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Миколаївський національний аграрний університет
54008, вул. Георгія Ґонґадзе, 9, м. Миколаїв, Україна
Тел.: +38(0512) 70-93-54
E-mail: info@bsagriculture.com.ua
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Editorial Board

ЗМІСТ / CONTENTS

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Formation of stable soil-protective agrophytocenoses of essential oil plants in the conditions of the Southern Steppe of Ukraine

Tetiana Manushkina
PhD in Agricultural Sciences, Associate Professor
Mykolaiv National Agrarian University
54008, 9 Georgiy Gongadze Str., Mykolaiv, Ukraine
https://orcid.org/0000-0001-5843-271X

Antonina Drobitko*
Doctor of Agricultural Sciences, Professor
Mykolaiv National Agrarian University
54008, 9 Georgiy Gongadze Str., Mykolaiv, Ukraine
https://orcid.org/0000-0002-6492-4558

Abstract. In the context of a significant environmental load on soil resources, the issue of restoring and maintaining the fertility of degraded and anthropogenically disturbed lands through phytoreclamation technology aimed at improving altered landscapes by creating a sustainable vegetation cover that can improve soil quality and restore its ecological functions is relevant. The aim of the study was to investigate the adaptive properties, growth and development processes, productivity formation and peculiarities of soil protection agrophytocenoses of English lavender and medicinal hyssop in anthropogenically transformed lands of the Southern Steppe of Ukraine. To achieve this goal, a field experiment was set up, phenological observations of plant development were carried out, and the peculiarities of the formation of soil-protective agrophytocenoses were studied. The survival rate of essential oil plants was high: English lavender – 89.7-92.5%, and medicinal hyssop – 85.9-90.5%. A high ability of lavender and hyssop to withstand adverse climatic conditions during wintering was found: during three years of cultivation, winter hardiness was 81.5-98.1%. Over the three years of vegetation, lavender plants formed shoots 50.7-51.3 cm high, the diameter of the bush was 62.4-89.6 cm, and the number of inflorescences was 594.9-650.3, which corresponds to their varietal characteristics. The highest yield of lavender plants was formed in the third year of vegetation – 5.29-5.84 t/ha at standard humidity. The maximum height of hyssop plants was reached in the third year of cultivation – 69.5-83.3 cm. The number of vegetative-generative shoots in the bush increased from the second year of vegetation, their number in the second year of cultivation was 54.5-67.1 pcs. and in the third year – 70.4-85.9 pcs. The highest yield of flower raw materials of hyssop was formed in the third year of cultivation – 10.94-12.43 t/ha. The highest rates of projective plant coverage were noted in the third year of cultivation: 75.2-83.7% in hyssop and 58.4-62.5% in English lavender, which allows to recommend the use of agrophytocoenoses of these essential oil plants for phytomelioration and reclamation of anthropogenically transformed territories in the Southern Steppe of Ukraine

Keywords: *Lavandula angustifolia* Mill.; *Hyssopus officinalis* L.; winter hardiness; performance; projective coating

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*Corresponding author

INTRODUCTION

In Ukraine, the priority tasks of the national environmental policy are the reclamation and rehabilitation of anthropogenically disturbed areas. Degraded soils, salt marshes, sloping lands, and technogenically contaminated areas are subject to restoration. The urgency of restoring agricultural land damaged by military operations has become particularly acute, particularly in the Southern region, where active hostilities took place and certain territories were occupied, and part of the Kherson region is still under occupation as of 2024. Researchers I. Bulba *et al*. (2024) found that the soils are currently contaminated with polutants, their structure is disturbed, erosion processes have intensified, and ammunition explosions have led to sinkholes, scrap metal accumulation, and heavy metal contamination.

Phytomelioration and reclamation are relevant ways to restore disturbed areas, which involve developing measures and carrying out comprehensive works to restore the productivity and aesthetic value of landscapes. The phytoremediation of such lands is aimed at improving anthropogenically altered landscapes by creating a sustainable vegetation cover that can improve soil quality. Phytomelioration plantations can have both practical (agrocenoses, forest plantations) and decorative purposes. Scientists A. Litalien & B. Zeeb (2020) consider the use of plants for soil restoration in the context of climate change. Since disturbed areas may contain polytunnels, it is not permissible to grow crops for human consumption. R. Dobrovolskyi *et al*. (2021) emphasise the expediency of using phytomeliorant soil consolidating plants, which include the perennial essential oil crops English lavender and medicinal hyssop, which are characterised by wide ecological plasticity. Agrophytocenoses from such crops can be economically profitable, as the demand for natural plant materials and essential oils is growing worldwide, and they can also be tourist attractions.

Lavandula angustifolia Mill. is a perennial evergreen shrub containing 1-3% of essential oils in its inflorescences. Lavender raw materials and essential oil are used in medicine, cosmetics, perfumery, and the food industry. Researchers K. Pokajewicz *et al*. (2021) and F. Radi *et al*. (2021) found that the main components of lavender essential oil are linalool (10-20%) and linalyl acetate (30-50%). The Southern Steppe zone of Ukraine with a temperate continental climate may be suitable for growing this crop due to its natural and climatic conditions. The study of N. Minev *et al*. (2022) and T. Manushkina *et al*. (2023) show that when applying optimal agrotechnological measures, lavender exhibits high adaptive properties, forms high-quality flower raw materials and is characterised by decorative qualities.

Hyssopus officinalis L. is grown as an essential oil and spice and flavour crop, used in medicine, canning and alcoholic beverage industries. F. Borrelli *et al*. (2019), V. Kumar *et al*. (2023) and G. Atazhanova *et al*. (2024) note that hyssop is characterised by medicinal properties, anti-inflammatory, astringent, tonic, wound healing, antioxidant and antimicrobial activity, as well as antifungal and antiviral properties in vitro. It is a perennial shrub, winter-hardy, a typical xerophyte, well adapted to drought, and undemanding to soil conditions. The positive results obtained in the work of P. Dobrovolskyi *et al*. (2021) indicate the prospects of research on hyssop cultivation in the Southern Steppe zone of Ukraine. However, the peculiarities of the formation of the productivity of English lavender and medicinal hyssop on depleted and degraded soils are still poorly understood. In this regard, it is relevant to determine the feasibility of using these species to create soil-protective agrophytocenoses on anthropogenically disturbed soils for their phytomelioration.

The aim of the research was to study the adaptive capabilities, peculiarities of growth, development, productivity formation and creation of soil-protective agrophytocenoses of English lavender and medicinal hyssop in the soil conditions of the Southern Steppe of Ukraine. The goal was achieved by solving the following tasks: to study the survival rate of plants and winter hardiness of English lavender and medicinal hyssop; to investigate the peculiarities of plant growth and development during three years of cultivation; to determine the yield of flower raw materials and the projected coverage of anthropogenically disturbed lands with plants in the Southern Steppe of Ukraine.

MATERIALS AND METHODS

The material for the research was English lavender *L. angustifolia* Mill. varieties Hemus and Imperial Gem and medicinal hyssop *H. officinalis* L. varieties Natsionalnyi and Markiz. The study was conducted in 2020-2023 on the basis of the farm Agrolife in Vitovskyi district of Mykolaiv region, a branch of the Department of Agriculture, Geodesy and Land Management of Mykolaiv National Agrarian University. The experimental plot of 0.45 hectares was an anthropogenically disturbed landscape due to the accumulation of construction waste and desolation. The soil of the experimental plot is Southern chernozem. The humus content in the topsoil is 2.75%, and the reaction of the soil solution is neutral (pH 6.6-6.8). The density of the topsoil is 1.12-1.20 g/cm^3, with a moisture content of 25.1-28.3%. In terms of the content of available forms of nutrients, the soil was characterised by low nitrogen availability, medium

mobile phosphorus availability, and high exchangeable potassium availability. No excess of heavy metals, radionuclides, or pesticides was detected in the soil. Meteorological conditions during the growing season of the research were characterised by high temperatures and moisture deficit. In addition, the unfavourable conditions included late spring and early autumn frosts, which significantly affected the duration of the growing season. In general, the natural climatic conditions of this zone are suitable for growing essential oil crops.

The field experiment was conducted in a randomised design. During the research, phenological, biometric and laboratory methods were used according to generally accepted methods (Ushkarenko *et al.*, 2016). A survey of the disturbed area was carried out at the experimental site to determine its suitability for plant cultivation and application of $N_{60}P_{60}K_{60}$ mineral fertiliser. The seedlings were planted in October 2020. The planting scheme for lavender plants was 1.2 × 0.5 m, and for hyssop plants – 0.75 × 0.5 m. Plant care included loosening row spacing, weed control, and drip irrigation. Soil moisture in the 30-40 cm layer was maintained at 90-80-70% of the lowest moisture capacity, and irrigation was stopped 14 days before harvesting the flower raw materials. Harvesting was carried out at the stage of technical ripeness, when the presence of 50% of flowers in the ear was noted. The gross harvest was calculated by weighing raw materials from the entire plot. The yield per hectare was converted to a standard moisture content of 70%. The mass fraction of moisture in the plant material was determined using the thermostat-weight method. The authors followed the recommendations of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (1979) and the Convention on Biological Diversity (1992). Mathematical processing of the research results was carried out using descriptive statistics and analysis of variance in MS Excel.

RESULTS AND DISCUSSION

Formation of agrophytocenosis *L. angustifolia* Mill. The survival rate of lavender plants of the Hemus variety was 92.5%, and of the Imperial Gem variety – 89.7%. In the areas where the seedlings did not take root, they were replanted, as it is necessary to form an optimal plant density from the first year of life, as plantation repairs are usually ineffective in the future, and the empty spaces left behind create favourable conditions for weeds to grow. The autumn and winter periods during the years of research were favourable for the growth and overwintering of lavender plants. The winter hardiness of plants was determined in the spring during the spring regrowth phase as the percentage of plants that did not die during the winter (Fig. 1; Table 1). Adaptation of plants to low temperatures is a complex physiological process that includes morphological and biochemical changes. First of all, adaptation is manifested in the adaptation of plant ontogeny to seasonal temperature conditions. The analysis of the data obtained shows that the winter hardiness of lavender plants was quite high – 82.7-98.1%. There was no significant difference in winter hardiness between the studied varieties. The obtained results allow to conclude that English lavender has high adaptive capabilities to negative environmental factors of the winter period in the research area.

Figure 1. *English lavender plants in the first year of cultivation, 2021*
Source: *authors' photo*

Table 1. *Winter hardiness of English lavender plants depending on the year of cultivation, 2021-2023*

Variety	Year of cultivation	Winter hardiness, % of viable plants
Hemus	First	90.5
	Second	92.3
	Third	98.1
Imperial Gem	First	82.7
	Second	95.0
	Third	96.5

Source: *authors' development*

English lavender is a perennial evergreen semi-bushy plant that forms a spherical bush 35-60 cm high. The results of determining the biometric parameters of English lavender are shown in Table 2.

Table 2. *Biometric parameters of English lavender plants, 2021-2023*

Variety	Year of cultivation	Bush height, cm	Bush diameter, cm	Number of inflorescences, pcs./bush
Hemus	First	31.0 ± 2.7	51.3 ± 4.8	81.2 ± 9.1
	Second	37.1 ± 2.3	73.4 ± 6.8	334.8 ± 37.0
	Third	50.7 ± 3.7	89.6 ± 9.4	650.3 ± 20.0
Imperial Gem	First	38.9 ± 4.0	44.7 ± 5.3	53.7 ± 8.8
	Second	45.3 ± 4.7	50.1 ± 5.3	297.3 ± 32.3
	Third	51.3 ± 1.4	62.4 ± 6.8	594.9 ± 30.3

Source: *authors' development*

The greatest increase in shoot height was observed in the first year of vegetation. The height of the shoots of the seedlings was 15.0 cm, so the growth in the first year in the studied varieties was 16.0-23.9 cm. During the second year of vegetation, the increase in bush height was 6.1-6.4 cm, and in the third year – 6.0-13.6 cm. The total increase in bush height during the cultivation period was 35.7-36.3 cm. Comparing the varieties with each other, it can be concluded that in the first two years of vegetation, the plants of Imperial Gem variety were taller than Hemus variety, and in the third year of vegetation, according to this parameter, the varieties did not differ significantly from each other, their height was 50.7-51.3 cm, which corresponds to their varietal characteristics.

