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# The impact of continuous maize cultivation on grain yield and agrophysical parameters of the arable soil layer

Andrii Donets[1], Tetiana Marchenko[1,2], Yurii Lavrynenko[1], Olena Piliarska[1], Serhii Mishchenko[3,4*]

[1] Institute of Climate-Smart Agriculture, National Academy of Agrarian Sciences of Ukraine, 24 Maiatska doroha Str., Khlibodarske, Odesa Region, 67667, Ukraine,
[2] Odessa State Agrarian University, 99 Kanatna Str., Odesa, 65039, Ukraine,
[3] Oleksandr Dovzhenko Hlukhiv National Pedagogical University, 24 Kyivska Str., Hlukhiv, Sumy Region, 41400, Ukraine,
[4] Institute of Bast Crops, National Academy of Agrarian Sciences of Ukraine, 45 Tereshchenkiv Str., Hlukhiv, Sumy region, 41400, Ukraine,
* Corresponding author's e-mail: tmarchenko74@ukr.net

## ABSTRACT

The objective of the study was to determine the dynamics of the agrophysical parameters of the arable layer of dark chestnut soil under continuous maize cultivation with the use of chemical soil ameliorants, as well as to evaluate the grain yield dynamics of maize hybrids of various FAO maturity groups and the efficiency of plant protection systems under surface drip irrigation in the Steppe zone of Ukraine. It was established that long-term continuous maize cultivation under surface drip irrigation in the Southern Steppe of Ukraine during 2021–2025 is possible without a significant decline in grain yield, provided that integrated pest management and chemical ameliorant application are implemented. Among the yield-stabilizing factors, plant protection systems demonstrated the greatest effect. Soil fertility maintenance measures were of secondary importance for yield stability but of primary importance for long-term soil fertility preservation. The genotype of maize hybrids, particularly their FAO maturity group and resistance to harmful organisms, played a crucial role in yield stabilization under continuous cultivation. The average grain yield of maize hybrids decreased by 1.50 t/ha (11.92%) over five years of monocropping. The smallest yield reduction was observed in hybrids with a shorter growing period when chemical ameliorants and integrated protection systems were applied. In the fifth year of continuous cultivation, grain yield of the hybrids Stepovyi (FAO 190) and Askaniia (FAO 320) decreased by 0.45 and 0.24 t/ha, respectively, whereas the hybrid Skadovskyi (FAO 290) maintained the initial yield level (13.15 t/ha). A significant yield reduction was recorded in the late-maturing hybrid Vira (FAO 430): its grain yield during the first two years was 15.43 and 15.18 t/ha, while during the subsequent three years it decreased by 0.76, 1.54, and 1.53 t/ha, respectively. The yield decline of late-maturing hybrids was associated with longer vegetation periods, prolonged pest pressure, and increased numbers of pest generations.

**Keywords:** maize, grain, crop capacity, yield, continuous growing, drip irrigation, hybrid, humus content, soil bulk density, soil porosity, chemical ameliorant.

## INTRODUCTION

The formation of sustainable agricultural systems is closely linked to the optimization of crop rotation structures and the use of modern breeding achievements. In recent years, the specialization of farms has narrowed considerably, with agricultural production focusing on a limited number of economically profitable crops. As a result, crop rotations have undergone systemic changes, often transforming into short-rotation or continuous cropping systems, particularly for maize, which many farmers cultivate on the same field for several consecutive years.

Previous studies have shown that maize can be grown on the same field for several years without a decline in productivity, as well as in short-rotation systems, provided that all technological requirements are met (Sindelar et al., 2015; Grover et al., 2009; Simić et al., 2020).

However, despite examples of crop tolerance to continuous cultivation, several challenges remain inherent to this system. Maize exemplifies this issue: practical experience shows that maintaining continuous maize cultivation beyond 4–6 years is generally unadvisable. After such a period, it becomes necessary to interrupt the cycle for at least two years by planting crops from different botanical families that do not share the same pathogens or pests (Bocsa et al., 2000).

Continuous cultivation of any crop, including maize, requires optimal environmental conditions, particularly sufficient soil fertility, for successful growth and development. These conditions are equally essential for maize grown in traditional crop rotations (Klymchuk, 2005; Cherney and Small, 2016). Breeding maize for genotype tolerance to various growing conditions offers promising solutions for mitigating ecological challenges and ensuring sustainable agricultural development (Loro et al., 2023). Therefore, in adaptive agriculture, it is crucial to align the genotypic characteristics of maize hybrids with the agroecological conditions of cultivation (Vozhehova et al., 2023).

Under unstable moisture conditions of the Left-Bank Forest-Steppe of Ukraine, long-term studies were conducted at the Poltava Research Station named after Vavilov (1984–2023) to investigate continuous maize cultivation for grain production. In this region, atmospheric precipitation serves as the main source of available moisture for maize plants. Variability in hydrothermal conditions, especially rainfall during the growing season, caused significant fluctuations in annual grain yields. The use of modern innovative hybrids contributed greatly to yield improvement, while the application of organic and mineral fertilizers stabilized both quantitative and qualitative humus parameters in the soil (Hlushchenko et al., 2024).

