Influence of growing white mustard under the conditions of the Southern Steppe of Ukraine

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ABSTRACT

This research assesses the impact of white mustard (Sinapis alba L.) cultivation on soil characteristics and agroecosystem productivity in Ukraine's Southern Steppe. The study examined southern chernozems, evaluating the physical and chemical parameters of the soil prior to and following mustard planting. The results indicated that mustard cultivation markedly enhanced soil structure, evidenced by an increase in water-stable aggregates (56-60% versus 42-45% in the control group). It also improved water infiltration rates (3.5-3.8 mm/min compared to 2.1-2.4 mm/min), moisture retention, and decreased bulk density (1.18-1.22 g/cm³ compared to 1.28-1.33 g/cm³). Furthermore, the crop elevated humus content to 3.00-3.05% and yielded 3.5-4.0 t/ha of dry organic matter, hence enhancing the soil's nutritional composition. The chemical enhancements comprised elevated concentrations of nitrogen, phosphorus, potassium, calcium, and magnesium, which are vital for facilitating plant growth. Furthermore, white mustard demonstrated a decrease in wind and water erosion losses, hence improving soil resilience. The crop exhibited competitive benefits by decreasing weed infestation by 58-62%, hence fostering more sustainable agricultural practices in the region. The findings indicate that white mustard is a viable green manure crop for promoting soil fertility, reducing erosion, and bolstering agroecosystem resilience in semi-arid areas such as the Southern Steppe. Additional investigation is advised to examine its enduring effects across various agroecological regions.

***Keywords**:* Erosion resistance, humus complexes, organic matter, soil fertility, water permeability,

INTRODUCTION

The relevance of the topic arises from the need to adapt agricultural production to climate change occurring in the Southern Steppe of Ukraine. This region is characterized by unstable moisture supply, high summer temperatures, frequent droughts, and declining soil fertility (Lykhovyd *et al.,* 2023; Goloborodko *et al.,* 2024). Loss of humus, alongside increasing risks of erosion and salinisation, has limited the potential for stable farming. M'hammed *et al.* (2025) demonstrated that steppe zones are characterised by high sensitivity to aridity, unstable vegetation cover, and increased vulnerability to soil degradation and desertification under irregular precipitation and anthropogenic pressure. Under such conditions, the use of phytomeliorative crops becomes particularly important. Phytomeliorative crops, such as white mustard, are utilised primarily to enhance soil quality by improving its physical and chemical characteristics. These crops enhance soil fertility by augmenting organic matter, refining soil structure, and mitigating erosion. They can also rehabilitate soil health in damaged or dry environments. Conversely, green manure crops are generally cultivated and subsequently incorporated into the soil to enhance organic matter and nutritional content (Vyshnevsky and Vyshnivskyi, 2024). The primary distinction resides in their overarching function, whereas green manure crops primarily enhance soil nutrient content, phytomeliorative crops additionally improve soil structure, moisture retention, and mitigate soil erosion. White mustard owing to its rapid growth, substantial green mass, and allelopathic properties, can simultaneously improve the physical and chemical properties of the soil and reduce weed infestation (Valujeva *et al.,* 2022; 2024). Its use is regarded as one of the approaches to enhancing the resilience of agroecosystems to climate-related risks. The research problem stems from the insufficient study of the integrated effects of white mustard on the soil and climatic conditions of the Southern Steppe and on agroecosystem productivity (Panfilova *et al.,* 2025). A systematic assessment that includes changes in soil physical properties, chemical composition, levels of heavy metals, and after-effects on subsequent crops has been insufficiently presented. This limits the practical application of mustard as a universal crop with phytomeliorative potential and highlights the need to clarify its role in improving the ecological and agronomic resilience of farming systems.

This study aimed to assess the influence of white mustard plants on the physical and chemical properties of the soil under the conditions of the Southern Steppe of Ukraine. The research tasks involved identifying changes in the physicochemical properties of the soil under the influence of agrotechnical practices that affected the agronomic and biological indicators of the crop in this region.