Indicators of bush diameter for all years of research were significantly higher in the variety Hemus. The increase in the diameter of the bush in this variety in the second year of vegetation was 22.1 cm, and in the third year – 16.2 cm. In the Imperial Gem variety, the increase in the studied indicator was 5.4 cm in the second year of vegetation, and 12.3 cm in the third year. The diameter of the bush of Hemus variety compared to Imperial Gem variety was larger: in the first year of vegetation – by 6.6 cm (the difference is insignificant), in the second and third years of vegetation – by 23.3 cm and 16.2 cm, respectively, which is a significant difference between the varieties and is due to their genetic characteristics.

The analysis of the dynamics of the number of inflorescences in lavender plants showed that in the first year of vegetation 53.7-81.2 inflorescences per bush were formed, which is 9.0-12.5% of the number of inflorescences formed in the third year of vegetation. During the second year of vegetation, 4.1-5.5 times more inflorescences were formed compared to the first year, and compared to the third year, their number was 49.9-51.5%. When comparing the studied varieties, it was found that in all years of cultivation the number of inflorescences in the variety Hemus was significantly higher compared to the variety Imperial Gem. Thus, the largest number of inflorescences was formed in the third year of cultivation. The parameters of the yield structure of English lavender were determined during three years of cultivation (Table 3).

Table 3. *Crop structure parameters of English lavender, 2021-2023*

Variety	Year of cultivation	Inflorescence length, cm	Number of rings per inflorescence, pcs.	Number of flowers per half-ring, pcs.
Hemus	First	2.9 ± 0.3	4.3 ± 0.3	3.8 ± 0.4
	Second	4.1 ± 0.2	5.1 ± 0.5	4.7 ± 0.5
	Third	5.5 ± 0.5	6.4 ± 0.8	5.2 ± 0.1
Imperial Gem	First	3.9 ± 0.4	3.5 ± 0.4	2.9 ± 0.3
	Second	5.1 ± 0.7	4.2 ± 0.2	4.0 ± 0.1
	Third	6.8 ± 0.7	5.2 ± 0.1	6.4 ± 0.8

Source: *authors' development*

The parameters of the yield structure of lavender plants increased with increasing age of plants and in the third year of cultivation were as follows: inflorescence length 5.5-6.8 cm, number of rings in the inflorescence 5.2-6.4 pcs, number of flowers in the semi-ring 5.2-6.4 pcs. Differences between varieties in terms of yield structure were also found. In the third year of cultivation, the Imperial Gem variety formed inflorescences of the longest length – 6.8 cm and the number of flowers in a semi-ring – 6.4 pcs; the Hemus variety had the largest number of rings in an inflorescence – 6.4 pcs. The lavender inflorescences were harvested in

such a way that the length of the spikelet with the cut shoot was no more than 18 cm. Weighing and determination of the yield and moisture content of the raw materials were immediately carried out and the yield at standard moisture content was recalculated. The results are shown in Table 4.

Table 4. *Yield of English lavender, 2021-2023*

Variety	Year of cultivation	Yields, t/ha at standard moisture content	Increase by the first year, t/ha
Hemus	First	0.78	-
	Second	3.04	2.26
	Third	5.84	5.06
Imperial Gem	First	0.67	-
	Second	2.75	2.08
	Third	5.29	4.62
LSD_{05}	by variety factor	0.41	-
	by year of cultivation factor	1.87	-
	by the interaction of factors	2.07	-

Source: *authors' development*

Based on the results of studying the parameters of lavender productivity in the first year of vegetation, it can be concluded that the yield of Hemus and Imperial Gem varieties did not differ significantly and was low. In the second year of vegetation, this trend continued. The highest yield of lavender plants was formed in the third year of vegetation, and the yield of Hemus variety was significantly higher than that of Imperial Gem. In the first year of vegetation, the yield of plants was 12.7-13.4% of the yield in the third year, and in the second year – 52.0%.

Formation of agrophytocenosis *H. officinalis* L. The survival rate of medicinal hyssop plants in variety Natsionalnyi was 90.5%, variety Markiz – 85.9%. Winter hardiness in all years of the research was quite high, in the first year – 81.5-83.7%, and increased in the second and third years – 87.1-96.4%, which indicates high adaptive properties of the crop to a complex of adverse winter conditions (Table 5). Based on the study of the dynamics of growth processes of medicinal hyssop during three years of vegetation, it was found that the maximum plant height was reached in the third year of cultivation (69.5-83.3 cm), while the minimum plant height was recorded in the first year – 30.0-41.5 cm. The number of vegetative-generative shoots in the bush increased from the second year of life. In the second year, their average number was 54.5-67.1, and in the third year – 70.4-85.9 (Table 6; Fig. 2).

Table 5. *Winter hardiness of medicinal hyssop plants depending on the year of cultivation, 2021-2023*

Variety	Year of cultivation	Winter hardiness, % of viable plants
Natsionalnyi	First	81.5
	Second	87.1
	Third	96.4
Markiz	First	83.7
	Second	91.5
	Third	95.0

Source: *authors' development*

Table 6. *Biometric parameters of medicinal hyssop plants, 2021-2023*

Variety	Year of cultivation	Bush height, cm	Bush diameter, cm	Number of inflorescences, pcs./bush
Natsionalnyi	First	30.0 ± 2.5	18.6 ± 1.7	37.1 ± 3.1
	Second	49.1 ± 4.3	28.9 ± 3.0	54.5 ± 5.0
	Third	69.5 ± 7.0	39.7 ± 3.7	70.4 ± 6.7
Markiz	First	41.5 ± 4.0	24.3 ± 2.3	41.5 ± 3.8
	Second	58.2 ± 5.7	33.8 ± 3.3	67.1 ± 5.3
	Third	83.3 ± 7.4	42.1 ± 6.8	85.9 ± 7.3

Source: *authors' development*

Figure 2. *Hyssop plants of the first year of life, 2021*
Source: *authors' photo*

As a result of the research, it was found that the yield of medicinal hyssop flower raw materials increased from the first to the third years of cultivation (Table 7). The highest yield of hyssop flower raw materials was formed in the third year of cultivation 10.94-12.43 t/ha, with the yield of the Markiz variety being significantly higher than that of the Natsionalnyi variety – by 13.6%. In the first year of vegetation, the yield of plants was 21.5-28.4% of the yield in the third year, and in the second year – 61.0-66.7%.

Thus, in the conditions of the Southern Steppe of Ukraine, the success and prospects of growing medicinal hyssop (*Hyssopus officinalis*) varieties Natsionalnyi and Markiz were evaluated. These varieties were characterised by high seedling survival and winter hardiness. The maximum biometric parameters of plants were formed in the third year of life.

Soil-protective properties of agrophytocenoses *L. angustifolia* Mill. and *H. officinalis* L. These crops are perennial plants capable of growing on stony, unproductive soils, and have anti-erosion properties due to their powerful root system and long life span. To determine the soil protection properties, the indicators of the projected coverage of the area by lavender and hyssop plants were determined (Table 8; Fig. 3-4).

Table 7. *The yield of medicinal hyssop, 2021-2023*

Variety	Year of cultivation	Yields, t/ha at standard moisture content	Growth by the first year, t/ha
Nationalnyi	First	2.35	-
	Second	6.68	4.33
	Third	10.94	8.59
Markiz	First	3.53	-
	Second	8.30	4.77
	Third	12.43	8.90
LSD_{05}	by variety factor	0.53	-
	by year of cultivation factor	1.93	-
	by the interaction of factors	2.24	-

Source: *authors' development*

Table 8. *Projected area coverage with essential oil plants*

Year of cultivation	*L. angustifolia* Mill.		*H. officinalis* L.	
	Variety Hemus	Variety Imperial Gem	Variety Nationalnyi	Variety Markiz
First	37.2	41.2	42.4	45.7
Second	47.8	52.1	63.8	69.0
Third	58.4	62.5	75.2	83.7

Source: *authors' development*

Figure 3. *Phytocoenosis of English lavender in the third year of cultivation, 2023*
Source: *authors' photo*

Figure 4. *Phytocoenosis of medicinal hyssop in the third year of cultivation, 2023*
Source: *authors' photo*

Based on the results obtained, it was found that the biometric parameters of plants increased from the first to the third years of cultivation, and thus the soil-protective properties of phytocenoses increased. The highest indicators of projected plant cover were formed in the third year of cultivation of medicinal hyssop and reached 75.2-83.7%, the density of bushes and the degree of overgrowth of disturbed areas were high, the bushes closed together, forming a dense plant cover. In English lavender, the projected cover in the third year of cultivation was slightly lower compared to hyssop – 62.5-58.4%, which is due to the planting scheme, as the experimental plot after reclamation is planned to be used not only for the collection of plant materials, but also for ecological tourism and photo shoots, for which the formation of clearly defined rows of plants is important.

For research on the formation of sustainable soil-protective agrophytocenoses on anthropogenically transformed lands, English lavender have been chosen as a valuable essential oil crop that can grow and produce stable yields on low-productive soils and can be used for phytoremediation, essential oil production, agritourism, and medicinal hyssop, which has been shown to be able to produce valuable plant material in a wasteland abandoned territory. The analysis of the adaptive properties of essential oil plants in the natural and climatic conditions of the Southern Steppe of Ukraine showed a high survival rate of 89.7-92.5% for lavender plants, 85.9-90.5% for hyssop, and 81.5-98.1% for winter hardiness. R. Kremenchuk & O. Kytaiev (2017) also found a high ability of lavender to withstand low temperatures. Of the eight lavender varieties studied, not a single plant died under the influence of low temperatures. Frost-resistant varieties were identified, with core damage not exceeding 2.5 points when grown in the Forest-Steppe of Ukraine, which is characterised by lower winter temperatures than in the Steppe zone. S. Küçük *et al.* (2018) successfully cultivated English lavender in four provinces of Turkey, which indicates the wide ecological plasticity of this species. B. Kiprovski *et al.* (2023) determined that the climatic conditions of Central and Northern Serbia did not affect the quality of lavender, which shows the possibility of cultivating it in different zones.

Studies within the framework of the tested method of phytomelioration on anthropogenically transformed lands of the Southern Steppe of Ukraine showed the yield of lavender flower mass in the third year of cultivation at the level of 5.29-5.84 t/ha. Such data can be compared with the previously obtained results for lavender cultivation on agricultural plots. In the work of O. Markovska *et al.* (2020), the yield was 5.0 t/ha, and in the work of T. Manushkina *et al.* (2023) – 5.45-6.45 t/ha. The dependence of yield on the variety was established, which in the Third Year of cultivation in the Hemus variety was 9.4% higher compared to the Imperial Gem variety. The results of research by E. Détár *et al.* (2020) and S. Demasi *et al.* (2021) also confirmed that, based on intraspecific variability, it is necessary to take into account the specific requirements and characteristics of lavender varieties to optimise their cultivation and use.

Along with a sufficiently high productivity on the anthropogenically transformed plot, lavender plants formed an agrophytocenosis with a projective cover of 58.4-62.5% already in the third year of cultivation, which allows to characterise it as soil-protective. Taking into account the morphological and biological characteristics of lavender (Lis-Balchin, 2002), the area of projective cover will increase in the following years of vegetation, which will contribute to phytomelioration. L. Mykhalska *et al*. (2018) also showed that English lavender plants can be used as a crop for phytoremediation due to its ability to accumulate significant amounts of metals from the soil. At the same time, lavender essential oil contains residual amounts of metals, the content of which was below the detection level (DL) of ICPMS Agilent 7700x. I. Crișan *et al*. (2023) note that *L. angustifolia* Mill. remains one of the most valuable essential oil plant species, the area under which can be expanded without competing for productive land, instead using marginal, contaminated or unproductive land. B. Kiprovski *et al*. (2023) emphasise that lavender cultivation would be an innovative approach to further increase the income of smallholder farmers and primary producers in a time of climate change, while K.L.Adam (2018) points to the growing popularity of lavender agritourism and lavender value-added products.