A key issue in continuous cropping systems lies in the biochemical nature of root exudates known as colines which can lead to soil fatigue. The allelopathic activity of rhizospheric soils and plant extracts from aerial parts can act as strong inhibitors in monoculture systems (Jalgaonwala and Mahajan, 2014). The annual accumulation of these biologically active substances in the arable soil layer can progressively alter the conditions for plant growth. Numerous examples of soil fatigue under long-term monocropping are known from various agricultural practices, including fruit crops, flax, sugar beet, and sunflower (Skrypchenko et al., 2020; Grodzinsky, 1991). Continuous maize cultivation leads to soil fatigue, yield reduction, and an increase in diseases, pests, and weeds. The negative effects can be mitigated by applying higher doses of mineral fertilizers and intensifying crop protection measures (Tkachuk and Bondarenko, 2022).

Research conducted in Ecuador (Jipijapa Canton) confirmed that long-term maize monoculture leads to a decline in soil organic matter, deterioration of soil fertility and texture, and delayed plant development (Mera et al., 2021). It is well known that crops such as maize, winter rye, potatoes, and others are capable of sustaining continuous cultivation over decades (Fedotov and Shoba, 2019). Continuous maize cultivation can be maintained on chernozem soils for 6–10 years, provided that organic fertilizers are applied. On less fertile soils, this period is reduced to 3–5 years (Edleusa et al., 2022).

Specialization in the agricultural sector is a key factor in increasing farmers' profitability. Farming systems have become increasingly simplified, as farmers tend to grow only a limited number of crops with favorable market prices. However, monocultural systems require greater use of agrochemicals, leading to unsustainable ecological costs (Arrobas et al., 2015).

Maize is among the agricultural crops increasingly cultivated under no-tillage systems. This approach enables more efficient use of agricultural land, which, in addition to allowing for high yields, improves the overall organization and economic efficiency of agricultural production. In Poland, studies have shown that the lowest average maize yield occurred under monoculture with direct sowing (No-Till). The yield obtained under monoculture was 17–27% lower than in crop rotation systems. The humus content in soil under monoculture maize grown with direct sowing or plowing did not change, whereas it increased in soils where maize was grown in rotation with other cereals (Księżak et al., 2018).

The growing demand for maize grain in Thailand has led to a massive shift of farmers toward continuous monoculture. Research has demonstrated the fragile nature of such systems, accompanied by soil fertility loss, yield decline, and increased pesticide use (Bruun et al., 2017; Charoenratana et al., 2021).

Yield reduction under continuous maize cultivation can vary from 0% to 30%, but typically ranges between 5% and 15%. This decline is associated with nitrogen (N) immobilization, increased disease risk, and allelopathic effects, all of which are negatively influenced by the accumulation of maize residues. Continuous maize requires more nitrogen than maize following soybean. The selection of maize hybrids adapted to continuous cultivation plays a crucial role (Licht, 2019).

Studies examining the long-term effects of maize monoculture and crop rotation on soil biological activity revealed a statistically significant increase in enzymatic activity, as well as in the total number of bacteria and actinomycetes in soils under monoculture (Gałązka et al., 2017).

Intensive agroecosystem use can become a major cause of soil degradation, adversely affecting the relationship between agricultural production and climate change. To increase soil organic carbon (SOC) and total nitrogen (STN) stocks, conservation tillage (i.e., zero and minimum tillage) is recommended. This practice has a positive impact on food security, biodiversity, water quality, and the environment. After eight years of comparing tillage practices in irrigated maize monoculture, it was found that minimum tillage (MT) is a valuable option for enhancing maize yield and biomass return compared to conventional tillage (CT) (Fiorini et al., 2020).

Diversified maize–soybean rotations had a significant positive effect on average crop yields compared to monocultures in Heilongjiang Province, China (Yuan et al., 2022).

Monocultural farming pollutes the environment by increasing resource use, accelerating soil erosion, contaminating water resources, raising atmospheric carbon levels, and reducing biodiversity (Demirdogen et al., 2023).

The economics of crop production in Ukraine determine the structure of sown areas. Highly profitable and high-margin crops dominate crop rotations, often violating traditional scientifically based systems. As a result, the share of maize, soybean, and sunflower in rotations has increased substantially. Scientists have recommended and promoted crop rotations such as a three-field system with two maize fields, a two-field rotation (maize: soybean), and a four-field system with three maize fields (Zubets et al., 2010).

Studies of continuous maize cultivation for grain on typical chernozem soils in the Left-Bank Forest-Steppe of Ukraine have shown that anthropogenic and natural factors differently affect yield levels and soil fertility. Maize yield depends primarily on weather conditions and, to a lesser extent, on the duration of cultivation in one place (Kokhan et al., 2019).

