biodiversity and may increase the risk of floods and extreme natural events in other regions, such as Ukraine and Southern Europe (Didur & Pantsyreva, 2025).

In Southern Europe, the average air temperature has been increasing by 3–4°C in recent years, which causes more intense evaporation of moisture from the soil. In 2022, drought covered about 650 thousand square kilometers of EU land. On the Mediterranean coast, the reduction in summer precipitation amounted to more than 50%, which transforms the temperate climate of this region into arid and contributes to the advancement of semi-desert zones to the north. Rising temperatures and water scarcity reduce the natural resilience of lands. By 2025, almost 23% of Europe's territory, including southern, central and eastern regions, is estimated to be vulnerable to degradation. At the same time, 13 EU countries have officially declared themselves affected by desertification, including Spain, Italy, Greece, Portugal, Bulgaria, Romania and Hungary. In Ukraine, the southern regions are most threatened by this process, where, due to more frequent droughts, there is a risk of losing fertile lands and their possible transformation into deserts (Okrushko, 2022). Inappropriate and irrational land use is one of the main anthropogenic factors contributing to the aggravation of the water shortage problem in Europe. It disrupts the natural water cycle through peatland reclamation, excessive soil cultivation, the dominance of monocultures in crop rotations, the reduction of forest areas through deforestation, and the expansion of urban areas (Petrichenko et al., 2017).

Global conflicts in recent years have both direct and indirect impacts on Europe's climate resilience, exacerbating the problem of droughts through increased CO₂ emissions and the greenhouse effect. Direct emissions alone from the war in Ukraine are equivalent to the annual emissions of the four average EU countries combined by the end of 2025. This contributes to accelerating global warming, making droughts in Europe 20 times more likely. Armed conflicts also lead to massive forest fires and forest loss (for example, Germany has already lost about 5% of its forest cover due to climate stress and increased disease). In addition, military actions cause soil degradation and water pollution, which significantly limits the ability of ecosystems to recover (Bakhmat et al., 2023).

According to research institutions of Ukraine, the area of degraded and low-fertile lands, which are the basis for the development of desertification processes, is from 6.5 to 10 million hectares. Desertification of soils in Ukraine from the southern regions (Odesa, Mykolaiv, Kherson, Zaporizhia regions) is beginning to spread to the central part of Ukraine (Cherkashchyna, Vinnytsia regions), which is a significant environmental problem (Hnatiuk et al., 2019; Didur, et al., 2020). It is caused by climate change, overuse of soils for intensive agriculture, deforestation and the consequences of war, and the destruction of irrigation systems. These factors cause the loss of soil fertility, the emergence of dust storms, and a decrease in yields. The main manifestation of desertification of agricultural lands is the loss or complete absence of biodiversity of both cultivated plants and weeds (Pohrishchuk et al., 2023; Ivanyshyn et al., 2021; Lutkovska, 2020).

The main factors contributing to the intensification of aridification processes of desertification include climatic conditions, in particular low soil moisture levels, uneven

distribution of precipitation, and increased evaporation, which can be significantly exacerbated by crop rotation violations, excessive use of pesticides, intensive tillage, and other factors (Didur, *et al.*, 2019; Petrychenko *et al.*, 2020; Khaietska *et al.*, 2023; Pansyryeva *et al.*, 2023; Pryshliak, *et al.*, 2023; Petrychenko *et al.*, 2024). The level of soil moisture depends on factors such as weather conditions, soil type, its mechanical composition, types of plants grown. This parameter is critically important for monitoring agricultural activities, predicting natural disasters, managing water supply, etc. In particular, it can more effectively than other indicators signal the threat of flooding or moisture deficiency, which in the long term can lead to the formation of deserts (Mazur *et al.*, 2023; Pansyryeva, 2021; Zagorulko *et al.*, 2020).

Soil moisture affects its oxygen saturation; salinity and the amount of toxic substances in it; soil structure; temperature and heat capacity; soil resistance to weathering. In addition, the degree of soil moisture allows you to determine the readiness of the field for the start of agricultural tillage and sowing work. Therefore, its determination is extremely important for growing agricultural plants (Kaletnik G. & Lutkovska, 2020; Mazur *et al.*, 2021; Didur *et al.*, 2025; Pansyryeva, 2024). This parameter characterizes not only the water content in a specific area, but also determines the general condition of the field. First of all, moisture is absorbed by plant roots, so their condition directly depends on the amount of moisture in the soil and the degree of its aeration. Ultimately, this determines the yield of agricultural crops (Pansyryeva *et al.*, 2020; Didur, *et al.*, 2021; Petrychenko *et al.*, 2025; Butenko *et al.*, 2025).