The cultivation of medicinal hyssop on an anthropogenically transformed site allowed the plants to form a yield of 10.94-12.43 t/ha and a phytocoenosis with a projected cover of 75.2-83.7% in the third year of vegetation. Such yields are 22.4-36.6% higher than those obtained in the studies of P. Dobrovolskyi *et al*. (2021), which indicates the high adaptive capacity of hyssop when grown in the soil and climatic conditions of the Southern Steppe of Ukraine. S. Kizil *et al*. (2016) concluded that hyssop can be successfully grown in the semi-arid climatic conditions of Southern Turkey. G. Duschanova *et al*. (2022) also determined the structural and adaptive characteristics of *H. officinalis* L. based on a comparative analysis of anatomical features in vegetative organs and showed that the species fully passes all stages of development in Tashkent and Jizzakh (Uzbekistan), which also confirms the adaptation of plants to hot and arid climates, which is relevant in the context of climate change for the Steppe zone of Ukraine. S. Sorokina & N. Hnatiuk (2017) found that the soil of the rhizosphere and row spacing accumulates kolinium during the growing season, the content of which depends on environmental factors and the excretory function of plants. Researchers have shown that at the beginning of plant development and in the budding phase, there are practically no phytotoxic substances, and in the flowering phase, on the contrary, there is an increase in the content of inhibitory compounds. This fact should be taken into account when growing subsequent crops after phytomelioration of anthropogenically altered soils.

Essential oil crops are in the focus of research due to their growing economic importance and market demand is expected to continue to increase. At the same time, perennial essential oil plants of the *Lamiaceae* Lindl. family have soil protection and reclamation value, and can be grown without competing for productive soils, and can be used on marginal lands. In addition, the cultivation of drought-resistant essential oil crops will contribute to the expansion of agricultural biodiversity and further diversification of agriculture in the face of climate change.

CONCLUSIONS

On the basis of the conducted scientific research, the adaptive properties and processes of growth, development, formation of productivity of lavender and medicinal hyssop were studied, and soil-protective agrophytocenoses were created in the conditions of anthropogenically transformed lands of the Southern Steppe of Ukraine. High indicators of adaptive capacity of lavender and hyssop plants were revealed. The survival rate of lavender was 89.7-92.5%, and that of hyssop – 85.9-90.5%. Winter hardiness during the three years of cultivation was 81.5-98.1%. During the three years of vegetation, lavender plants formed bushes with a diameter of 62.4-89.6 cm, shoots with a height of 50.7-51.3 cm, the number of inflorescences 594.9-650.3 pcs, which corresponds to their varietal characteristics. The largest parameters of the lavender yield structure were formed in the third year of vegetation: inflorescence length 5.5-6.8 cm, number of rings in the inflorescence 5.2-6.4 pcs, number of flowers in the half-ring 5.2-6.4 pcs. These parameters provided the highest yield: in the Hemus variety it was 5.29 t/ha, in the Imperial Gem variety – 5.84 t/ha at standard humidity. In the first year of vegetation, the yield was 12.7-13.4%, in the second year – 52.0% of the yield in the third year. Hyssop plants reached a maximum height of 69.5-83.3 cm in the third year of cultivation. The number of vegetative-generative shoots in the bush increased from the second year of life, when the number was 54.5-67.1 pcs. and in the third year increased to 70.4-85.9 pcs. The highest yield of hyssop flower raw materials was formed in the Third year of cultivation (10.94-12.43 t/ha), with the yield of Markiz variety being significantly higher than that of Natsionalnyi variety – by 13.6%. In the first year of vegetation, the yield was 21.5-28.4% of the yield in the third year, and in the second year – 61.0-66.7%. Essential oil plants formed an agrophytocenosis with sufficiently high projective coverage in the third

year of cultivation: 75.2-83.7% in medicinal hyssop, 62.5-58.4% in English lavender, which allows the use of these essential oil plants for phytomelioration of anthropogenically transformed areas in the Southern Steppe of Ukraine. Prospects for further research are to study the growth, development, productivity of plants and the quality of raw materials during the next years of vegetation and to determine the ability to phytoremediation.

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CONFLICT OF INTEREST

None.

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Формування стійких ґрунтозахисних агрофітоценозів ефіроолійних рослин в умовах Південного Степу України

Тетяна Манушкіна
Кандидат сільськогосподарських наук, доцент
Миколаївський національний аграрний університет
54008, вул. Георгія Ґонґадзе, 9, м. Миколаїв, Україна
https://orcid.org/0000-0001-5843-271X
Антоніна Дробітько
Доктор сільськогосподарських наук, професор
Миколаївський національний аграрний університет
54008, вул. Георгія Ґонґадзе, 9, м. Миколаїв, Україна
https://orcid.org/0000-0002-6492-4558

Анотація. В умовах значного екологічного навантаження на ґрунтові ресурси актуальним є питання відновлення та підтримки родючості деградованих і антропогенно порушених земель за рахунок технології фітомеліорації, що спрямована на покращення змінених ландшафтів шляхом створення стійкого рослинного покриву, який може поліпшувати якісні характеристики ґрунту та відновлювати його екологічні функції. Мета дослідження – вивчити адаптаційні властивості, процеси росту і розвитку, формування продуктивності та особливості створення ґрунтозахисних агрофітоценозів лаванди вузьколистої та гісопу лікарського в умовах антропогенно трансформованих земель Південного Степу України. Для досягнення цієї мети було закладено польовий дослід, здійснено фенологічні спостереження за розвитком рослин та вивчено особливості формування грунтозахисних агрофітоценозів. Приживлюваність ефіроолійних рослин була високою: лаванди вузьколистої – 89,7-92,5 %, гісопу лікарського – 85,9-90,5 %. Виявлено високу здатність лаванди та гісопу протистояти несприятливим кліматичним умовам під час перезимівлі: упродовж трьох років культивування зимостійкість становила 81,5-98,1 %. За три роки вегетації рослини лаванди сформували пагони висотою 50,7-51,3 см, діаметр куща становив 62,4-89,6 см, кількість суцвіть – 594,9-650,3 шт., що відповідає їх сортовим характеристикам. Найбільша врожайність рослин лаванди сформувалася на третьому році вегетації – 5,29-5,84 т/га при стандартній вологості. Максимальної висоти рослини гісопу досягали на третій рік вирощування – 69,5-83,3 см. Кількість вегетативно-генеративних пагонів у кущі зростала починаючи з другого року вегетації, їх кількість на другий рік вирощування становила 54,5-67,1 шт., а на третій – 70,4-85,9 шт. Найбільша урожайність квіткової сировини гісопу формувалася на третій рік культивування – 10,94-12,43 т/га. Найвищі показники проєктивного покриття рослин відмічено у третій рік вирощування: у гісопу – 75,2-83,7 %, у лаванди вузьколистої – 58,4-62,5 %, що дозволяє рекомендувати використовувати агрофітоценози цих ефіроолійних рослин для фітомеліорації та рекультивації антропогенно трансформованих територій в умовах Південного Степу України

Ключові слова: *Lavandula angustifolia* Mill.; *Hyssopus officinalis* L.; зимостійкіть; продуктивність; проєктивне покриття

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Express Gold herbicide effectiveness based on application methods in sunflower crops

Volodymyr Kozechko*
PhD in Agricultural Sciences, Associate Professor
Dnipro State Agrarian and Economic University
42009, 25 Serhiy Yefremov Str., Dnipro, Ukraine
https://orcid.org/0000-0002-3843-3093

Olha Ivanchenko
Postgraduate Student
Dnipro State Agrarian and Economic University
42009, 25 Serhiy Yefremov Str., Dnipro, Ukraine
https://orcid.org/0009-0003-0235-1496

Abstract. One of the main challenges in sunflower cultivation is weed infestation, which significantly affects crop yield. This study aimed to determine the effectiveness of the Express Gold herbicide under different application methods and rates in sunflower crops. The Suomi sunflower hybrid, adapted to the ExpressSun technology, was selected for the research. Various application rates and methods of Express Gold herbicide were examined, including ground spraying and drone application, with an assessment of their effectiveness. The experiments were conducted in the research field of LLC Ahross+, with trials carried out in 2022, 2023, and 2024. The experiment involved two application methods (ground and drone), three herbicide doses (half, optimal, and maximum), and four working solution application rates. A control plot (without the application of a post-emergence herbicide) was included for comparison. The two-year average results indicated that the herbicide performed effectively at both the half and optimal application rates across all plots. When applied at a rate of 20 g/ha, the herbicide demonstrated higher efficacy compared to treatments with working solution application rates of 50 L/ha and 100 L/ha. As the herbicide dose and working solution volume increased, no further differences were observed in herbicidal performance across plots, with comparable effectiveness at both 50 L/ha and 200 L/ha. It was established that drone application maintained a consistently high treatment quality, regardless of the herbicide dose applied per hectare

Keywords: adjuvant; low-volume spraying; drone; biometric indicators; yield

INTRODUCTION

In modern agriculture, the rational use of energy resources and the need to minimise pesticide load on the environment have become increasingly urgent issues. Farmers are actively seeking alternative approaches to crop protection applications, particularly methods such as low-volume spraying and drone technology. These approaches not only enhance production efficiency but also contribute to maintaining ecological balance. In sunflower cultivation under a system that does not involve soil-applied herbicides, weed infestation presents a significant challenge. However, the scientific literature provides limited coverage of alternative crop

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*Corresponding author

protection methods in such conditions. This highlights the need for research into plant responses to varying doses of plant protection products (PPPs) and different working solution application rates.

The effectiveness of chemical treatment depends on the degree of coverage of the target surface with the working solution. Improved results can be achieved by increasing droplet density in plants. High treatment efficiency is attained through both the use of modern formulations and the optimisation of application technologies. Yu.I. Tkalich *et al.* (2022) investigated the effectiveness of adjuvants in combination with the herbicide tribenuron-methyl in sunflower crops. Their findings indicated that the addition of adjuvants improved the uniformity of herbicide coverage on plant surfaces, thereby enhancing weed control efficacy. Furthermore, the authors emphasised that the rational use of adjuvants allows for a reduction in herbicide consumption, mitigating its environmental impact. The study concluded that optimising herbicide and adjuvant dosing according to weather conditions and the growth stage of sunflower is advisable.

M. Radchenko *et al.* (2022) analysed the effectiveness of herbicide mixtures containing flumioxazin and fluorochloridone in sunflower crops. Their study demonstrated that the use of combined formulations enables more effective control of a broad spectrum of weeds while reducing the risk of resistance development. The authors highlighted that the correct selection of application rates and spraying techniques is crucial for achieving high herbicidal effectiveness. Additionally, they examined the impact of these formulations on sunflower yield, concluding that adherence to manufacturer recommendations is essential to prevent phytotoxicity. These findings indicate that the effectiveness of herbicides and their combinations with adjuvants depends on multiple factors, including product selection, application method, dosage, weather conditions, and crop growth stage. Further research in this area will contribute to improving sunflower crop protection efficacy and enhancing the environmental safety of agronomic practices.

The findings of A.W. Howell *et al.* (2023) and A. Panfilova *et al.* (2024) confirmed that ultra-low-volume spraying in aerial applications using unmanned aerial vehicles (UAVs) enhanced treatment efficiency, reduced costs by minimising the number of refills and water consumption, and ensured high biological effectiveness through precise distribution of the working solution. However, this method also has certain drawbacks, including a high risk of solution drift and rapid evaporation. O.O. Ivashchenko *et al.* (2018) stated that weeds exhibit high seed productivity, meaning that even a small number of surviving weed plants can produce a substantial amount of viable seeds, replenishing the soil seed bank. Although sunflower is relatively more weed-tolerant than most other row crops, yield losses due to weed infestation remain significant.

Studies by S. Okrushko (2010) and K. Siva Sankar & D. Subramanyam (2011) have shown that if sunflower crops are infested with weeds during the early stages of development, significant yield losses can be expected. The more advanced the sunflower growth stage, the lower its sensitivity to weed competition. This finding reinforces the importance of post-emergence herbicide applications. A review of the literature reveals inconsistent conclusions regarding the effects of different herbicides in sunflower cultivation, highlighting the need for further research under field conditions. According to G. Delchev *et al.* (2022), numerous new production systems, including ExpressSun, have emerged, covering up to 25-30% of the sunflower-growing area in different years. However, despite their widespread adoption, these new systems have yet to undergo thorough field validation and require adaptation to various soil and climatic conditions.