In the southern regions of Ukraine, maize is mainly grown under irrigation, ensuring optimal moisture supply and high profitability. However, researchers note a concerning trend toward the degradation of agrophysical and physicochemical soil properties under prolonged irrigation with water of increased mineralization (Vozhegova et al., 2014). Intensive cultivation technologies for high-profit grain crops such as maize and soybean require increased irrigation rates (up to 6–8 thousand $m^3$/ha) and greater technical pressure on the soil, leading to secondary salinization and the destruction of the topsoil structure. The issue of preserving and regenerating soil fertility has therefore become a matter of national importance. Regenerative agriculture should primarily rely on the use of chemical and phytomeliorants (Vozhegova et al., 2020).

With the rapid global expansion of maize production, growing concerns have arisen regarding its continuous cultivation, localized environmental impacts, and broader global consequences. Agronomists have developed innovative farming systems and assessed them through long-term experiments to make arable systems more sustainable. However, knowledge about the resilience of such innovative systems compared with highly intensive ones, such as maize monoculture, remains limited (Bockstaller et al., 2024). It has been established that cultivating resistant maize hybrids under continuous cropping is the most radical and economically effective method for controlling Fusarium diseases. Therefore, production systems are increasingly focused on using genotypes resistant to pests and diseases (Donets et al., 2025; Mostovyak et al., 2020). In Ukraine, under irrigated farming conditions, there is also a growing need for scientific justification of the economic and soil-conservation assessment of continuous maize cultivation due to its high profitability and widespread inclusion in crop rotations.

The aim of this research was to determine the dynamics of agrophysical parameters of the arable layer of dark chestnut soil under continuous maize cultivation with the use of chemical soil amendments, to study the grain yield dynamics of maize hybrids of different FAO groups, and to assess the effectiveness of plant protection systems under surface drip irrigation in the Steppe zone of Ukraine.

## MATERIALS AND METHODS

The study was conducted within the framework of the Research Program of the National Academy of Agrarian Sciences of Ukraine "Irrigated Agriculture" under task 05.00.01.03.F "Theoretical substantiation of maize growing technologies in repeated and permanent crops under irrigation" (state registration number 0121U198070). The research was conducted using methodological approaches consistent with international practice and compliant with the state standards of Ukraine.

The response of maize hybrids to different cultivation conditions was studied at the Institute of Climate-Smart Agriculture, National Academy of Agrarian Sciences of Ukraine (Kherson, Ukraine; 46°44′33″ N, 32°42′28″ E; 50 m above sea level) during 2020–2025. Surface drip irrigation was applied, maintaining pre-irrigation soil moisture at 80% of the lowest field capacity in the 0–30 cm soil layer (Vozhehova et al., 2014). The irrigation rate was 3600–4350 m³/ha, with 15–19 irrigations applied depending on weather conditions.

As a chemical soil ameliorant, gypsum ($CaSO_4 \cdot 2H_2O$) was applied at a rate of 5 t/ha. Agrophysical parameters of the arable soil layer were determined after the maize harvest.

Soil moisture was determined by the thermostat–gravimetric method, drying the samples at 105°C according to DSTU ISO 16586:2005. The total soil moisture capacity of the 0–30 cm soil layer was 24.0%, and the soil moisture wilting point was 9.0% of the oven-dry soil mass. At the beginning of the study, the humus content in the arable layer was 2.61%, determined according to DSTU 4289–2004. The bulk density of the soil was measured in accordance with DSTU ISO 11272-2001 (soil quality determination of dry bulk densiry). The content of available phosphorus ($P_2O_5$) was 59 mg/kg of soil, exchangeable potassium ($K_2O$) – 276 mg/kg, and nitrates – 16.3 mg/kg. The pH of the aqueous extract was 7.0 in the arable layer. Determination of the agronomic parameters of the arable soil layer was carried out at the Department of Analytical Research, Institute of Climate-Smart Agriculture of the National Academy of Agrarian Sciences of Ukraine (NAAS).

ISO 11272:1998 Soil quality – Determination of dry bulk density. bulk density in a dry mill it is stagnated simultaneously from the strength of the solid phase (ISO 11508) for calculating instead of the solid phase and the porosity of the soil using the method of assessing the soil structure and transferring instead of fluxes in the soil volumetric concentration in mass fraction. Core method: this method is used to harden soils that are not rocky or slightly rocky. Core samples of a given volume are selected using a metal sampler. The dough is dried in the oven, and the thickness of the folded dough is calculated. Core trimmers, thin-walled metal cylinders with a volume of 100 cm³ to 400 cm³ with a steel tip for screwing into the ground and a device for screwing in. Press or screw without axial release and reinforced core volume into the vertical or horizontal ground surface far enough to fill the container for display. Carefully remove the core extractor from its place in order to preserve the natural structure, and remove the tough soil from both ends of the core extractor using a flat knife or a sharp spatula. In this way, the volume of the soil core is comparable to the internal volume of the core extractor. Take at least six cores from the skin soil ball. Place the mixture in an oven at 105 °C and evacuate until a stable mass is reached (at least 48 years). Remove the crusts from the oven and allow them to cool in a desiccator. Call for help immediately after getting out of the desiccator (m1). The control mass will be available if the difference between successive samples of the refrigerated sample at intervals of 4 years does not exceed 0.01% of the yield mass of the sample.