The optimal soil moisture range depends on the type of crop, but for most plants it is 20-60%. This parameter is influenced by various factors, including relief, vegetation and climatic conditions. The main characteristics of the soil that determine the water balance are its texture (mechanical composition), structure, temperature, bulk and specific gravity of the soil, the content of organic matter (humus) and salts. The finer the texture (mechanical composition) of the soil, the longer the moisture is retained; a porous structure with a high degree of aggregation improves moisture content; the more organic matter in the soil, the higher its ability to retain moisture; high density makes it difficult for water to penetrate; the moisture content in soils is higher at lower temperatures; with a large amount of salt in the soil, plants can absorb less moisture, since it is a natural absorbent. It is the study of these parameters in soils that will allow us to identify and prevent the initial stages of desertification processes, which are already occurring in the Vinnytsia region and are manifested in the formation of areas on agricultural lands where there is a complete absence of vegetation cover, including weedy vegetation (Mazur *et al.*, 2020; Kaletnik & Yaropud, 2023; Honcharuk *et al.*, 2022).

2. Materials and methods

The object of the research was determined by test polygons - specially selected experimental plots of soil cover, within which the vegetation cover in the late spring period was partially or completely absent, or was characterized by significant liquefaction due to soil drying and the manifestation of signs of degradation and desertification. The selection of such plots was carried out on the basis of the analysis of remote sensing materials of the Earth within the Right-bank Forest-Steppe zone Vinnytsia district of the Vinnytsia

region (Ukraine), which made it possible to identify territories with a disturbed water regime and a reduced level of biological productivity. According to the geographical coordinates of the established observation points and using soil cover cartograms, three main types of soils were distinguished: sod-podzolic, gray podzolic and podzolic chernozems. Each of the specified soil types in terms of mechanical composition was represented by sandy and sandy loam varieties, which are most vulnerable to moisture deficiency and the development of aridization processes. Within the formed test plots, the actual soil moisture was determined using the laboratory gravimetric method of moisture extraction. Soil samples were collected in three replicates during the characteristic phases of the growing season: in mid-April, which corresponded to the period of spring sowing; in mid-July, when there is intensive growth and development of spring crops; and in mid-October, which coincided with the timing of sowing and the initial phases of germination of winter crops. The obtained experimental values of soil moisture were compared with the main water-physical indicators, in particular with the field moisture capacity of the soil (FC, %), the value of critically low moisture content or the wilting point of plants (PWP, %), as well as with the reserves of moisture available to plants (TAW, %). In parallel, an analysis of meteorological conditions was carried out based on the indicators of decadal and monthly average daily air temperatures and the amount of atmospheric precipitation during the growing season (April–October). The obtained data were compared with the average long-term climatic norms. Meteorological information was provided by the Vinnytsia Regional Center for Hydrometeorology.

3. Results

Analysis of the amount of precipitation in the Forest-Steppe zone of Right-Bank Ukraine during the growing season of 2025 showed significant unevenness of their arrival, which significantly affected the conditions for the formation of soil moisture. In April, only 23.0 mm of precipitation was recorded, which is 38.3% less than the average long-term norm for this month. The moisture deficit in the early spring period was exacerbated by intensive evaporation from the soil surface, since the average monthly air temperature exceeded the climatic norm by 1.7 °C. This caused a decrease in the moisture content of sandy soils to the level of inaccessible moisture, which prevented seed germination and provoked their loss of field germination. This combination of factors created unfavorable conditions for the accumulation of productive reserves of soil moisture. In May, weather conditions changed dramatically: the amount of precipitation increased significantly and amounted to 189 mm, which exceeded the average long-term value by 28.0%. Additional soil moisture preservation was facilitated by the reduced air temperature, which was 1.3 °C lower than the long-term norm, which limited evaporation processes (Table 1).