Unmanned aerial vehicles (UAVs) are increasingly used in agriculture for the application of fertilisers and crop protection products. As noted by J. Martinez-Guanter *et al.* (2020) and M.L. Shulyak & S.P. Sokolik (2024), UAV technology enhances application precision and efficiency, reduces agrochemical use, and contributes to environmental protection. This approach optimises agricultural processes by preventing excessive fertiliser and pesticide application, which is beneficial from both an environmental and economic perspective.

The findings of S. Kaya & Z. Goraj (2020) and C. Hiremath *et al.* (2024) highlighted the advantages of UAV technology in terms of time efficiency for herbicide application, reducing the required time by up to 99% compared with conventional spraying methods. The use of agricultural drones also significantly decreased water and labour requirements. Notably, drone-based herbicide spraying demonstrated the potential to reduce herbicide dosage by 30%, emphasising its role in minimising herbicide use.

This study aimed to determine the effectiveness of Express Gold herbicide in sunflower crops under different application methods and rates.

Research objectives:

➥ to determine the feasibility of using alternative herbicide application methods in sunflower crops;

➥ to analyse the impact of working solution rates and application methods on herbicide efficacy;

➥ to evaluate the influence of herbicide dosage and the use of different adjuvants on grain yield formation.

MATERIALS AND METHODS

Field experiments were conducted on the commercial farmland of LLC Ahross+ in the Dnipro District of Dnipropetrovsk Region from 2022 to 2024. During this period, trials were established, and observations were carried out to examine the effects of two application methods (trailed boom sprayer and UAV), three herbicide doses of Express Gold (20, 30, 40 g/ha), various working solution rates (7, 50, 100, 150, 200 L/ha), and two adjuvants (Trend and Esterlip) on sunflower growth, development, and yield compared with the control.

The cultivation technology for the Suomi sunflower hybrid followed the standard agronomic practices for the northern Steppe zone of Ukraine. The preceding crop was maize. Primary tillage involved mouldboard ploughing to a depth of 25-27 cm using a Lemken Diamant 11 reversible plough (Lemken, Germany). Once the soil reached physical maturity, a Solomiya harrow (Haleshchyna Mashzavod, Ukraine) was used to level the soil surface and aid moisture retention. Before sowing, the soil was cultivated to a depth of 5-6 cm with a Kompaktomat pre-sowing unit (Farmet, Czech Republic) to create an optimal seedbed for uniform and efficient sunflower germination. Sowing was carried out using a Horsch Maestro precision seeding system (Horsch, Germany) with a seeding rate of 55,000 plants/ha, a row spacing of 70.0 cm, and a sowing depth of 4.0 cm, with simultaneous application of $N_{20}P_{20}$ mineral fertiliser. Plant protection products were applied using an Amazone Badilli trailed boom sprayer (Amazonen-Werke H. Dreyer SE & Co. KG, Germany) and an Agras t30 drone (DJI, China). Yield measurements and observations in the experimental plots were conducted using generally accepted methods and recommendations from the Institute of Grain Crops of the National Academy of Agrarian Sciences of Ukraine. The research was carried out following the ethical standards outlined in the Convention on International Trade in Endangered Species of Wild Fauna and Flora (1973) and the Convention on Biological Diversity (1992). The plots were arranged in a systematic design with three replications. Each plot had a sowing area of 0.4 ha (40×100 m) and a measurement area of 0.24 ha (30×80 m). The total sowing area was 11.0 ha.

According to the results of agrochemical soil surveys (2020-2023), the arable soil of the farm contained an average of 3.0-3.9% humus, 8.0-9.2 mg/100 g of hydrolysable nitrogen, 6.68.1 mg/100 g of available phosphorus, 9.2-13.7 mg/100 g of exchangeable potassium, a pH of 5.5 in saline solution, 6.5 in aqueous solution, a hydrolytic acidity of 0.99 mEq/100 g, and a cation exchange saturation of 97%. The Express Gold herbicide was applied at doses of 20, 30, and 40 grams, with the addition of adjuvants Trend and Esterlip to compare their efficacy. Working solution rates were 50, 100, 150, and 200 L/ha using the trailed boom sprayer, and 7 L/ha using the drone (Table 1).

Table 1. *Experimental design for determining the efficacy of the protective herbicide using different applications*

Working solution rate, L/ha (A)	Herbicide dose (B)	Adjuvant (C)
Control		
7	20 30 40	Trend
50	20 30 40	Trend
50	20 30 40	Esterlip
100	20 30 40	Trend
100	20 30 40	Esterlip
150	20 30 40	Trend
150	20 30 40	Esterlip

Table 1, Continued

Working solution rate, L/ha (A)	Herbicide dose (B)	Adjuvant (C)
Control		
200	20	Trend
	30	
	40	
200	20	Esterlip
	30	
	40	

Source: *developed by the authors*

Yield assessments were conducted by direct combining at the full seed maturity stage of the sunflowers. The measurement area was 0.24 ha. Seed weight from each plot was measured using electronic portable platform scales. Yields were calculated to 100% purity and 8% seed moisture content of the sunflower seeds. Plant height and leaf area were determined at the full flowering stage of the crop.

RESULTS AND DISCUSSION

Table 2 presents the results of leaf area assessment at the full flowering stage, based on the working solution rates, herbicide doses, and the use of adjuvants. Analysis showed that the control treatment (without herbicide or adjuvant application) had an average leaf area of 29.19 thousand m^2/ha over the three years of research. This value was used as the baseline for comparing results.

Table 2. *Leaf area during the full flowering stage based on the factors studied, thousand m^2/ha*

Working solution rate, L/ha (A)	Herbicide dose (B)	Adjuvant (C)	Years				
			2022	2023	2024	Average	+/-
Control			27.55	36.81	23.22	29.19	-
7	20	Trend	36.35	39.64	30.40	35.46	6.27
	30		35.42	37.40	29.13	33.98	4.79
	40		33.24	35.90	27.66	32.27	3.07
50	20	Trend	34.78	34.90	27.87	32.52	3.32
	30		37.80	36.94	29.90	34.88	5.69
	40		36.88	33.27	28.06	32.74	3.54
50	20	Esterlip	28.65	42.55	28.48	33.23	4.03
	30		28.95	56.33	34.11	39.80	10.60
	40		29.72	40.32	28.02	32.69	3.49
100	20	Trend	38.90	49.10	35.20	41.07	11.87
	30		30.96	42.64	29.44	34.35	5.15
	40		32.11	45.29	30.96	36.12	6.93
100	20	Esterlip	41.67	56.50	39.27	45.81	16.62
	30		35.90	63.53	39.77	46.40	17.21
	40		42.06	44.16	34.49	40.24	11.04
150	20	Trend	33.76	49.01	33.11	38.63	9.43
	30		34.46	42.99	30.98	36.14	6.95
	40		36.75	37.04	29.52	34.44	5.24
150	20	Esterlip	39.47	45.94	34.16	39.86	10.66
	30		40.86	47.33	35.28	41.16	11.96
	40		37.00	44.21	32.48	37.90	8.70
200	20	Trend	38.20	43.53	32.69	38.14	8.95
	30		42.11	31.11	29.29	34.17	4.98
	40		34.91	42.85	31.10	36.29	7.09
200	20	Esterlip	36.82	42.49	31.72	37.01	7.82
	30		34.16	40.55	29.88	34.86	5.67
	40		39.81	33.90	29.48	34.40	5.20

Source: *developed by the authors*

The application of a working solution rate of up to 7 L/ha with the use of a drone showed that the average leaf area increased based on the herbicide dose. The maximum value in this group was achieved with a dose

of 20 g/ha using the Trend adjuvant, which amounted to 35.46 thousand m²/ha, 6.27 thousand m²/ha higher than the control. Increasing the working solution rate to 50 L/ha resulted in improved leaf area in all the experimental variants. When applying the herbicide at a dose of 30 g/ha with the addition of the Trend adjuvant, the value reached 34.88 thousand m²/ha, exceeding the control by 5.69 thousand m²/ha. The use of the Esterlip adjuvant in the same variant yielded an even higher result – 39.80 thousand m²/ha (+10.60 thousand m²/ha compared to the control).

The largest increases in leaf area were observed with a working solution rate of 100 L/ha. In the variant with a herbicide dose of 30 g/ha and the Esterlip adjuvant, the average value was 46.40 thousand m²/ha, which was 17.21 thousand m²/ha higher than the control. A similar trend was observed with the use of the Trend adjuvant, where the leaf area reached 41.07 thousand m²/ha (+11.87 thousand m²/ha). When the working solution rate was increased to 150-200 L/ha, the leaf area values slightly decreased but remained higher than the control. Specifically, with a rate of 150 L/ha, a dose of 30 g/ha, and the Esterlip adjuvant, the average value was 41.16 thousand m²/ha (+11.96 thousand m²/ha compared to the control). At a rate of 200 L/ha, the maximum leaf area was achieved in the variant with the Trend adjuvant (38.14 thousand m²/ha), which exceeded the control by 8.95 thousand m²/ha. It was established that the control variant, without the use of herbicides or adjuvants had an average plant height of 124 cm over three years of observation (Table 3).

Table 3. *Plant height at the full flowering stage based on the investigated factors, cm*

Working solution rate, L/ha (A)	Herbicide dose (B)	Adjuvant (C)	Years				
			2022	2023	2024	Average	+/-
Control			116	149	106	124	-
7	20	Trend	130	167	119	139	15
	30		129	158	115	134	10
	40		130	162	117	136	13
50	20	Trend	142	158	120	140	16
	30		138	163	120	140	17
	40		128	158	114	133	10
50	20	Esterlip	129	160	116	135	11
	30		123	162	114	133	9
	40		135	144	112	130	7
100	20	Trend	141	174	126	147	23
	30		128	170	119	139	15
	40		127	159	114	133	10
100	20	Esterlip	136	156	117	136	13
	30		135	163	119	139	15
	40		145	153	119	139	15
150	20	Trend	130	158	115	134	11
	30		142	153	118	138	14
	40		134	156	116	135	12
150	20	Esterlip	139	153	117	136	13
	30		127	159	114	133	10
	40		134	167	120	140	17
200	20	Trend	128	163	116	136	12
	30		130	165	118	138	14
	40		125	161	114	133	10
200	20	Esterlip	130	162	117	136	13
	30		127	160	115	134	10
	40		130	160	116	135	12

Source: *developed by the authors*

The application of a working solution rate of up to 7 L/ha using a drone contributed to an increase in plant height compared to the control. With a herbicide dose of 20 g/ha and the Trend adjuvant, the average height was 139 cm, which exceeded the control by 15 cm. In the variants with doses of 30 and 40 g/ha, the plant height was 134 cm and 136 cm, respectively, which was 1,013 cm higher than the control. The application of a working solution rate of 50 L/ha further promoted an increase in plant height. The highest values were

recorded with a herbicide dose of 30 g/ha and the Trend adjuvant, where the average height was 140 cm (+17 cm compared to the control). The use of the Esterlip adjuvant in the same variant yielded a slightly lower result of 133 cm (+9 cm compared to the control).

At a working solution rate of 100 L/ha, the highest plant height values were recorded. In the variant with a herbicide dose of 20 g/ha and the Trend adjuvant, the average height reached 147 cm, which was 23 cm higher than the control. Other variants with the use of this adjuvant also demonstrated consistently high results (139-147 cm), exceeding the control by 15-23 cm. Increasing the working solution rate to 150 and 200 L/ha was associated with a slight reduction in effectiveness. At a rate of 150 L/ha, a herbicide dose of 30 g/ha, and the use of the Esterlip adjuvant, the average height was 140 cm, which exceeded the control by 17 cm. At a rate of 200 L/ha, the maximum value (138 cm) was recorded in the variant with the Trend adjuvant at a dose of 30 g/ha (+14 cm compared to the control). It was established that the control variant, without the use of herbicides and adjuvants, resulted in the lowest yield, averaging 1.80 t/ha over the three years (Table 4).