Bulk density on dry weight is calculated by the formula

$$b_{\rho_s} = \frac{m_d}{V} \quad (1)$$

where: $b_{\rho s}$ – bulk density, dry weight, g/cm³; $m_d$ – mass of soil from the core sample after drying at 105 °C, minus the mass of the core holder, V – core holder volume, cm³; $m_s$ – weight of empty core holder, g; $m_t$ – mass of the core holder together with the soil sample, dried at 105 °C, g.

Porosity of the soil is defined as the ratio of the total volume of all pores to the total volume of the soil sample, expressed as a percentage.

This indicator is calculated based on data on the bulk density of the soil and the density of its solid phase. Porosity determines the amount of space for air and water, which is key for plant life. An undisturbed soil sample is used, which is taken using a special cylindrical sampler (for example, by the "core" method). The dry soil sample contained in the cylinder is weighed. Knowing the volume of the cylinder and the mass of dry soil, the bulk density is calculated.

Total porosity (*P*t) calculated by the formula:

$$P_t = (1 - S_b / S_p) \times 100 \% \qquad (2)$$

where: $S_b$ – soil bulk density (bulk weight), g/cm³; $S_p$ – density of soil particles (solid phase density), which is usually taken as a standard value of approximately 2.65 g/cm³.

Humus content was determined by the oxidimetric method. This method consists in the oxidation of organic matter of soils and rocks with a solution of potassium dichromate in sulfuric acid with subsequent determination of the organic carbon content through the determination of potassium dichromate after oxidation by titrimetric or spectrophotometric methods. The thermal method consists in the dry combustion of organic matter at a temperature of 900 °C in a stream of oxygen-containing gas purified from carbon dioxide. The carbon dioxide released during combustion is determined, depending on the device used, by titration, gravimetrically, conductometrically, chromatographically with the use of infrared spectrophotometry. Since when heated to a temperature of 900 °C, any carbonates decompose with the release of carbon dioxide, then to determine the carbon of organic compounds, carbonates are first removed by treating the soil with hydrochloric acid.

Organic carbon content. Calculate the organic carbon content based on its determination by dry combustion according to the following equation:

$$W_{C,o} = W_{C,t} - (0.12 \times W_{CaCO3}) \qquad (3)$$

where: $W_{C,o}$ – organic carbon content determined by the dry combustion method of soil, g/kg; $W_{C,t}$ – total carbon content determined by the dry combustion method of soil, g/kg; 0.12 – conversion factor; $W_{CaCO3}$ – carbon content of carbonates determined according to ISO 10693, g/kg.

The organic matter content of a soil sample can be calculated from the organic carbon content using the following equation:

$$W_{om} = f \times W_{C,o} \qquad (4)$$

where: $W_{om}$ – organic matter content in the soil, %; $W_{C,o}$ – soil organic carbon content, %; *f* – conversion rate.

Mathematical processing of experimental data was performed using analysis of variance (ANOVA) with the Agrostat software package (Ushkarenko et al., 2014). In particular, the evaluation of the significant difference between mean values at the 0.05 probability level ($LSD_{0.5}$) and analysis of variance (ANOVA) for a three-factor experiment were performed.

The cultivation practices corresponded to standard technologies for grain maize production under irrigation (Vozhehova et al., 2023). Autumn plowing was carried out after the harvest of the previous crop (maize for grain) to a depth of 26–28 cm. Spring tillage included early spring harrowing at the stage of physical soil maturity, followed by pre-sowing cultivation to a depth of 6–8 cm (seed embedding depth). During pre-sowing cultivation, nitrogen and phosphorus fertilizers were applied at rates of $N_{180}P_{120}$, in accordance with zonal recommendations (Vozhegova et al., 2020). The preceding crop for the five-year maize cultivation cycle was soybean.

The experiment involved Ukrainian maize hybrids registered in the State Register of Plant Varieties of Ukraine: Stepovyi (FAO 190), Skadovskyi (FAO 290), Askaniia (FAO 320), and Vira (FAO 430).

In the plant protection system, the biological preparation "Trikhopsyn BT" from the Biotechnology Engineering Institute was used. The preparation is an insecto-fungicidal bioproduct containing biologically active growth-regulating substances, produced in Ukraine.

The active base of the preparation consists of mycelium and spores of fungi of the genus Trichoderma and rhizosphere bacteria of the genus Pseudomonas, with a titer of not less than $2.0 \times 10^{10}$ CFU/cm³, as well as biologically active compounds produced by the producer strains (Biotekhnika, 2025). Additionally, the synthetic chemical insecticide Bi-58 (active ingredient: dimethoate; manufacturer: BASF) and the fungicide Abacus (BASF) were applied.

Crop treatments were carried out using a Euro-Pulve boom sprayer of the compressor type ("bicycle" model), equipped with TeeJet 1 XR 11003-VP nozzles. The working fluid consumption was 250 L/ha, the working pressure – 3.0 kPa/atm, with six nozzles and a sprayer boom width of 3 m. The experiments were arranged in four replications using a systematic plot layout. The total plot area was 50 m², and the accounting area – 20 m² (Ushkarenko et al., 2014).