MATERIALS AND METHODS

A study was conducted in 2024 at the Educational, Scientific and Practical Centre of Mykolaiv National Agrarian University (Mykolaiv Region). The experiment used the white mustard variety Vesnianka, which is characterized by rapid initial growth, high green mass yield, and resistance to dry conditions. The selection of this variety was justified by its adaptability to the steppe zone and its suitability for use in green manure crop rotations. Sampling was carried out in triplicate on accounting plots of 25 m². In analyzing the climatic characteristics of the region and assessing their influence on the crop, standard methodologies were applied (Voloshchuk, 2023). The experiment was performed on a singular representative soil type – southern chernozem, which predominates in the experimental field. White mustard was sown in early spring, in April, when the soil temperature reached 6-8 °C. The crop was harvested approximately 120 days after sowing, in early August.

Humus content in the upper horizon and deeper layers was determined according to DSTU 7855:2015 Soil quality. Determination of the group composition of humus by the Tyurin method in the modification of Kononova and Belchykova (DSTU 7855:2015, 2015) using a Shimadzu UV-1800 spectrophotometer (Japan). Soil solution pH was measured potentiometrically with a Hanna HI 2211 pH meter (USA). Bulk density was determined using Eijkelkamp cylinders (Netherlands), and total porosity was calculated relative to the solid phase. Climatic – including mean annual air temperature, July-August temperatures, January temperature and absolute summer maximum, precipitation, and the duration of rainless periods – were recorded using meteorological station data (Meteoblue, 2025). Available moisture reserves under favourable and dry conditions were measured gravimetrically by oven-drying samples in a Binder ED115 drying cabinet (Germany). Relative air humidity in winter, spring, summer, and during drought periods was assessed using psychrometric observations (Assmann Psychrometer, Germany). The speed and duration of dry winds were measured with a Testo 405-V1 anemometer (Germany). Soil solution electrical conductivity in saline areas was measured with a Mettler Toledo Seven Compact conductivity meter (Switzerland).

To assess the influence of white mustard on the physical state of the soil, samples were collected from the 0-10 cm and 0-20 cm layers in triplicate before sowing, at the budding stage, when the plant starts to develop buds (undeveloped flower) before flowering, and after harvesting. Water-stable aggregates were determined by the wet-sieving method using an Eijkelkamp Wet Sieving Apparatus (Netherlands). The rate of water infiltration was measured with an Eijkelkamp ring infiltrometer (Netherlands). Available moisture reserves in the one-metre layer were assessed gravimetrically in a Binder ED115 drying cabinet (Germany). Bulk density in the 0-10 cm layer was measured using Eijkelkamp cylinders (Netherlands). Wind erosion losses were monitored using field dust collectors (Ukraine), while water erosion was assessed by measuring the volume of rills formed after heavy rainfall. Residual dry organic matter after the growing season was determined by weighing on Kern ABT 120-5DM analytical balances (Germany). The content of organic matter was analysed using the Tyurin method in the Kononova-Belchykova modification (DSTU 7855:2015, 2015).

To analyse changes in the chemical composition of the soil under the influence of white mustard, samples were collected from the 0-10 and 0-20, layers in triplicate. Humus content was determined according to DSTU 7855:2015 (2015), total nitrogen by the Kjeldahl method (Nitrogen analysis, 2024) using a Gerhardt Vapodest 50 apparatus (Germany), and the C:N ratio (the ratio of carbon to nitrogen) with an Elementar Vario EL Cube elemental analyser (Germany). Available phosphorus was determined according to DSTU 4115:2002 (2002), and exchangeable potassium was measured photometrically using a BWB-XP flame photometer (United Kingdom). Sulphur was determined by the turbidimetric method using a Shimadzu UV-1800 spectrophotometer (Japan). Calcium and magnesium were measured by titrimetric methods, and) and soil solution pH was measured potentiometrically.

Soil microbiological activity and enzymatic processes under the influence of white mustard were assessed by the abundance of key microbial groups and functional enzymatic indicators in the 0-20 cm layer. The total number of microorganisms, as well as cellulolytic, nitrogen-fixing forms, actinomycetes, and microscopic fungi, was determined using the serial dilution method with plating on nutrient media in a Binder BD 115 incubator (Germany).