Table 1: Characteristics of meteorological conditions in the Forest-Steppe zone of Right-Bank Ukraine during the growing season in 2025 (according to data from the Vinnytsia weather station)

Month	Decade	Air temperature °C	Average long-term air temperature, °C	Precipitation amount, mm	Average long-term precipitation, mm
April	I	4,9	7,5	20,0	6,6
	II	11,1	7,5	2,0	15,3
	III	14,9	10,8	1,0	15,3

	Per month	10,3	8,6	23,0	37,3
May	I	11,9	11,7	40,0	43,3
	II	9,8	14,8	47,0	43,5
	III	15,4	14,6	102,0	49,2
	Per month	12,4	13,7	189	136,0
June	I	21,8	18,0	16,0	21,2
	II	17,7	18,1	0,7	21,7
	III	18,6	22,1	3,0	30,0
	Per month	19,4	21,4	19,7	72,5
July	I	22,7	20,5	18,0	17,0
	II	20,3	20,2	42,0	11,8
	III	22,1	21,7	43,0	27,7
	Per month	21,7	20,8	103,0	56,5
August	I	20,6	20,2	19,0	9,7
	II	18,9	20,3	13,0	6,4
	III	18,2	19,9	11,0	8,4
	Per month	19,2	20,1	43,0	32,0
September	I	17,3	17,4	7,0	2,8
	II	16,4	15,6	32,0	2,3
	III	15,0	12,8	18,0	26,0
	Per month	16,5	15,3	57,0	31,2
October	I	10,5	11,2	15,0	16,3
	II	8,1	10,7	40,0	7,0
	III	7,0	8,6	8,0	0,6
	Per month	8,4	10,1	63,0	33,0
Overall during the growing season		15,4	15,7	497,7	398,5

June, on the contrary, was characterized by a sharp deficit of atmospheric moisture. Only 19.7 mm of precipitation fell during the month, which corresponded to 27.2% of the average long-term norm. Despite the fact that the average monthly air temperature was 2.0 °C lower than the climatic indicator, the lack of precipitation negatively affected the water regime of the soils. In July, the situation with moisture significantly improved. The amount of precipitation reached 103.0 mm, which exceeded the average long-term value by 45.1%. This contributed to the intensive replenishment of soil moisture reserves, even with an increase in the average monthly air temperature by 0.9 °C relative to the norm. Significant soil moisture saturation in July provoked intensive weed germination in areas not occupied by cultivated plants due to the lack of available moisture in the soil in the spring. August was also marked by excessive moisture: the amount of precipitation was 43.0 mm, which was 25.6% higher than the average monthly long-term indicators. At the same time, the air temperature during this period was 0.9 °C lower than normal, which created favorable conditions for moisture retention in the soil profile.

In September, the amount of precipitation was 57.0 mm, which was 45.3% more than the average multi-year norm for this month. The average monthly temperature was 0.8 °C more than the average multi-year norm. In October, the amount of precipitation

was also significant and was 63.0 mm, which was 47.7% more than the average multi-year monthly norm with the average monthly temperature 1.7 °C below the average multi-year value. This provoked oversaturation of soils with moisture and the postponement of autumn field work, in particular the sowing of winter crops. Thus, during the growing season, the amount of precipitation exceeded the average multi-year value by 100 mm. Less than the monthly average multi-year norm of precipitation fell only in April and June, and in the remaining months, precipitation was above the established norm. And the average air temperature during the growing season exceeded the average multi-year value by only 0.3 °C. Observations of the dynamics of moisture content of the studied soils with sandy and sandy loam mechanical composition showed that in the spring, in mid-April, the moisture content of the sod-podzolic sandy soil was the lowest and amounted to 5.1%. The sod-podzolic sandy loam soil was 0.5% wetter. The moisture content of the gray podzolic sandy soil was 0.7% higher than that of the sod-podzolic sandy soil and 0.2% higher than that of the sod-podzolic sandy loam soil and amounted to 5.8%. The wettest was the podzolic sandy chernozem with a moisture level of 10.3%, which had a moisture content of 0.7% higher than the podzolic sandy chernozem, 2.8% more than the gray podzolic sandy chernozem, and 4.7% more than the sod-podzolic sandy chernozem (Table 2).