The grain yield of maize hybrids was determined by manual harvesting of ears, followed by measurement of grain harvest moisture, threshing, and conversion of yield to 14% grain moisture content. The harvested ears of corn from the plot were weighed, threshed, the grain moisture content was determined (by thermostatic drying at a temperature of 103 °C to constant mass), the grain yield per ear with subsequent conversion to standard yield. (Figures 1–5)

## RESULTS AND DISCUSSIONS

The analysis of humus content dynamics in different soil layers over a six-year rotation showed that, without the application of a chemical ameliorant (gypsum at a rate of 5 t/ha), the greatest losses occurred in the 0–10 cm soil layer (Table 1). In the 10–20 cm and 20–30 cm layers, the decrease in humus content was approximately two times smaller. The loss of humus under the application of the chemical ameliorant was twice as low compared to the variants without ameliorant use.

Fluctuations in humus content and the possible decreasing trend were minor: the deviation from the baseline year (2020) ranged from 0.02–0.05% without the ameliorant to +0.01 – –0.01% with the ameliorant. Thus, the use of the chemical ameliorant reduced humus losses in the 0–30 cm soil layer to within 0.01%.

The greatest humus losses were observed in the 0–10 cm soil layer (up to 0.05%), which may be associated with increased moisture supply in this layer under drip irrigation and higher root system activity. The fluctuation of humus content values in the soil over the five-year period remained within the margin of error under the technology without ameliorant use and was even smaller with the application of the chemical ameliorant. This indicates the feasibility of continuous maize cultivation under irrigation without significant losses of humus in the arable soil layer.

The bulk density of medium-loamy dark chestnut soil under continuous maize cultivation with drip irrigation was more indicative for analysis (Table 2). Without the application of a chemical ameliorant, the bulk density increased by 1.90–4.70% compared to the baseline year of 2020. The highest soil compaction was observed in the 10–20 cm layer. In this horizon, the bulk density increased from 1.340 to 1.405 g/cm³ over the five-year period of continuous maize cultivation without ameliorant application, whereas with

**Figure 1.** Treatment of maize with means of protection against harmful organisms at the stage of corn development BBCH 15

**Figure 2.** Treatment of maize plants with means of protection against harmful organisms at the stage of corn development BBCH 65

ameliorant use, the bulk density increased only slightly – from 1.270 to 1.280 g/cm³, which is six times less compared to the variant without ameliorant. Bulk density was generally higher in the deeper soil layers (10–20 cm and 20–30 cm) during all study years, regardless of ameliorant application. In the 0–30 cm soil layer, the bulk density without ameliorant increased from 1.336 g/cm³ in 2020 to 1.386 g/cm³ in 2025 (an increase of 3.74%). Under chemical ameliorant application, bulk density in the 0–30 cm layer decreased from 1.336 to 1.259 g/cm³ in 2020 and from 1.386 to 1.260 g/cm³ in 2025, indicating the high efficiency of chemical ameliorant use under long-term continuous maize cultivation.

The dynamics of porosity in medium-loamy dark chestnut soil under continuous maize cultivation at the end of the growing season showed a tendency toward decreased porosity in the absence of chemical ameliorant application (Table 3). In absolute terms, soil porosity decreased by 1.7–2.0%, and in relative terms by 2.9–4.0%. The application of the chemical ameliorant slowed down the reduction in porosity by almost an order of magnitude – to 0.2 relative percent.

Soil compaction increased with depth, reaching its maximum in the 20–30 cm layer. The porosity of all soil horizons was significantly higher under the application of the chemical ameliorant, indicating an improvement in the soil aeration regime under maize cultivation with drip irrigation.

In the study, maize hybrids of different FAO maturity groups – from 190 to 430 – were used. These hybrid maturity groups correspond to the agro-climatic potential of the Southern Steppe zone of Ukraine. A decrease or increase in the

**Figure 3.** Preparation of soil samples for analysis of humus content

**Figure 4.** Addition of a chromic mixture (a mixture of potassium dichromate and sulfuric acid) to crushed, sieved, and weighed soil samples. Initial stage of soil analysis for organic matter determination

**Figure 5.** Marchenko Tetiana and Donets Andrii determining the degree of damage to maize plants of continuous maize cultivation *Helicoverpa armigera* (Hübner)

FAO group leads to yield losses either due to a low genetic potential (FAO below 190) or an insufficient number of effective temperatures for grain formation (FAO above 450). The highest average grain yields across factors were observed in the hybrids Askaniya (FAO 320) and Vira (FAO 430), amounting to 11.60 and 12.12 t/ha, respectively (Table 4). These hybrids demonstrate