Dehydrogenase activity was assessed by the formation of triphenylformazan (TPF) using the TTC reduction method with a Shimadzu UV-1800 spectrophotometer (Japan). Catalase activity was measured by the gasometric method based on the volume of released oxygen using an OxiTop® IS 6 system, WTW (Germany). Urease activity was determined colourimetrically by the amount of ammonium formed, using a PhotoLab S6 photometer, WTW (Germany). The microbial carbon pool was determined by the fumigation-extraction method followed by analysis with a Shimadzu TOC-L analyser (Japan). Comparisons were made between the control plots (without mustard) and the experimental plots (with white mustard sowing).

Agronomic parameters included the determination of green mass yield. Plant height was measured on days 7-9, after 20-25 days, at the budding stage, and at the onset of flowering. Leaf surface area was measured using a LI-3100C Area Meter (LI-COR, USA). Weed dry matter was recorded by weighing samples on Kern ABT 120-5DM analytical scales (Germany), and the reduction in overall weed infestation was expressed as a percentage. The competitiveness coefficient was calculated as the ratio of crop biomass increase to weed biomass reduction according to formula (1):

$$C = \frac{B_{mustard}}{B_{weeds}}, (1)$$

where C is the competitiveness coefficient, $B_{mustard}$ is the biomass increase of white mustard (t/ha), and B_{weeds} is the reduction in weed biomass under the mustard canopy (t/ha).

Data were processed using analysis of variance (ANOVA) with the Statistica 12.0 software package (StatSoft, USA). The significance of differences between treatments was determined using Fisher's and Student's criteria at a significance level of $p \leq 0.05$.

RESULTS AND DISCUSSION

Agroclimatic conditions of the Southern steppe of Ukraine and their impact on agricultural practices

The Southern Steppe of Ukraine exhibits a demanding agroclimatic landscape marked by significant temperature fluctuations and scarce rainfall. The region exhibits a pronounced continental climate, with yearly air temperatures fluctuating between 10.1°C and 10.8°C, and notably elevated summer temperatures, particularly in July and August, averaging between 23.7°C and 24.9°C. The severity of the climate is accentuated by frigid winters with temperatures plummeting to -2.5°C to -3.8°C in January, and sporadic intense summer heat, with maximum temperatures soaring to 40°C. The climatic conditions are exacerbated by erratic rainfall patterns, with total annual precipitation between 320 and 420 mm, approximately 70% of which occurs in the warm season. The region is susceptible to prolonged dry spells, lasting 25-30 days in the summer, which presents a considerable threat to agricultural productivity, particularly under drought conditions (Table 1). Elevated summer temperatures, combined with recurrent and extended drought periods, lead to significant moisture shortages in the soil, particularly during peak growing seasons. This may constrain crop growth and severely diminish yields. Moreover, the low relative humidity throughout summer (35-40%) intensifies evaporation rates, rendering water retention in the soil increasingly vital for crop viability. Wind erosion, propelled by arid winds attaining velocities of 15-20 m/s, intensifies the soil's susceptibility, complicating the preservation of soil fertility and structure. Notwithstanding these obstacles, the agroclimatic conditions of the Southern Steppe offer potential for drought-resistant crops that can boost soil resilience, such as white mustard, which exhibits drought tolerance and contributes to soil stabilisation and fertility improvement.