Table 2: Dynamics of moisture content of overdried soils depending on the season, $M \pm m$

Soil type	Mechanical composition of the soil	Soil moisture depending on the season, %		
		April	July	October
Sod-podzolic	sandy	5,1±0,2	8,7±0,2	15,4±0,2
	loamy	5,6±0,2	13,1±0,2	24,2±0,3
Gray podzolized	sandy	5,8±0,1	9,2±0,3	17,6±0,3
	loamy	7,5±0,3	18,3±0,2	27,8±0,2
Podzolized chernozem	sandy	9,6±0,2	20,2±0,2	25,6±0,2
	loamy	10,3±0,1	33,1±0,2	41,0±0,2

In the summer period, in mid-July, soil moisture increased by 3.6-22.8%, which was caused by significant rainfall in the summer period and amounted to 8.7-13.1% in sod-podzolic soil, depending on the degree of sandiness, 9.2-18.3% in gray podzolic soil, and 20.2-33.1% in podzolic black soil. In the autumn period, in mid-October, intense precipitation contributed to a further increase in the moisture content of the studied soils. In particular, sod-podzolic sandy soil contained the lowest amount of moisture – 15.4%. This was 8.8% less than the moisture content of sandy soil. Gray podzolic sandy soil in mid-October had a moisture content of 27.8%. This was 10.2% more than sandy soil and 3.6% more than soddy-podzolic sandy soil. Podzolized sandy chernozem had the highest soil moisture content – 41.0%. This was 15.4% more than the moisture content of podzolized sandy chernozem, 13.2% more than the moisture content of gray podzolized sandy soil and 16.8% more than the moisture content of soddy-podzolic sandy soil. The study of the dynamics of moisture in overdried soils can become an important basis for further scientific exploration, in particular on modeling dry periods and identifying areas with an increased risk of desertification. Involving multi-year data sets and taking into account different climate scenarios will contribute to the development of early warning systems for aridification processes. The combination of remote sensing technologies with continuous monitoring of soil moisture will provide an opportunity to improve the

temporal detail and effectiveness of forecasts of desertification risks in Europe in the near future. The required moisture content in the soil for the growth and development of agricultural crops depends on the soil's capacity to absorb and retain moisture (FC) and the value of the permanent wilting point, which determines the critically low moisture content in the soil (PWP) (Fig. 1).

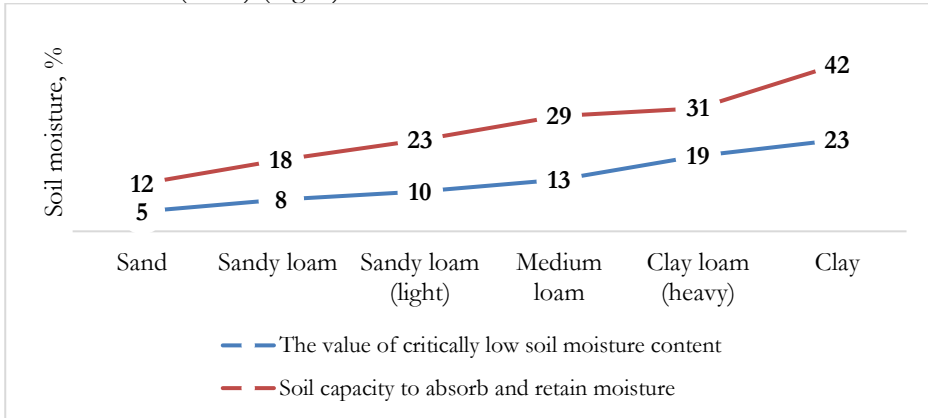


Fig. 1: Distribution of available and unavailable water in the soil depending on its mechanical composition

The soil's water holding capacity (FC) affects how much water the soil can hold after excess water has drained away. This value reflects the water-air balance in the soil. If the percentage of moisture is too high, there is not enough oxygen in the soil. The value of the permanent wilting point, which determines the critically low soil moisture content (PWP), reflects the temperature threshold below which plants begin to wilt and die due to water deficiency. Both indicators depend on the mechanical composition of the soil. An important indicator in assessing soil moisture is available water (TAW), i.e. the amount of water that plants can obtain. It is estimated as the difference between the soil's water holding capacity (FC) and the critically low soil moisture content (PWP). When the soil moisture content exceeds the soil's moisture absorption and retention capacity (FC), crops can only receive moisture for 1-3 days, and when the soil moisture content is below the critical low moisture content (PWP), crops can no longer absorb the necessary water. Different soils by mechanical composition have different values of moisture absorption and retention capacity (FC), the value of the permanent wilting point, which determines the critically low soil moisture content (PWP), and available moisture (TAW) (Table 3).