Table 4. *Sunflower seed yield based on the investigated factors, t/ha*

Working solution rate, L/ha (A)	Herbicide dose (B)	Adjuvant (C)	Years				
			2022	2023	2024	Average	+/-
Control			1.65	2.37	1.37	1.80	-
7	20	Trend	2.64	3.39	2.05	2.69	0.90
	30		2.69	3.29	2.03	2.67	0.88
	40		2.61	3.28	2.00	2.63	0.84
50	20	Trend	2.30	3.39	1.93	2.54	0.75
	30		2.24	3.26	1.87	2.46	0.66
	40		2.06	3.04	1.73	2.28	0.48
50	20	Esterlip	1.73	3.28	1.70	2.24	0.44
	30		2.06	3.22	1.80	2.36	0.56
	40		2.30	3.02	1.81	2.38	0.58
100	20	Trend	2.26	3.41	1.93	2.53	0.74
	30		2.17	3.31	1.86	2.45	0.65
	40		2.20	2.97	1.76	2.31	0.51
100	20	Esterlip	2.07	3.40	1.86	2.44	0.65
	30		2.51	3.13	1.92	2.52	0.72
	40		2.41	2.80	1.77	2.33	0.53
150	20	Trend	2.71	3.30	2.04	2.68	0.89
	30		2.73	3.31	2.05	2.70	0.90
	40		2.16	2.95	1.74	2.28	0.49
150	20	Esterlip	2.29	3.38	1.93	2.53	0.74
	30		2.56	3.30	1.99	2.62	0.82
	40		2.55	3.01	1.89	2.48	0.69
200	20	Trend	2.71	3.27	2.03	2.67	0.88
	30		2.57	3.27	1.99	2.61	0.81
	40		2.93	3.01	2.02	2.65	0.86
200	20	Esterlip	2.57	3.26	1.98	2.60	0.81
	30		2.46	3.13	1.90	2.50	0.70
	40		2.49	2.95	1.85	2.43	0.63

Source: *developed by the authors*

The application of a working solution rate of 7 L/ha in combination with the herbicide and Trend adjuvant significantly increased yield. The maximum value in this group was achieved with a herbicide dose of 20 g/ha, where the average yield was 2.69 t/ha, exceeding the control by 0.90 t/ha. Other herbicide doses (30 and 40 g/ha) resulted in only slight reductions in yield – 2.67 and 2.63 t/ha, respectively (+0.88 and +0.84 t/ha compared to the control). At a working solution rate of 50 L/ha, yield decreased slightly compared to variants with lower rates, especially at a dose of 40 g/ha, where the average yield was 2.28 t/ha (+0.48 t/ha compared to the control). In variants with the Esterlip adjuvant, yields ranged from 2.24 to 2.38 t/ha (+0.44-0.58 t/ha compared to the control). Increasing the working solution rate to 100 L/ha positively impacted yield. The highest results were achieved with a herbicide dose of 30 g/ha combined with Trend, resulting in 2.53 t/ha (+0.74 t/ha

compared to the control). However, using Esterlip in the same variant yielded slightly lower results – 2.44 t/ha (+0.65 t/ha compared to the control).

The highest yield values were recorded with a working solution rate of 150 L/ha. With a herbicide dose of 30 g/ha combined with Trend adjuvant, the average yield was 2.70 t/ha, exceeding the control by 0.90 t/ha. The use of Esterlip provided slightly lower results – 2.62 t/ha (+0.82 t/ha compared to the control). The working solution rate of 200 L/ha showed consistently high results. With a herbicide dose of 40 g/ha and Trend adjuvant, the average yield was 2.65 t/ha (+0.86 t/ha compared to the control). The use of Esterlip in the same variant resulted in a similar yield – 2.60 t/ha (+0.81 t/ha compared to the control). Weeds are an important biotic constraint for sunflower production, and the application of herbicides can provide effective weed control in this crop. The reduction in sunflower seed yield in the control group compared to all the other plots where herbicide was applied ranged from 20-33%. According to R.H. Wanjari *et al.* (2001), competition from weeds can reduce sunflower yield by up to 81%, depending on weed density, timing and duration of competition, and the weed spectrum. In the study by M. Jursík *et al.* (2020), competition from weeds reduced sunflower yield by nearly 40%.

An analysis of the literature reveals conflicting conclusions regarding the effects of various herbicides on sunflower cultivation. Some authors prefer soil-applied herbicides, such as E. Pannacci *et al.* (2007), E. Nádasy *et al.* (2008), and O. Kilinc *et al.* (2011), used active substances like linuron, flurochloridone, oxyfluorfen, pendimethalin, prosulfocarb, biphenox, aclonifen, flumioxazin, and lenacil in combination with acetamide herbicides (acetochlor, dimethenamid, petoxamid, metolachlor, flufenacet, propisochlor) for pre-emergence control of broadleaf weeds in sunflowers. It is well-known that the effectiveness of soil-applied herbicides is significantly influenced by soil moisture. In their study, M. Jursík *et al.* (2015) demonstrated that in dry conditions, the effectiveness of soil-applied herbicides generally decreases. However, intense rainfall following the application of these herbicides can cause crop damage. This effect is particularly important for sunflowers, as the selectivity of most herbicides depends on the placement of the herbicide layer on the soil surface and the distribution of seeds in the soil profile. Sandy soils, with lower adsorption capacity, are at greater risk of herbicide leaching after heavy rainfall or irrigation, which increases the risk of crop damage.

However, most researchers believe that to obtain weed-free sunflower crops, it is necessary to apply both soil-applied and post-emergence herbicides. In particular, I. Mostoviak *et al.* (2024) demonstrated the negative impact of weed vegetation on sunflower yield formation, which manifested in a reduction in seed productivity as the number of weeds in the crops increased. The lowest weed infestation in sunflower agrocenoses (1.5 plants/m^2) at harvest was observed in the variant with the application of soil herbicide (Oscar Premium, suspension emulsion, 3.75 L/ha) and a tank mix of post-emergence herbicides (Challenge, suspension concentrate, 1.0 L/ha + Heliantex, suspension concentrate, 0.045 L/ha + surfactant Vivolt, 0.25 L/ha) at the BBCH 14 growth stage. The highest yield of the studied crop was also recorded in this variant of the experiment – 4.13 t/ha, which was 2.58 t/ha higher than the control variant.

Numerous studies have been conducted regarding the effectiveness of using CLEARFIELD herbicides on IMI-resistant sunflower hybrids. In particular, M. Pfenning *et al.* (2008) demonstrated that the application of CLEARFIELD herbicides provides exceptional post-emergence and soil activity for controlling a wide range of weeds found in regions where sunflowers are grown. They noted that one of the main advantages of the CLEARFIELD system for sunflowers is the post-emergence control of a broad spectrum of weeds with imazamox, and pointed out that, depending on local needs, a soil-applied herbicide such as pendimethalin complements the residual activity of imazamox very well. S. Jocić *et al.* (2008) extensively studied the effect of tribenuron-methyl on broadleaf weeds in the crops of imidazolinone-resistant sunflower hybrids. They found that the development of hybrids resistant to tribenuron-methyl enabled the use of a wider range of herbicides for sunflowers, provided more effective chemical control of harmful vegetation, and made it economically advantageous to control certain annual and perennial broadleaf weeds post-emergence in sunflower crops, including troublesome species such as common ragweed, lamb's quarters, redroot pigweed, rag sumpweed, creeping thistle, and others.

CONCLUSIONS

Complete control and the death of broadleaf weeds in the investigated sunflower plots were achieved by drone application at a herbicide dose of 30 g/ha of Express Gold, as well as by spraying in the plot group with application rates of 50, 100, and 150 L/ha using herbicide doses of 30 and 40 g/ha at the 5-6 leaf stage of the sunflowers. At application rates of 150 and 200 L/ha with a herbicide dose of 20 g/ha, deformation of the weed growth point and cessation of growth were observed; complete death occurred only in weeds at the initial stage of vegetation. The highest sunflower yield was recorded when applying half the recommended

dose of Express Gold herbicide (20 g/ha) via drone, amounting to 2.69 t/ha, indicating a reduction in pesticide load on the crop. The herbicide's effect on the weeds was lethal due to the fine droplets and maximum leaf surface coverage.

The best results across all aspects (leaf area, plant height, yield) were observed with application rates of 100-150 L/ha, herbicide doses of 20-30 g/ha, and the addition of the Trend adjuvant. These combinations ensured optimal coverage of the working solution, an increase in the plants' assimilatory surface, and, consequently, maximum yield. The yield in the control plot was 1.80 t/ha, the lowest among all the experimental plots, indicating that weed infestation had a greater negative impact on sunflower yield than increased pesticide load on the crop. Therefore, the optimal method of herbicide application involves using medium rates of working solution and herbicide doses, with drone application being a promising approach, though it requires further detailed and careful study.

Given the current labour outflow from Ukraine due to martial law and the need for intellectual agricultural production, it is expected that the use of agricultural UAVs will further unlock the production potential. Therefore, research and development in the use of agricultural unmanned equipment are promising, representing a crucial step in implementing the technological modernisation of smart agriculture. This will enable the timely intellectual transformation of agriculture in today's context.

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CONFLICT OF INTEREST

None.

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Ефективність гербіциду «Експрес Голд» залежно від способів застосування в посівах соняшнику

Володимир Козечко
Кандидат сільськогосподарських наук, доцент
Дніпровський державний аграрно-економічний університет
42009, вул. Сергія Єфремова, 25, м. Дніпро, Україна
https://orcid.org/0000-0002-3843-3093
Ольга Іванченко
Аспірант
Дніпровський державний аграрно-економічний університет
42009, вул. Сергія Єфремова, 25, м. Дніпро, Україна
https://orcid.org/0009-0003-0235-1496

Анотація. Однією з головних проблем на посівах соняшнику є забур'яненість, яка має значний вплив на урожайність культури. Метою роботи було встановити ефективність застосування гербіциду «Експрес Голд» при різних методах та нормах внесення на посівах соняшнику. Для дослідження було обрано гібрид соняшнику Суомі під технологію ExpressSun. У ході досліджень вивчалися різні норми та методи внесення гербіциду «Експрес Голд», зокрема наземне обприскування та використання дронів, а також оцінювалась ефективність їх застосування. Експериментальні роботи проводилися на дослідному полі ТОВ «Агросс+», дослідження закладались і здійснювались у 2022, 2023 та 2024 роках. В експерименті використано два методи (наземне та дрон), три дози препарату (половинна, оптимальна, максимальна) та чотири норми впливу робочої рідини. Для порівняння також було включено контрольну ділянку (без застосування страхового гербіциду). Усереднене за два роки дослідження показало, що гербіцид спрацював половинною і оптимальною нормами максимально якісно на всіх ділянках. У варіанті застосування гербіциду з нормою 20 г/га ефективність була вищою ніж при обробці з нормами виливу робочої рідини 50 л/га та 100 л/га. Коли підвищувалась доза гербіциду і норма виливу робочого розчину, то на тих ділянках уже не було видно різниці між кількістю робочого розчину на гектар: гербіцид однаково якісно спрацював і при 50 л/га і на 200 л/га. Встановлено, що при використанні методу внесення дроном, незалежно від досліджуваної дози гербіциду на 1 га, якість обробки залишалася високою

Ключові слова: прилипач; малообʼємне обприскування; дрон; біометричні показники; урожайність

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Investment strategies for the development of agricultural formations in a crisis economy

Olha Khrystenko*
PhD in Economic Sciences, Associate Professor
Mykolaiv National Agrarian University
54008, 9 Georgiy Gongadze Str., Mykolaiv, Ukraine
https://orcid.org/0000-0003-0431-5328

Iryna Potochylova
Master, Assistant
Mykolaiv National Agrarian University
54008, 9 Georgiy Gongadze Str., Mykolaiv, Ukraine
https://orcid.org/0000-0001-7785-4053

Valentyn Kertychak
Postgraduate Student
Mykolaiv National Agrarian University
54008, 9 Georgiy Gongadze Str., Mykolaiv, Ukraine
https://orcid.org/0009-0004-6522-546X