Physical and chemical properties of soil before cultivation of white mustard in the Southern Steppe of Ukraine

Based on the data regarding the physical and chemical properties of the soil before the cultivation of white mustard (cv. Vesnianka), the Southern Steppe soils exhibit specific characteristics that influence the growth potential of crops. The soil in this region is primarily southern chernozem, which is known for its relatively fertile qualities. Humus content in the upper horizon ranges between 2.8% and 3.4%, which is moderately high, but it decreases in deeper layers, reaching 1.2%-1.5%. This suggests a soil profile that supports organic matter in the upper soil layers, essential for nutrient availability and microbial activity. The pH of the soil solution ranges from 6.5 to 7.3, indicating near-neutral conditions, which is ideal for most crop nutrient absorption. Additionally, bulk density values range from 1.25 to 1.32 g/cm³, and total porosity is between 49% and 52%, reflecting well-structured soil capable of supporting plant root development and water infiltration (Table 2). Available moisture reserves in the one-meter soil layer, which range from 125-135 mm under favourable conditions and 95-105 mm under dry conditions, are critical in determining the soil's water retention capacity and its ability to withstand periods of drought. Electrical conductivity of the soil solution, ranging from 2.5 to 3.0 dS/m, (Table 2) indicates the presence of salts in the soil, which may affect crop growth, particularly if they accumulate to harmful levels. The soil's physical properties, such as bulk density and porosity, also suggest that the region's soils have good structure, promoting root growth while maintaining moisture availability. These soil characteristics collectively influence the suitability of the Southern Steppe for cultivating white mustard, a crop known for its drought tolerance and ability to improve soil structure and fertility.

Effect of white mustard cultivation on physical properties of soil in the Southern Steppe of Ukraine

The growth of white mustard (cv. Vesnianka) has significantly impacted the soil's physical attributes, notably enhancing its structure and moisture retention capacity (Table 3). In the 0-10 cm and 0-20 cm soil layers, critical characteristics include water-stable aggregates, water infiltration rate, accessible moisture reserves, bulk density, and organic matter content illustrate the crop's contribution to soil quality enhancement. Water-stable aggregates, essential for soil structure and erosion resistance, exhibit enhancement under mustard cultivation, indicating that the root system facilitates the binding of soil particles and enhances soil cohesion. Moreover, the rate of water infiltration is enhanced, signifying that mustard cultivation facilitates improved water circulation through the soil, hence augmenting its capacity to store moisture during arid intervals. The reduction in bulk density enhances soil porosity and root penetration, hence facilitating improved plant growth. The decrease in wind and water erosion losses illustrates mustard's capacity to stabilise soil, alleviating degradation in erosion-prone regions. Residual dry organic matter persists in the soil post-growing season, augmenting soil fertility, while the elevation in organic matter content further enhances the soil's nutrient composition. These modifications illustrate the advantageous effects of white mustard on soil physical qualities, particularly in areas such as the Southern Steppe, where drought and soil erosion are ongoing issues.

Effect of white mustard cultivation on chemical properties of soil in the Southern Steppe of Ukraine

The growth of white mustard significantly influences the soil's chemical qualities, improving its fertility and nutrient availability. The humus concentration is significantly elevated in the 0-10 cm and 0-20 cm layers, which is crucial for enhancing soil structure, nutrient retention, and microbial activity. Moreover, the overall nitrogen concentration is augmented, facilitating improved plant growth and enhanced nutrient cycling. The soil's carbon-to-nitrogen ratio diminishes, signifying enhanced nitrogen availability, which is especially advantageous for succeeding crops. Improvements in available phosphorus and exchangeable potassium enhance the soil's nutritional status, which is essential for supporting plant growth. The rise in sulphur concentration is significant, as it aids in the synthesis of organic compounds and is integral to plant metabolism (Table 4). The enhancement in nitrogen, phosphorus, and potassium content, together with elevated calcium and magnesium levels, further augments soil fertility. These modifications are especially beneficial in the Southern Steppe region, where soils are susceptible to deterioration and nutrient depletion. The soil solution's pH, ranging from 6.3 to 6.5, is slightly acidic to neutral, fostering optimal nutrient availability while safeguarding plant growth. The enhancements in soil chemistry demonstrate the advantageous function of white mustard in augmenting soil fertility and resilience, particularly in dry and semi-arid areas.