**Table 1.** Dynamics of humus content in medium-loamy dark chestnut soil on carbonate loess under continuous maize cultivation with drip irrigation, %

| Experimental variant | Soil layer, cm | Years of research | | | | | | Changes in 2025 compared to 2020 | |
|---|---|---|---|---|---|---|---|---|---|
| | | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | Absolute values | Relative, % |
| Without ameliorant | 0–10 | 2.75 | 2.75 | 2.74 | 2.74 | 2.71 | 2.70 | –0.05 | –1.82 |
| | 10–20 | 2.70 | 2.70 | 2.69 | 2.69 | 2.68 | 2.68 | –0.02 | –0.74 |
| | 20–30 | 2.37 | 2.36 | 2.35 | 2.35 | 2.35 | 2.34 | –0.03 | –1.27 |
| | 0–30 | 2.61 | 2.60 | 2.59 | 2.59 | 2.58 | 2.57 | –0.04 | –1.53 |
| With ameliorant | 0–10 | 2.75 | 2.75 | 2.73 | 2.74 | 2.74 | 2.74 | –0.01 | –0.36 |
| | 10–20 | 2.70 | 2.70 | 2.71 | 2.70 | 2.71 | 2.71 | +0.01 | +0.37 |
| | 20–30 | 2.37 | 2.36 | 2.36 | 2.36 | 2.36 | 2.36 | –0.01 | –0.42 |
| | 0–30 | 2.61 | 2.60 | 2.60 | 2.60 | 2.60 | 2.60 | –0.01 | –0.38 |
| $LSD_{05}$ | | 0.11 | 0.12 | 0.09 | 0.10 | 0.09 | 0.08 | | |

**Table 2.** Dynamics of bulk density of medium-loamy dark chestnut soil under continuous maize cultivation with drip irrigation, g/cm³

| Experimental variant | Soil layer, cm | Years of research | | | | | | Changes in 2025 compared to 2020 | |
|---|---|---|---|---|---|---|---|---|---|
| | | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | Absolute values | Relative, % |
| Without ameliorant | 0–10 | 1.298 | 1.303 | 1.301 | 1.342 | 1.350 | 1.358 | +0.060 | +4.62 |
| | 10–20 | 1.340 | 1.351 | 1.374 | 1.386 | 1.405 | 1.403 | +0.063 | +4.70 |
| | 20–30 | 1.371 | 1.376 | 1.380 | 1.391 | 1.392 | 1.397 | +0.026 | +1.90 |
| | 0–30 | 1.336 | 1.343 | 1.351 | 1.373 | 1.382 | 1.386 | +0.050 | +3.74 |
| With ameliorant | 0–10 | 1.199 | 1.201 | 1.203 | 1.198 | 1.205 | 1.195 | –0.004 | –0.33 |
| | 10–20 | 1.270 | 1.273 | 1.274 | 1.279 | 1.281 | 1.280 | +0.010 | +0.79 |
| | 20–30 | 1.307 | 1.315 | 1.310 | 1.304 | 1.302 | 1.305 | –0.002 | –0.15 |
| | 0–30 | 1.259 | 1.262 | 1.262 | 1.260 | 1.262 | 1.260 | +0.001 | +0.08 |
| $LSD_{05}$ | | 0.045 | 0.039 | 0.042 | 0.053 | 0.048 | 0.044 | | |

**Table 3.** Dynamics of porosity in medium-loamy dark chestnut soil under continuous maize cultivation with drip irrigation, %

| Experimental variant | Soil layer, cm | Years of research | | | | | | Changes in 2025 compared to 2020 | |
|---|---|---|---|---|---|---|---|---|---|
| | | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | Absolute values | Relative, % |
| Without ameliorant | 0–10 | 58.3 | 58.0 | 57.4 | 56.9 | 56.8 | 56.6 | –1.7 | –2.9 |
| | 10–20 | 54.5 | 54.2 | 53.2 | 52.9 | 52.7 | 52.5 | –2.0 | –3.7 |
| | 20–30 | 50.6 | 50.3 | 49.7 | 49.5 | 48.8 | 48.6 | –2.0 | –4.0 |
| | 0–30 | 54.4 | 54.2 | 53.4 | 52.8 | 52.7 | 52.6 | –1.8 | –3.3 |
| With ameliorant | 0–10 | 61.2 | 61.0 | 60.9 | 60.9 | 61.0 | 61.3 | +0.1 | +0.2 |
| | 10–20 | 55.4 | 55.3 | 55.0 | 55.2 | 55.2 | 55.3 | –0.1 | –0.2 |
| | 20–30 | 51.1 | 51.2 | 51.3 | 51.2 | 51.0 | 51.2 | +0.1 | +0.2 |
| | 0–30 | 55.9 | 55.8 | 55.7 | 55.7 | 55.7 | 55.9 | +0.0 | +0.0 |
| $LSD_{0.05}$ | | 2.31 | 1.87 | 2.14 | 2.40 | 2.15 | 2.03 | | |