Abstract. The purpose of this study was to determine the clustering of enterprises in the agricultural industrial sector as the most effective investment strategy for the development of agriculture in crisis economic conditions. This study is a systematic review of papers based on the search for development strategies for the agricultural sector in critical economic conditions and determining the most effective ones for strengthening the action of agricultural formations. According to the results of this study, the cluster investment strategy was identified as the most effective for the development of agricultural enterprises, but in contrast to this, a number of its negative consequences were established. The need to build an effective strategy for attracting additional investment processes was identified. The negative and positive aspects of investments in agriculture were examined which helped to establish the manifestation of possible risks and profits from the agricultural and industrial sector of activity. Using additional theoretical materials, in the course of this study, the cluster investment strategy was evaluated as one that is more resistant to crisis conditions. A separate issue was considered regarding the importance of attracting external investment resources since this type of investment proved to be more reliable in crisis financial and economic periods. In addition, in the course of this study, the negative consequences of the impact of crisis conditions on enterprises and organisations in various sectors of activity were identified and a number of recommendations were given for potential investors in agricultural and industrial activities. It is determined that the crisis financial and economic spectra represent a number of gaps that should be considered when choosing an effective strategic policy, which should be aimed at strengthening the competitiveness of agricultural enterprises and based on

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*Corresponding author

innovative aspects of high activity. Notably, the cluster policy is chosen in this study as one that appropriately met the presented criteria for selecting an effective strategic action

Keywords: cluster; competition; innovation; industrialisation; regression model; material-resource structure

INTRODUCTION

During the period 2019-2023, the priority focus of attention of various countries of the world is primarily aimed at promoting their own economic development, increasing the level of financial security and stimulating the improvement of the life of the population, which makes it necessary to use the most effective measures and tools for managing the public sector, which has numerous negative impacts on the social and economic structure, at the international level, in particular, in countries with a transition economic period. However, according to the research of some scientists who consider the agro-industrial sphere of production, it was determined that agro-industrial enterprises show a reduced level of attractiveness for investment, in the event of a crisis period (Poltorak *et al.*, 2022). Thus, in accordance with the low level of attractiveness of enterprises, their financial security is threatened by massive economic shifts, which negatively affects the functioning of these firms. In this case, the question arises of creating and implementing an effective strategy for attracting additional financial resources.

Instead, according to E.K. Duramany-Lakkoh *et al*. (2022), it was determined that the strategy for attracting investment provides for the formation of the most flexible, innovative, and efficient agricultural and food complexes. Thus, considering modern research, it is determined that the weakest point of agricultural enterprises, as a rule, is the lack of innovative criteria that would be satisfactory in performing food tasks. Additionally, according to S. Zubair *et al*. (2020), the critical point that hinders the development of agricultural production is the inability to provide technological foundations to agricultural workers.

According to the definition of L.T. Thuong (2020), a particularly relevant and effective method aimed at overcoming many crises financial and economic difficulties for many countries of high economic development, is considered to be the cluster strategy. The clustering of enterprises is based on considering useful systems created to increase the sustainability and stability of the activities of organisations that become members of the cluster. According to A. Berxolli *et al*. (2023), who examined possible strategies for the development of agricultural and industrial production, cluster policy provides for a network of enterprises that are geographically connected, engaged in one type of activity, and also aimed at achieving a common goal. In accordance with this, a specific formulation of criteria for the agricultural sector was defined, which identify it as the most profitable and sustainable for attracting external investment resources. The general definition of agro-industrial production is defined as the most profitable, dynamic, and competitive sector, which provokes an increase in the value of agricultural products, even in crisis economic conditions.

According to K. Otsuka & M. Ali (2020), the cluster strategy most effectively defines the space for industrialisation. Therewith, gaps in numerous studies aimed at determining an effective strategy for agribusiness were determined by the omission of a number of shortcomings of clustering, which can contribute to the complication of the development of agricultural enterprises that are united in a cluster. According to the conclusions of the study by O. Odintsov (2019), it is identified that the clustering process is associated with economic and social criteria that substantially affect its development and stability. A gap in a number of these studies was the failure to consider certain features of competition, namely its dynamism and simultaneously, instability in crisis conditions. Thus, some enterprises, considering the criteria of crisis circumstances, can help strengthen their own competitiveness in the market and substantially mitigate the number of shortcomings that affect production losses. According to the study by Z. Titenko (2023), competition, which is a priority goal for agro-industrial enterprises, is based on substantially more productive resource costs. It follows that to increase the competitiveness of enterprises, it is necessary to use strategies focused on attracting the innovation spectrum to agricultural activities, and therefore, clustering can be considered the most appropriate strategy. Notably, the boundaries of clustering are determined by complementary and interrelated relationships between enterprises and organisations of the same production industry, as well as firms bound by common rules and attitudes, and are considered the most appropriate for creating competition in the economic market.

Clustering is also defined as a modern structured form of close relations between enterprises of the same industry category, a system based on the hierarchical aspect of relationships. According to this, a cluster is

considered an alternative method of creating a value chain of relationships between firms, in the middle of a clustering network. Compared to other strategic actions, the interconnection of cluster strategy participants, their proximity, and their focus on one goal guarantees a better level of trust for potential investors. Therefore, the cluster strategy helps to resolve many problematic situations caused by crisis phenomena, showing better flexibility, orientation, and adaptability in the economic market. Thus, the purpose of this study was to define the clustering strategy as the most effective and sustainable method that provokes the attraction of investment resources for the agricultural industry in crisis economic conditions.

LITERATURE REVIEW

Various researchers apply a number of different theories to justify the investment behaviour of enterprises. For example, Z. Titenko (2023) argues that when enterprises implement investments, in fact, they have favourable conditions for improving their efficiency and competitiveness. In turn, C. Emmanuel *et al.* (2024), argue that imperfect investment markets cause businesses to encounter certain levels of financial liability rigidity. Usually, such circumstances contribute to enterprises resorting to different amounts of financial investments. Given that the financial and economic crisis is associated with fewer available chances for development and large amounts of material opportunities, it can be said that each of these theoretical assumptions contributes to reducing the amount of capital investment in conditions of financial crisis danger. M. Andriamampiandra *et al.* (2021) note that the attraction of additional capital from banking institutions and various types of lending, shock states of demand in the market in the context of crisis economic shifts, lead to the fact that enterprises of different types of farms, forcibly reduce their own investments. That is, despite the fact that enterprises have the potential to increase profits, with the beginning of crisis periods in the market, firms tend to refrain from new investments due to increased risk and lack of additional capital.

According to the interpretation of S. Xiong (2019) and A. Berxolli *et al.* (2023), sources of financing can be both internal (operating profit, dividends) and external (additional investment resource or lending), and it is also possible to combine the two types simultaneously. Thus, enterprises should analyse and determine the optimal financial resource provision for them, considering the fact that each of the resource types of financing involves certain features and risks. However, W. Ruland (2013) determined that theoretical approaches to the choice of financing strategy and analysis of factors of predisposition to certain material losses, and various kinds of moral risks existing in the market, prove the feasibility of using internal sources over external ones for enterprises operating in conditions of instability and competition against the background of shortcomings in the functioning of market financing mechanisms.

According to S. Zubair *et al.* (2020), an increase in the degree of inequality in informative aspects leads to a complication in attracting resources from outside (in particular, by attracting additional borrowing or increasing the cost of share capital). As a result, enterprises are motivated to invest at the expense of resources attracted from internal financial channels. Only if the use of internal financial security is used, do enterprises have to apply to continue their investment activities following the requirements of external investors. According to this, the amount of financing of enterprises depends mainly on material resources obtained from their own sources, that is, using internal resources. According to the interpretation of O. Odintsov (2019), in the context of economic and financial difficulties, such companies face additional difficulties in attracting additional funds for investment activities. Thus, during the financial crisis, funds generated internally turn into independent resource support for the private sector of enterprises. However, from this standpoint, organisations of various types of activities that finance their investments will have a substantial need for their own funds and therefore will depend on their use.

Considering possible strategies to attract additional investment income, M. Fan & W. Phromphitakkul (2021), consider the need for enterprise clustering, as they believe that such a strategy is the most effective and consistently balanced. It is appropriate to compare the formation of entrepreneurship with the course of industrial transformation processes but the feedback between them was at least as active as direct. A large number of sources emphasise the presence of difficulties and constraints in the formation of industrial business entrepreneurship, as well as some of its limitations. Given the wide list of these problems – weak development of the innovation spectrum, limited access to cash receipts, reduced market sales of products, and unstable strategic policies that contribute to the effective passage through such shifts, without deterioration of profitability, the issue of enterprise development can be a difficult task. Instead, according to K. Otsuka & M. Ali (2020), and E.K. Duramany-Lakkoh *et al.* (2022), it is determined that entrepreneurial work within the framework of a clustering campaign becomes a source for effectively overcoming certain obstacles on the way to the development

of firms forming a cluster. In addition to this, K.O. Alabi (2019) noted specific methods according to which cluster policy becomes an effective and convenient tool for overcoming crisis circumstances. According to the first method, clustering performs the function of effective collectivisation of enterprises, which ensures their competitiveness in the market. The second method is to position enterprises for growth in small but stable steps. In the end, the third aspect is the positioning of clustering as one that can refute possible negative reactions of enterprises to crisis economic conditions.

However, D.L. Putri *et al.* (2015) and D. Gakhar (2019) introduced consideration of the shortcomings of the clustering position, noting that clustering of agricultural enterprises is not the only effective way out of crisis situations. Among the main disadvantages of clustering, researchers highlight the use of external assets for small and medium-sized businesses since they can be reasonably correlated only with the help of government support, which is not always evident. However, according to a study by L.T. Thuong (2020), the involvement of government officials in investing in clustering enterprises is possible if the activities of firms act as a profitable source for the economy of the country in which clustering took place. Thus, for the agricultural business of the economy, attracting additional investment resources, especially from government officials, is not an obstacle since agricultural activities have always been and remain in demand for economic growth.

MATERIALS AND METHODS

This study is based on the theoretical aspects of agricultural policy in a crisis economy and therefore is exclusively theoretical in nature. The materials for this study were papers by W. Ruland (2013), O. Odintsov (2019), L.T. Thuong (2020), S. Zubair *et al.* (2020), E.K. Duramany Lakkoh *et al.* (2022), and Z. Titenko (2023), as sources who have generally examined the issues of investment strategies. The criteria that served to search for relevant materials were: investment strategies, economic shifts in agricultural policy, and methods for the development of agricultural policy. All the materials used for this study only partially met the set criteria. The aspects that highlighted the main issues related to investment strategies were selected from the total results of each of the materials used. The main differences between the results of all the materials used were the examination of different directions of investment strategies in enterprises of various types of activities related to the investigation of aspects that determine an effective strategy and confirmation of the negative consequences of crisis conditions on business activities in general.

As the first material for this study, the study by O. Odintsov (2019) was used, which considered the key criteria for activating investment in agricultural policy, which is based on the creation of agro-industrial clusters to ensure the competitiveness of the agricultural spectrum. The study was based on the identified main aspects that provoke investment in the agricultural sector. The second material for this study is a paper of Z. Titenko (2023), which considered the need to form strategies for the development of agricultural enterprises in general, which is the key to creating their financial security. The study is based on a block diagram aimed at introducing the financial stability of agricultural enterprises. Instead, this material was used to investigate possible aspects to identify reliable strategies for the development of agricultural policy. In addition to these materials, the results obtained in the study by S. Zubair *et al.* (2020) were used in this paper, which examined the current consequences of crisis situations, using the example of private firms with a staff of 50 to 249 employees in the Netherlands. The total sample included 469 privatised firms, including wholesale and retail (26%), manufacturing (21%), construction (20%), light industry (16%), transport (11%), and agricultural industries (2%). The study was based on the use of a regression model that determined the impact of the crisis state on external and internal investment. In addition, the study used the Wald criterion to compare the differences in the statistical impact of two types (sources) of investment. The statistics in the material used were collected using statistics from Breusch and Pagan. This third material was used to demonstrate the impact of the crisis state of the economy on the investment of enterprises and identify an additional effective source of investment for privatised firms. In general, all the materials were used to identify the main aspects, which should include a strategy aimed at attracting investment for the development of agricultural and industrial enterprises in accordance with the crisis states of the economy.