Effect of white mustard cultivation on soil microbiological activity and enzymatic processes in the 0-20 cm soil layer

The cultivation of white mustard positively influences microbiological activity and enzymatic activities in the soil, particularly within the 0-20 cm layer (Table 5). The incorporation of this crop increases the overall microbial population in the soil, which is essential for enhancing soil fertility and enabling nutrient cycling. Cellulolytic microbes, which decompose plant leftovers, proliferate greatly during mustard production, enhancing organic material decomposition and improving soil structure. Nitrogen-fixing organisms, such as rhizobacteria, exhibit a significant increase, augmenting nitrogen availability in the soil and consequently benefiting subsequent crops. Actinomycetes, recognised for their function in organic matter decomposition and humic substance formation, exhibit heightened activity, hence improving soil health. The proliferation of tiny fungus is positively impacted, promoting a diversified and balanced microbial community that enhances soil resilience (Table 5). Enzymatic activities, including dehydrogenase, catalase, and urease, serve as critical indicators of soil microbial function and nutrient cycling. The heightened dehydrogenase activity indicates an escalation in overall microbial metabolism, essential for organic matter decomposition and nutritional accessibility. Likewise, catalase activity signifies increased oxidative activities in the soil, facilitating the detoxification of deleterious chemicals and fostering plant health. Urease activity, pivotal in nitrogen mineralisation, is also heightened, facilitating the availability of nitrogen from organic matter to plants. Furthermore, the microbial carbon pool, functioning as an energy reservoir for soil microorganisms, expands under mustard cultivation, indicating heightened microbial activity resulting from the degradation of mustard biomass.

Effect of white mustard cultivation on agronomic parameters

The production of white mustard has a significant impact on a number of agronomic indicators that characterize its growth and competitiveness under field conditions. The green mass yield is a vital metric of crop productivity, and white mustard exhibits a notable enhancement in biomass relative to control plots. This crop is recognised for its fast growth and significant biomass yield, rendering it an efficient green manure. The plant height measurements recorded at several intervals, days 7-9, 20-25, throughout the budding stage, and at the commencement of flowering, demonstrate the crop's robust growth. The elevation in plant height at each phase signifies the crop's capacity for rapid establishment and competition with weeds. The surface area of leaves is a crucial characteristic, since an increased leaf area correlates with heightened photosynthetic activity and improved water retention, hence enhancing overall crop output (Table 6). The efficacy of white mustard in inhibiting weeds is evidenced by the substantial decrease in weed dry biomass and total weed prevalence (Table 6). The biomass of weeds in mustard-planted fields is significantly reduced compared to control fields, demonstrating mustard's competitive superiority in resource acquisition, including water, light, and nutrients. The eradication of weed development is essential in the Southern Steppe, where weeds can considerably affect crop output.

The research indicates that white mustard can markedly increase soil characteristics and boost agroecosystem productivity in Ukraine's Southern Steppe. The development of this green manure crop resulted in enhanced soil fertility, evidenced by improvements in humus content, water permeability, and microbial activity. The influence of white mustard on soil structure was demonstrated by its capacity to decrease bulk density, boost water infiltration rates, and augment the percentage of water-stable aggregates, all of which jointly enhance soil aeration and root system growth. Furthermore, the crop's influence on the soil's chemical qualities, such as elevated nitrogen, phosphorus, and potassium levels, substantiates its capacity to improve nutrient availability for future crops. White mustard exhibited a significant decrease in weed infestation, highlighting its competitive superiority in agricultural settings. These findings highlight the promise of white mustard as a sustainable agricultural method for improving soil health and resilience in areas susceptible to drought and soil erosion, like the Southern Steppe of Ukraine. Subsequent investigations should examine its enduring impacts and relevance in alternative agroecological regions encountering comparable environmental issues.

CONCLUSIONS

This study highlights the extensive ecological advantages of white mustard beyond just yield enhancement. Mustard enhances soil structure, increases organic matter, and reduces erosion, making it a viable choice for bolstering the environmental and agronomic resilience of Ukraine's Southern Steppe. These findings validate the crop's efficacy as both a green manure and a sustainable agricultural practice under the region's adverse climatic conditions. It is advisable to conduct additional research on mustard's long-term effects on soil health and its function in agroecosystem restoration.