The results of our research showed that in spring, in April, during the spring field work for sowing crops, the sod-podzolic sandy soil had a moisture content of 5.1%. This practically corresponded to the value of the critically low soil moisture content (PWP) – 5.0%. Therefore, in this soil, the amount of available moisture was only 0.1%, which was insufficient for crop germination and could provoke a lack of seedlings and the transformation of the area into a desert.

Table 3: Threshold values of soil moisture depending on its mechanical composition

Mechanical composition of the soil	Soil moisture absorption and retention capacity (FC), %	Value of critically low soil moisture content (PWP), %	Value of available moisture in the soil (TAW), %
Sand	12	5	7
Sandy loam	18	8	10
Sandy loam (light)	23	10	13
Medium loam	29	13	16
Clay loam (heavy)	31	19	12
Clay	42	23	19

With a spring moisture content in the sod-podzolic sandy soil of 5.6%, the critically low moisture content in this soil is 8.0%. Therefore, this moisture in the soil is inaccessible to plants. The gray podzolic sandy soil had an available moisture value of 0.8%, and the sandy soil had no available moisture in the soil. Based on the data obtained, in the spring on the sod-podzolic sandy soil, as well as gray podzolic sandy and sandy soils, with the available moisture content, there were no seedlings of cultivated plants. The podzolic sandy chernozem contained 4.6% of available moisture, and the sandy soil contained 2.3% of available moisture, which contributed to the germination, growth and development of plants (Fig. 2).

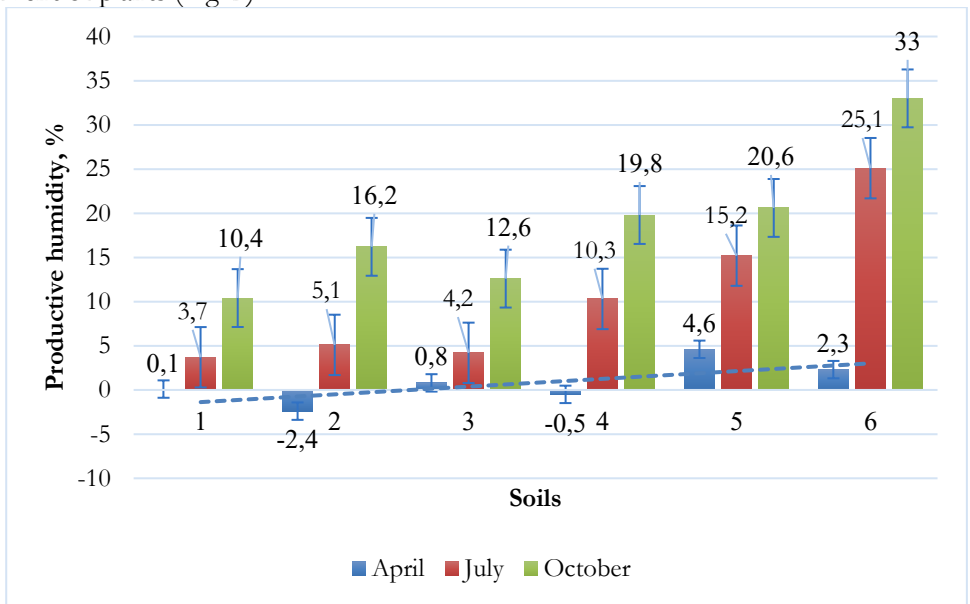


Fig. 2: Dynamics of productive moisture in the soil depending on its type, mechanical composition and season

*note: 1 – sod-podzolic sandy soil; 2 – sod-podzolic sandy soil; 3 – gray podzolic sandy soil; 4 – gray podzolic sandy soil; 5 – chernozem podzolic sandy soil; 6 – chernozem podzolic sandy soil.