In the course of this study, materials were used based on the examination of possible criteria for risks progressing in crisis conditions of the economy and to identify characteristic aspects of an effective strategy to summarise the theoretical aspects that related to the certainty of criteria for evaluating the best investment strategy (Ruland, 2013; Thuong, 2020; Duramany-Lakkoh *et al.*, 2022); as well as, other sources that correlated the issue of functionality of the agro-industrial sector (Putri *et al.*, 2015; Otsuka & Ali, 2020). Basically, additional materials helped to refute the definition of the most effective strategy that helps attract additional investments in the agro-industrial business.

RESULTS

Based on a systematic review of scientific sources that determined possible strategies for attracting investment, a substantial part of specialists in the field of agricultural development research mainly share the opinion that the main component of the problems of backwardness of the agricultural sector is the lack of proper technical potential. Notably, this concept of insufficient innovative development also considers problems with agricultural productivity and recommends choosing the best options for overcoming such obstacles. Thus, according to the results of the first material used, it was determined that the clustering of enterprises should be used as a strategy for stimulating financial investment. However, considering the clustering criteria, the cluster approach should be based on the introduction of an innovative aspect. Based on the results of the material used, it was determined that the introduction of an innovative basis in the cluster system plays a substantial impact on the creation of the company's competitiveness and ensures the stable development of corporate institutions included in the clustering grid.

It is worth noting that clustering in the agricultural economy is an association of organisations and enterprises, which in turn are interconnected by common interests, goals, and motivations, which allows rationally using their common potential to increase their competitiveness in the market. In addition, it was determined that the investment and innovation aspects of clustering have a close relationship. With the involvement of an innovative approach, the investment projection increases substantially, which is why these aspects form the core of the cluster approach. The basis of investing from this used material is the use of balanced, implemented principles and actions that allow enterprises to provide comfortable circumstances to rearm the sector and achieve an investment effect. Thus, the conditions for successful investment attraction, based on the expressed indicators from the first material used, form a balanced clustering foundation (Fig. 1).

Figure 1. *Key aspects that contribute to creating effective clustering of enterprises to attract additional investment*
Source: *compiled by the authors based on O. Odintsov (2019)*

Thus, the results of the first material used for this study allowed identifying key aspects that provoke investment in the agricultural sector. Considering the cluster strategy of development and attraction of investment processes, it is worth highlighting innovative and investment aspects, as well as support for state structures, as those that are the most effective and reliable. According to the first material, it is determined that clustering of agricultural enterprises most effectively contributes to the development of the agro-industrial sector, through the introduction of innovative projects, and creating a favourable working climate for agricultural sector workers. Thus, using the key aspects from Figure 1, it is determined that the creation of clusters provokes additional investment in the agro-industrial sector, due to an increase in market attractiveness.

Using additional theoretical materials for this study, it was also determined that the cluster approach for attracting investment has its drawbacks (Ruland, 2013). Since the core of enterprise clustering is innovation and investment aspects, it can be concluded that attracting larger investment processes is impossible without implementing these criteria. In other words, to ensure large investments for enterprises, they need to organise innovative implementations in their own technologies, which complicates the task in the case of a small or unstable budget. In this case, to create effective clustering of enterprises, the main condition will be considered stable budget revenues for the introduction of innovations, which is a difficult task in the crisis and post-crisis period of the economy. Therewith, there are additional negative aspects of combining agro-industrial enterprises into clusters, such as insecurity in the case of the need to change technologies, since small and medium-sized enterprises in clusters are closed in a certain way within the use of established equipment. In the event that economic activity is determined by substantial and accelerated shifts in the technologies used, possible clustering partners may be less adapted to such changes and rely on innovations that belong to other members of the clustering. Thus, in the event that the cluster member companies focus on a small number of consumers of products on the market or on the activity of only a single firm, they are overly inclined to imitate managerial influences from the management of this firm. In addition, clustering representatives are becoming less proactive in developing and implementing new developments and technologies because they believe that the strategy of following the leader works for them.

In turn, using other additional materials for this study can also highlight the additional benefits of enterprise clustering (Dovgal *et al.*, 2017; Thuong, 2020). Territorial industrial clusters are built based on the

criteria for the development of the material and resource structure and cover enterprises and organisations in various areas of the economy. An important task in attracting investment to the regions is played by the development and application of regional clusters since they are able to form various innovative methods of conducting economic activities. Cooperation and specialisation of the subjects included in the cluster gives them the ability to increase both competition in economic markets, on the one hand, and increase the level of their activities and overall stability in material terms, on the other. For the most part, the territorial cluster strategy provides for a number of direct, but mostly indirect measures aimed at reducing obstacles to the dissemination of experience between firms, due to the fact that various barriers make it difficult to establish effective contacts between different subjects of clustering activities. Thus, clustering of firms of various categories, including agricultural policy, can provide an increase in investment revenues due to clustering at the regional level. Businesses in clusters are managed more efficiently and, as a rule, respond more quickly to market challenges. In general, clustering allows for a more reliable flow of financial resources because previously separated suppliers are now defined as joint (collective), and the cost of failure of losses and profits becomes substantially lower.

For this study, the second material was used, which was based on a block diagram aimed at implementing the financial stability of agricultural enterprises to form a general judgment on whether the cluster strategy should be regarded as an incentive source for additional revenues to the agricultural sector. Thus, according to the indicators of the second material used, criteria for determining the most effective strategy for the development of agricultural and industrial enterprises are established for this study, which, instead, stimulate the financial security of organisations in this sector of activity. In this study, financial security includes ensuring investment for agricultural enterprises. Strategies for financial development should be based on a number of all possible potential threats (Fig. 2).

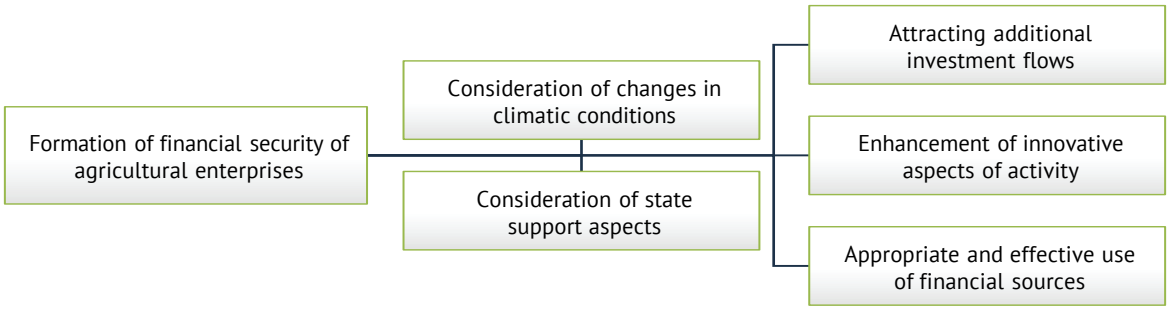

Figure 2. *Step-by-step provision of financial stability of agricultural enterprises, considering possible risks*
Source: *compiled by the authors based on Z. Titenko (2023)*

Based on the results of the second material used, for this study, it can be concluded that strategic planning and implementation of the development strategy at the enterprise involves the implementation of a number of tasks aimed at the implementation of all these stages, providing for the need to consider the existing potential hazards, as well as operational control over their implementation throughout the entire period of implementation. The implementation of a certain strategic action within each individual enterprise should be conducted according to the personal requirements of organisations, considering the actual state of their economic activity and the existing level of opportunities for further growth. A serious issue in establishing a specific strategy, as a rule, concerns the state programme of assistance to enterprises operating in the agricultural sector. On the other hand, the strategy implemented in the activities of enterprises will help to raise the financial stability rating and activate their own long-term economic and financial development. Therefore, the formation of an effective strategy, considering all possible threats of an economic nature, will ensure the financial security of the enterprise and encourage attracting investment. Comparing the results of the first and second materials used in this study it can be stated that the clustering strategy considered in the first source can be considered appropriate and effective for attracting additional investment since it involves considering the possible risks that were determined using the second scientific source. It distinguishes the cluster strategy of enterprise development among other models of attracting investment, in particular, territorial and production planned combinations, the presence of internal competition, and strong competitive foundations for development in the global currency space. In other words, the cluster is a combination of cooperation and compe-

tition, which are complementary links that contribute to building specific prerequisites for improving and developing innovative aspects of the agricultural sector.

Thereby, not all types of investments are equivalent. The negative effects of investing, in particular, large-scale direct foreign and private investments, often overlap the possible profits from it. Among the possible manifestations of the negative impact of direct foreign investment are restrictions on property freedoms, environmental destruction, and deterioration of the situation with food supply at the local level (Andrusiv *et al.*, 2020; Duramany-Lakkoh *et al.*, 2022). Insufficiently thought out and implemented investment projects often lead to substantial material losses both for investors themselves and countries accepting investments. It is necessary not only to increase the number of investments but also improve their effectiveness to ensure sustainable benefits for all stakeholders. On the other hand, investments that are able to prioritise local agricultural security, promote decent support for the labour force, organise the provision of land rights, guarantee equal access to the use of natural resources and the benefits of their economic growth are defined as those that are most effective in the agro-industrial sector. Such investments are supported by processes that are comprehensive and open to all participants in the agro-industrial business, making decisions that ensure access to the market and help protect the interests of the most vulnerable categories of society. Despite the fact that attracting direct foreign investments is considered a very substantial factor in ensuring the long-term functioning of the enterprise, it is worth developing and implementing strategies that would meet the specifics of a particular period of the economic cycle. Based on this, in times of crisis, it is necessary to consider all possible consequences of its impact on enterprises of various types of activity.

Material based on a regression model was used to identify the impact of the crisis state of the economy on two aspects of investment of enterprises, namely external and internal, which appropriately showed the correlates of this impact to identify the impact of the crisis state of the economy on two aspects of investment of enterprises, namely external and internal. Notably, the regression model is an equation, or system of equations that demonstrates which factors, from the point of view of scientists from this material, should have been guided when conducting the analysis, considering the interdependence of correlations projected in the equation (Zubair *et al.*, 2020). Paying attention to the formulation of investment aspects in this material, it was determined that external financing, for the most part, is the use of funds by enterprises from banking institutions, while internal financing is the attraction by organisations of their financial assets within the framework of investment programmes aimed both at improving the efficiency of the enterprise in which the investment action takes place and profits outside of it:

$$\begin{aligned} Investmen\ t_{it} = \alpha + \beta_1\ \text{Crisis}(Post\text{-}crisis) + \\ + \beta_2\ Internal\ Finance_{it} + \beta_3\ External\ Finance_{it} + \\ + \beta_4\ Internal\ Finance_{it} \cdot Crisis(Post\text{-}crisis) + \\ + \beta_5\ External\ Finance_{it} \cdot Crisis(Post\text{-}crisis) + \\ + \beta_6 Size_{it} + \beta_7\ Growth_{it} + Firm_i + \varepsilon_{it}, \end{aligned} \quad (1)$$

where t_{it} – years of crisis, post-crisis, and pre-crisis states, according to investments; *Size* – the size of the total assets of the enterprise; *Crisis* – a fictitious variable, the indicator of which is equal to 1, for the crisis periods of 2008-2009 (for others – 0); *Post-crisis* – a fictitious variable, the indicator of which is equal to 1, for 2010-2012 (for others – 0); *Growth* – the annual growth rate; $\beta_1, \beta_2, \beta_3, \beta_6, \beta_7$ – regression coefficients, for comparing firms' investments in crisis and post-crisis periods; β_4, β_5 – changing the impact of external and internal investments.

Thus, the results from the third material used showed that with the consequences of the crisis, the external supply of finances decreased quite substantially (Table 1). However, the most effective fund receipts for private firms in the Netherlands were investments made by banking institutions.