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Table 1: Agroclimatic conditions of the Southern steppe of Ukraine

Parameter	Data range/details
Annual air temperature	10.1°C to 10.8°C
July-August temperatures	23.7°C to 24.9°C
January temperature	-2.5°C to -3.8°C
Absolute summer maximum	38°C to 40°C
Precipitation	320-420 mm annually, 70% in the warm season
Duration of rainless periods	25-30 days in summer
Relative air humidity	Winter: 65-70%, Spring: 50-55%, Summer: 35-40%, During Drought: 15-20%
Speed and duration of dry winds	15-20 m/s for more than 5 days in spring

Table 2: Physical and chemical properties of soil before cultivation of white mustard in the Southern steppe of Ukraine

Parameter	Data range/details
Humus content (Upper horizon)	2.8-3.4%
Humus content (deeper Layers)	1.2-1.5%
Soil solution pH	6.5-7.3 (slightly acidic to slightly alkaline)
Bulk density	1.25-1.32 g/cm³
Total porosity	49-52%
Available moisture reserves (favourable conditions)	125-135 mm
Available moisture reserves (dry conditions)	95-105 mm
Soil solution electrical conductivity	2.5-3.0 dS/m

Table 3: Effect of white mustard cultivation on physical properties of soil in the Southern steppe of Ukraine

Parameter	0-10 cm (After cultivation)	0-20 cm (After cultivation)
Water-stable aggregates	56%-60%	52%-55%
Rate of water infiltration	3.5-3.8 mm/min	3.2-3.5 mm/min
Available moisture reserves	125-135 mm	120-130 mm
Bulk density	1.18-1.22 g/cm³	1.20-1.25 g/cm³
Wind erosion losses	3-4 t/ha	4-5 t/ha
Water erosion	2-3 t/ha	3-4 t/ha
Residual dry organic matter	3.5-4.0 t/ha	3.2-3.8 t/ha
Content of organic matter	3.00%-3.05%	2.95%-3.00%

Table 4: Effect of white mustard cultivation on chemical properties of soil in the Southern steppe of Ukraine

Parameter	0-10 cm (After cultivation)	0-20 cm (After cultivation)
Humus content	3.00-3.05%	2.95-3.00%
Total nitrogen content	0.155-0.160%	0.150-0.155%
C:N ratio	9.6-9.8	9.7-10.0
Available phosphorus	18.2-18.9 mg/kg	17.5-18.2 mg/kg
Exchangeable potassium	102-106 mg/kg	98-102 mg/kg
Sulphur content	12.8-13.5 mg/kg	12.5-13.0 mg/kg
Calcium and magnesium content	29-31 mmol/100g (Ca), 6.0-6.3 mmol/100g (Mg)	28-30 mmol/100g (Ca), 5.8-6.1 mmol/100g (Mg)
Soil solution pH	6.3-6.4	6.3-6.5

Table 5: Effect of white mustard cultivation on soil microbiological activity and enzymatic processes in the 0-20 cm soil layer

Parameter	0-20 cm (After cultivation)
Total number of microorganisms	3.8-4.2 million CFU/g
Cellulolytic microorganisms	1.2-1.4 million CFU/g
Nitrogen-fixing forms	0.95-1.05 million CFU/g
Actinomycetes	0.85-0.90 million CFU/g
Microscopic fungi	0.40-0.45 million CFU/g
Dehydrogenase activity	0.85-0.88 mg TPF/g soil per day
Catalase activity	5.2-5.4 mL O□ /g soil per minute
Urease activity	34-36 mg NH□□ /g soil per day
Microbial carbon pool	385-410 mg C/kg soil

Table 6: Effect of white mustard cultivation on agronomic parameters

Parameter	Data (After cultivation)
Green mass yield	24.5-26.8 t/ha
Plant height (days 7-9)	6-8 cm
Plant height (after 20-25 days)	25-28 cm
Plant height (budding Stage)	100-110 cm
Plant height (onset of flowering)	100-110 cm
Leaf surface area	22.5-24.0 thousand m^2/ha
Weed dry matter	0.8-1.2 t/ha
Reduction in overall weed infestation	58-62%