In July, due to heavy rains, the soil moisture level increased significantly, which affected the amount of available moisture in the soil. In particular, in sod-podzolic sandy and sandy loam soil, this indicator was 3.7 and 5.1%, respectively, in gray podzolic sandy

and sandy loam soil – 4.2% and 10.3%, respectively, and in podzolic sandy and sandy loam chernozem – 15.2 and 25.0%, respectively. Moreover, podzolic sandy and sandy loam chernozem had excess soil moisture, which indicates oversaturation of the soil with moisture. It is the sufficient moisture of sod-podzolic sandy and sandy loam, as well as gray podzolic soil in July that can provoke the growth of weeds in these areas, because they have been free of cultivated plants since spring due to lack of moisture. Intensive precipitation in October caused the oversaturation of all studied soils with moisture. In particular, with the maximum capacity of sandy soil for moisture absorption and retention within 12% and the amount of available moisture at 7%, sod-podzolic soil had a level of exceeding this indicator by 3.4%, gray podzolic – by 9.2%, and chernozem podzolic – by 18.1%. With the maximum capacity of sandy soil to absorb and retain moisture within 18% and the amount of available moisture at 10%, sod-podzolic soil exceeded this indicator by 6.2%, gray podzolic soil by 9.8%, and podzolic black soil by 23.0%. The practical consequences of desertification include a significant decline in crop yields, which poses a threat to food security; more frequent droughts and natural disasters such as dust storms; shortages of fresh water; mass migration of populations and a reduction in biodiversity.

This causes loss of soil fertility, salinization and erosion, making these areas unsuitable for habitation and agriculture. To restore such areas, special methods are required, including mulching and the creation of forest belts. Adaptive strategies for the management of dry soils in Europe should be based on the key principles set out in the EU Soil Strategy 2030, as well as the regulatory provisions of the Soil Monitoring Law.

To achieve sustainable land use, the main adaptive approaches currently include:

1. **Moisture conservation and regulation:** Soils with high levels of organic matter help retain moisture, providing protection against droughts and reducing the effects of rainfall deficits. **Efficient irrigation:** The use of water-saving technologies helps reduce the loss of this important resource. **Moisture monitoring:** The use of sensors to determine soil moisture levels and yield analysis provides more accurate resource management in the face of climate change.
2. **Agroecological practices include the following approaches:** **Agroforestry:** The introduction of trees and shrubs into agricultural land to create a favorable microclimate, reduce moisture loss through evaporation and protect soils from erosion. **Crop rotation optimization and the use of green manures:** The use of perennial grasses and green manures to improve soil structure and accumulate useful nutrients. **No-till/Strip-till:** reducing the level of tillage in order to conserve moisture, prevent soil degradation and increase ecosystem resilience.
3. **Carbon Farming:** This is an approach whose main objective is to increase the organic carbon content in mineral soils. This strategy helps to achieve climate neutrality and increase soil resilience to drought, while improving their quality.
4. **Government and scientific regulation includes several important initiatives.** By 2030, as part of the «A Soil Deal for Europe» program, it is planned to create a network of 100 «living laboratories».

These laboratories will become platforms for testing and implementing sustainable practices in real conditions. In addition, EU Member States are obliged to implement monitoring systems based on a unified methodology to assess the physical and biological

condition of soils. Combating desertification includes measures such as the restoration of degraded lands and the creation of buffer zones to counteract soil depletion. These initiatives are supported by financial instruments, in particular through the Common Agricultural Policy (CAP) and by dedicated awards such as the Land and Soil Management Award.

4. Implications and further research

The manifestation of desertification processes in sandy and sandy loam soils is largely determined by the level of their moisture at different time intervals, which is influenced by atmospheric precipitation. The minimum moisture content that can be available to plants in sandy soils should be more than 5.0%, and in sandy loams – 8.0%. It is precisely because of the lack of moisture in the spring period (April) that sod-podzolic and gray podzolic sandy and sandy loam soils under the existing weather conditions did not provide a productive supply of moisture for the germination of seeds of agricultural crops and began to turn into a desert. With a sharp increase in the moisture level in these soils due to significant precipitation in July, intensive germination of weeds is possible in areas free from cultivated plants. In the autumn period, all studied soils were oversaturated with moisture, which facilitated the germination of winter crop seeds, but delayed the timing of field sowing due to excessive soil moisture.

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