**Table 4.** Dynamics of grain yield of maize hybrids of different FAO maturity groups under continuous cropping, depending on chemical ameliorants and plant protection systems against harmful organisms

| Soil and plant protection system (Factor A) | Hybrid, FAO group (Factor B) | Grain yield by years, t/ha (Factor C) | | | | | | Average by factor, t/ha | |
|---|---|---|---|---|---|---|---|---|---|
| | | 2021 | 2022 | 2023 | 2024 | 2025 | Average | A | B |
| Without chemical ameliorant; without plant protection (control) | Stepoviy, FAO 190 | 9.67 | 9.26 | 8.32 | 7.45 | 7.54 | 8.45 | | 9.60 |
| | Skadovskiy, FAO 290 | 11.76 | 10.24 | 8.50 | 8.14 | 8.31 | 9.39 | | 10.98 |
| | Askania, FAO 320 | 12.78 | 10.04 | 9.41 | 8.03 | 8.14 | 9.68 | | 11.60 |
| | Vira, FAO 430 | 13.65 | 11.13 | 9.04 | 7.14 | 7.95 | 9.78 | | 12.12 |
| | Average | **11.97** | **10.17** | **8.82** | **7.69** | **7.99** | | 9.33 | |
| Without ameliorant; integrated plant protection | Stepoviy, FAO 190 | 10.25 | 10.11 | 9.85 | 9.30 | 9.56 | 9.81 | | |
| | Skadovskiy, FAO 290 | 12.43 | 11.48 | 11.78 | 11.40 | 11.89 | 11.80 | | |
| | Askania, FAO 320 | 13.54 | 13.22 | 13.04 | 12.87 | 12.97 | 13.13 | | |
| | Vira, FAO 430 | 14.36 | 14.12 | 13.65 | 13.02 | 13.11 | 13.65 | | |
| | Average | **12.65** | **12.23** | **12.08** | **11.65** | **11.88** | | 12.10 | |
| With chemical ameliorant; without plant protection | Stepoviy, FAO 190 | 9.89 | 9,35 | 8.25 | 7.74 | 7.89 | 8.62 | | |
| | Skadovskiy, FAO 290 | 11.96 | 10.81 | 8.79 | 8.35 | 8.65 | 9.71 | | |
| | Askania, FAO 320 | 12.82 | 10.87 | 10.03 | 8.45 | 8.92 | 10.22 | | |
| | Vira, FAO 430 | 13.96 | 11.60 | 9.84 | 8.14 | 8.55 | 10.42 | | |
| | Average | **12.16** | **10.66** | **9.23** | **8.17** | **8.50** | | 9.74 | |
| With chemical ameliorant + integrated plant protection | Stepoviy, FAO 190 | 11.70 | 11.55 | 11.82 | 11.17 | 11.25 | 11.50 | | |
| | Skadovskiy, FAO 290 | 13.04 | 12.87 | 13.22 | 12.91 | 13.15 | 13.04 | | |
| | Askania, FAO 320 | 13.54 | 13.44 | 13.70 | 12.89 | 13.30 | 13.37 | | |
| | Vira, FAO 430 | 15.43 | 15.18 | 14.67 | 13.89 | 13.88 | 14.61 | | |
| | Average | **13.43** | **13.26** | **13.35** | **12.72** | **12.90** | | 13.13 | |
| Mean by factor C | | 12.55 | 11.58 | 10.87 | 10.06 | 10.03 | 11.05 | | |
| $LSD_{05}$, т/га | | For partial differences: A =0.45; B=0.39; C=0.31 | | | | | | | |
| | | For the average (main) effects: A=0.41; B=0.35; C=0.38 | | | | | | | |

high adaptability to the agroecological conditions of the steppe zone of Ukraine and an enhanced genotypic productivity potential under irrigation. Significantly lower average yields were obtained from the hybrids Stepovyi (FAO 190) and Skadovskyi (FAO 290), reaching 9.60 and 10.98 t/ha, respectively. The grain yield of maize hybrids, averaged across hybrid composition and variants of soil and plant protection, decreased considerably over five years of continuous cropping – from 12.55 to 10.03 t/ha. However, an important factor mitigating the yield decline was the plant protection system combined with the application of a chemical ameliorant. Without the use of ameliorant and plant protection against harmful organisms, the most significant decrease in grain yield was recorded – from 11.07 to 7.99 t/ha on average across hybrids over five years of continuous cultivation.

The greatest yield losses by the fifth year were observed in the most productive hybrids, Askaniya and Vira – from 12.78 to 8.14 t/ha and from 13.65 to 7.95 t/ha, respectively. Early-maturing hybrids such as Stepovyi (FAO 190) and Skadovskyi (FAO 290) showed less sensitivity to the duration of continuous cropping. Notably, by the fifth year, these early-maturing hybrids achieved nearly the same yield level (7.54 and 8.31 t/ha) as the more productive (potentially) hybrids Askaniya and Vira (8.14 and 7.95 t/ha).

In the variant with the application of the plant protection system but without chemical ameliorant, the average yield of hybrids was significantly higher both in the first year of cultivation (12.65 t/ha) and in the fifth year of continuous cropping (11.88 t/ha). This indicates that the plant protection system against harmful organisms has a significant impact on stabilizing maize grain yield under five-year period monocropping conditions. When the plant protection system was used, the five-year yield decline was smaller in hybrids with a shorter vegetation period. Thus, in the hybrids Stepovyi (FAO 190), Skadovskyi (FAO 290), and Askaniya (FAO 320), the yield decreased by 0.69, 0.54, and 0.57 t/ha, respectively, while in the hybrid Vira (FAO 430) it decreased by 1.25 t/ha, indicating its higher sensitivity to continuous cropping.

The use of a chemical ameliorant without plant protection had a lesser effect on yield stabilization under continuous cropping compared to the variant with plant protection but without ameliorant. On average across hybrids, the grain yield decreased from 12.16 t/ha in the first year of monocropping to 8.50 t/ha in the fifth year. The grain yield of hybrids in the fifth year of continuous cropping was slightly higher (by 0.51 t/ha) compared to the control variant. The application of a chemical ameliorant without plant protection proved less effective than the plant protection system. By the fifth year of continuous cropping, the yield of maize hybrids with different productivity potentials had nearly leveled off. The highest yield was recorded in the medium-maturing hybrid Askaniya (8.92 t/ha), while the late-maturing hybrid Vira, despite its higher potential productivity, reduced its yield from 13.96 to 8.55 t/ha (by 38.8%). Therefore, it can be concluded that among the means of stabilizing grain yield under continuous maize cropping, plant protection systems are the most effective. Soil fertility-preserving measures play a secondary role in maintaining yield stability, but a primary role in preserving soil fertility itself.

The combined application of plant protection systems and soil fertility-preserving measures showed the highest efficiency during long-term continuous maize cultivation. On average, the grain yield of maize hybrids decreased by only 0.53 t/ha over five years of continuous cropping. However, the minimal yield reduction occurred in hybrids with a shorter vegetation period. By the fifth year of monocropping, the yield of hybrids Stepovyi (FAO 190), Skadovskyi (FAO 290), and Askaniya (FAO 320) decreased by 0.45, 0.24 t/ha, respectively, while the yield of Skadovskyi (FAO 290) remained at the level of the initial year (fluctuations within the LSD range). A significant yield decrease was observed in the late-maturing hybrid Vira. The grain yield of this hybrid during the first two years was 15.43 and 15.18 t/ha, respectively, and in the following three years, it gradually decreased by 0.76, 1.54, and 1.53 t/ha. The yield decline in the late-maturing hybrid Vira was associated with its longer vegetation period and greater exposure to harmful organisms. The accumulation of phytopathogens and harmful insects progressively increases under continuous cropping, making hybrids with longer vegetation periods more vulnerable due to longer exposure to invasive pressure and the higher number of pathogen and insect generations.

## CONCLUSIONS

The use of five-year continuous maize cropping under surface drip irrigation conditions in the Southern Steppe of Ukraine is feasible without a significant reduction in grain yield, provided that integrated plant protection against harmful organisms and the application of a chemical soil ameliorant are implemented. Among the means of yield stabilization in continuous maize cultivation, plant protection systems play the most decisive role. Measures aimed at preserving soil fertility are of secondary importance for yield stability, yet of primary importance for maintaining soil fertility itself. The genotype of the maize hybrid – particularly its FAO maturity group and resistance to pests and diseases – has a substantial influence on the stabilization of grain yield under continuous cropping conditions.

The application of a chemical soil ameliorant makes it possible to maintain the agrophysical parameters of medium-loamy dark chestnut soil at a sufficiently high fertility level during continuous maize cultivation under drip irrigation. Over a five-year period, fluctuations in soil humus content remained within the margin of error under the technology without ameliorant use and were even smaller with the use of the chemical ameliorant. This indicates the feasibility of continuous maize cultivation under irrigation without significant losses of humus in the arable soil layer.

Without the ameliorant, soil bulk density increased by 1.5–4.8% compared to the baseline year. The most pronounced compaction occurred in the 10–20 cm horizon without the ameliorant. In contrast, the use of the chemical ameliorant allowed the initial bulk density parameters to be maintained throughout continuous maize cultivation. In the 0–30 cm soil layer, bulk density decreased from 1.336 g/cm³ to 1.259 g/cm³ in 2020 and from 1.386 g/cm³ to 1.260 g/cm³ in 2025, indicating the high long-term effectiveness of chemical ameliorant application under continuous maize cropping.

However, the use of the chemical ameliorant without plant protection did not ensure yield stabilization of maize hybrids under continuous cropping. Under such conditions, the grain yield of hybrids decreased from 12.16 t/ha to 8.50 t/ha over the five-year period.

On average, across all studied factors, the grain yield of maize hybrids decreased by 1.50 t/ha (11.92%) over five years of continuous cropping. The smallest yield reductions occurred in hybrids with a shorter vegetation period when both chemical ameliorant and integrated plant protection were applied. In the fifth year of monoculture, yield reductions in the hybrids Stepovyi (FAO 190) and Askaniia (FAO 320) amounted to 0.45 and 0.24 t/ha, respectively, while the yield of Skadovskyi (FAO 290) remained at the baseline level (fluctuations within LSD).

A significant yield reduction was observed in the late-maturing hybrid Vira (FAO 430). The grain yield of this hybrid during the first two years was 15.43 and 15.18 t/ha, respectively, but declined over the next three years by 0.76, 1.54, and 1.53 t/ha. The decrease in yield for the late-maturing hybrid is attributed to its longer vegetation period, higher invasive load duration, and the increased number of pest generations during the growing season.

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