Table 1. *Indicators of investments and financial conditions of private firms in crisis, pre-crisis and post-crisis periods of different years in accordance with a certain model*

	Pre-crisis state (2004-2007)		Crisis state (2008-2009)		Post-crisis period (2010-2012)		Difference between pre-crisis and crisis status indicators		Difference between indicators of crisis state and post-crisis state	
	AV	M	AV	M	AV	M	AV	M	AV	M
I_1	0.055	0.031	0.042	0.019	0.035	0.016	-0.013	-0.012	-0.007	-0.003
I_2	0.086	0.05	0.076	0.041	0.065	0.033	-0.01	-0.009	-0.011	-0.008
I_3	0.053	0.029	0.042	0.019	0.033	0.015	-0.011	-0.01	-0.009	-0.004
I_4	0.073	0.043	0.067	0.034	0.057	0.03	-0.006	-0.009	-0.01	-0.004
CF	0.149	0.135	0.115	0.1	0.1	0.085	-0.034	-0.035	-0.015	-0.004
IF	0.114	0.102	0.092	0.079	0.082	0.069	-0.022	-0.023	-0.01	-0.01

Table 1, Continued

	Pre-crisis state (2004-2007)		Crisis state (2008-2009)		Post-crisis period (2010-2012)		Difference between pre-crisis and crisis status indicators		Difference between indicators of crisis state and post-crisis state	
	AV	M	AV	M	AV	M	AV	M	AV	M
EF	0.041	0.018	-0.007	-0.026	0.01	-0.003	-0.048	-0.044	0.017	0.023
TA	9.479	9.513	9.598	9.614	9.592	9.63	0.119	0.101	-0.006	0.016
FG	0.013	0	-0.004	0	-0.008	-0.006	-0.017	0	-0.004	-0.006

Notes: *AV – average value; M – median; I_1 – first investment; I_2 – second investment; I_3 – third investment; I_4 – fourth investment; CF – cash flow; IF – internal financing; EF – external financing; TA – total asset of enterprises; FG – financial growth*

Source: *compiled by the authors based on S. Zubair et al. (2020)*

Based on the performance indicators from the third material, it can be said that the crisis state substantially affected the investment of private firms, worsening their financial situation (Table 2). Notably, firms mostly relied on financing from banking institutions since this type of investment was considered more reliable in crisis and post-crisis periods.

Table 2. *Correlation data on the financial situation of privatised organisations in crisis, pre-crisis, and post-crisis states (calculated in Euro)*

	Pre-crisis state (2004-2007)		Crisis state (2008-2009)		Post-crisis state (2010-2012)		Difference between pre-crisis and crisis status indicators		Difference between indicators of crisis state and post-crisis state	
	AV	M	AV	M	AV	M	AV	M	AV	AV
I_1	821.92	349	661.9	251	601.61	200	-160	-98	-60.26	-51.5
I_2	1,260.9	575.5	1,227.17	534.5	1,095.3	505	-33.7	-41	131.9	-29.5
I_3	768.3	332	695	258	553	203	-73.6	-74	-141.8	-55
I_4	1,070.02	492.5	1,102.5	480.5	940.3	380	34.5	-12	-162.18	-101.5
CF	2,010.3	1,567.5	1,789.12	1,468	1,644.05	1,223	-221.14	-99.5	-145.06	-245
IF	1,547.28	1,191	1,409.13	1,090	1,318.4	953.5	-138.15	-102	-90.8	-135.5
EF	344.52	208	-241.86	-353	67	-56.5	-585.4	-561	308.9	296.5
TA	15,585.15	13,535	17,460	14,970	17,517.81	15,216	1,870.5	1,431	62.18	249.5

Notes: *AV – average value; M – median; I_1 – first investment; I_2 – second investment; I_3 – third investment; I_4 – fourth investment; CF – cash flow; IF – internal financing; EF – external financing; TA – total asset of enterprises*

Source: *compiled by the authors based on S. Zubair et al. (2020)*

Thus, from the indicators of the third material used for this study, it was established that the choice of investment type for firms was a determining factor in corporate financing. In particular, investments made by private sector enterprises during the economic crisis are more due to the availability of free fundraising from banks than to the use of financing from the domestic sector. In the case of private enterprises, bank receipts accounted for a stable strategic impact, considering all losses of organisations, which were especially observed in the post-crisis period. Thus, the amount of funds generated by enterprises (internal financing) cannot be interpreted as a determining factor for the investment of small and medium-sized enterprises in times of crisis but the availability of bank financing continues to be a crucial criterion for investment of enterprises in crisis financial and economic conditions. This proves that attracting external financing is more effective and reliable for ensuring the financial stability of enterprises in crisis periods. Therefore, to form effective and sustainable financial security, for representatives of the clustering of agricultural and industrial activities, it is most appropriate to attract external financing, namely, from banking institutions, state support, etc.

Summarising, in the first two materials used for this study, the role of investment strategy in the development of agricultural formations was crucial. Considering all the materials used in this study, it is worth highlighting that in most cases, an effective investment strategy for the development of enterprises, as well as for ensuring their financial stability and attracting

additional investments, should be considered as one that is built considering all possible risks (crisis economic and natural conditions), focuses on providing support to state institutions, and operates using innovative aspects of the enterprise. Thus, an effective investment strategy is based on the clustering of agricultural enterprises. Based on the results of the second material used, it was determined that the cluster strategy includes considering all possible threats in crisis states, which, based on the third material used, cause substantial negative consequences on the financial policy of firms, including the agricultural sector.

All the general views from the materials used agreed that an effective investment strategy should ensure the involvement of external finances and be based on innovative aspects since they are more reliable and balanced for the development of enterprises and their financial security. Considering all the criteria that determine the most effective strategic action aimed at attracting investment processes, it is determined that clustering of agricultural enterprises is able to properly create the necessary conditions for strengthening investment in agricultural business. The differences in the consensus of opinions from the sources used were the determination of the advantages of the agricultural sector of activity, which shows the interest of investors in investing in this business. According to the first and second materials, it is determined that state support for the agricultural sector and the constant need for innovative technologies serve as an incentive to invest in agricultural activities. The lack of sufficient arable land in the global economy encourages the agricultural market to introduce and improve technological innovations. These may also include vertical farming or other innovations aimed both at improving land fertility and increasing the level of agricultural crop yields. However, according to the third material used, it was established that the agricultural sector is in demand, mainly due to providing the population with basic needs, such as food. Considering additional theoretical sources that examined the advantages of investing in agricultural enterprises, a number of main criteria for the benefits of financing in the agro-industrial business can be distinguished (Table 3).

Table 3. *Advantages of the agricultural and industrial sector to attract additional investors*

Advantage	Explanation
The constant demand for goods	Agricultural products have a constant market demand, considering the fact that with the growth of the population, the need for food will increase in the same way
Increasing the cost of an agricultural business product	Price growth is linked to higher returns for investors
Favourable effect for economic development	By investing in the agricultural business, it is possible to develop and strengthen the economy of the country where this plan is being implemented
Rather low competitiveness	As a rule, the agricultural sector is the least likely to be selected to start doing business in comparison with any branches of other types of economic activity

Source: *compiled by the authors based on D.L. Putri et al. (2015)*

In this way, agricultural investments are much more effective in improving the well-being of low-income categories of the population, compared to investments in the non-agricultural sector of the economy. However, like every individual industry, the agricultural business has its drawbacks, which should also be considered by investors when investing in this sector. Among them, to a large extent, one can distinguish the dependence of production volumes on weather conditions and seasonal features. The criterion of sales of products is also noteworthy because excessive volumes of yield often lead to a decline in pricing policy and a substantial decrease in profitability. The disadvantages of investing in agriculture include the lack of insurance reserves necessary for the sale of products. Thus, the competitiveness of goods in the sales market may be negatively affected by certain unexpected circumstances, such as a decrease in labour productivity, an increase in depreciation charges and expenses for updating equipment necessary for production. In addition, the examination of investments in agribusiness takes a lot of work, which includes the analytical aspect of the action as assessing the cost links for investment, due to the lack of proper information resources and proper tools, to attract additional investments in the agricultural complex, will require substantial efforts on the part of possible investors. Ultimately, investing in the agricultural business involves both potential income opportunities and certain types of dangers that all future investors should be prepared for. Notably, it is impossible to create a single list of rules and actions that would properly guarantee the maximum result and the mandatory achievement of a large level of profitability because many areas and tools can be used in this field. However, in the course of this study, a number of generalised recommendation criteria were formed that can refute the risks of investing in the agricultural sector (Table 4).

Table 4. *Recommendations for possible investors who are focused on investing in the agricultural business*

Recommendation aspect	Characteristics
Financial condition analysis	Before making financial investments, calculating profits and losses and anticipating future prospects is necessary. An ordinary depositor with a small fortune usually needs only a notebook and a calculator to do this, while representatives of large businesses are advised to use the services of accountants.
Creating a fund reserve amount	It is not recommended to make investments using loans and borrowings, but it is advisable to create an insurance reserve for any period of time. Additional financial resources should be provided for all expenses, for a period of three to six months.
Setting investment goals	The purpose of monetary investments can be to preserve monetary resources, increase the value of assets, and ensure additional profit. Therewith, it is necessary that the set goals have specific deadlines for achieving them.
Identification of possible threats that provoke capital losses	Any investment plan and a separate financial resource have certain disadvantages, which is why it is very important for potential investors of agricultural production to approach the choice of candidates (enterprises and organisations) with whom they want to cooperate, especially, if necessary, with the involvement of professional investment experts.
Defining a future investment strategy	Choose a strategic investment action in advance, which will preferably include considering all possible risks and meeting the goals set.
Definition of the financing object	This point is usually performed by analysts using the ratio of profitability indicators of individual investment projects, with the calculation of possible income and selecting from them those that are most acceptable to the investor.

Source: *compiled by the authors based on K. Otsuka & M. Ali (2020)*

On the basis of a systematic review of all the materials used, this study identified the main aspects that identify effective strategic practices aimed at attracting additional investment. It is determined that the clustering investment strategy meets most of the identified criteria, and therefore, it is expediently considered effective for attracting additional financial investments in agricultural activities. Against the background of the obtained aspects of determining an effective strategy, for this study, the positive and negative aspects of the agro-industrial business were identified to attract additional investments and potential investors. A number of recommendation criteria and reservations were provided to help in forming a potential plan that will provide possible investors of agro-industrial activities to choose projects for financial investments, considering possible risks, especially in crisis economic conditions.

DISCUSSION

The study of the search for possible investment strategies that would appropriately ensure the financial security of agro-industrial businesses has so far been determined as necessary, due to the growth of economic and financial crises around the world. Considering the number of studies of specialists in the agro-industrial business and the economic sphere in general, it was determined that most analysts are focused on examining the clustering of enterprises, considering this strategy to be the most effective and reliable in crisis periods (Alabi, 2019; Xiong, 2019). Thereby, some studies investigate the impact of various crisis periods on the economy to consider possible risks to the financial activity of enterprises in general. W. Huang (2019) and Y. Huang (2019), focused on the financial crisis, in which there was a narrowing of the volume of loans in the financial sector of South Korean enterprises. The negative effects of reduced lending were also reviewed by L. Qian & F. Chen (2023), where researchers determined that in financial crises, small and medium-sized enterprises experienced more substantial losses in output compared to large companies and firms operating in the market. As part of the financial crisis analysis, D.L. Putri *et al.* (2015) examined the results of a survey of small and medium-sized industrial firms in China and identified certain categories of economic shocks, such as shock changes in the demand market, supply, and credit problems that businesses had to contend with. From the standpoint of consequences for investment activity, W. Ruland (2013), noted how negatively the financial disaster affected American joint-stock companies.

G. Gagné (2019) points to similar results for individual private corporations in Canada, China, Turkey, and Jordan. However, a large number of researchers agree that the construction and implementation of an investment strategy for agriculture is quite necessary. According to F. Karaev (2023), it is determined that a high-quality investment strategy can help increase the level of organisation funds security in accordance with various dangers caused by crisis states of the economy. In turn, it is the cluster investment policy that most harmoniously and expediently contributes to attracting additional financial revenues to the agricultural and industrial business, providing it with a foundation for efficient and rapid development (Otsuka & Ali, 2020). Notably, some shortcomings of this strategy are identified to counteract the effectiveness of clustering of enterprises in the agro-industrial sector according to other studies. For example, the findings of L. Zhang (2019)

demonstrate that cluster policies can only be effective if they attract external fund receipts, while domestic investments do not bring much stability to business activities. Such nuances are also identified by researchers who have focused on other investment plans, such as energy, production, and technology strategies (Ntamwiza & Masengesho, 2022). Contrary to this, the results of the study by D. Krummel (2022) refute the use of other strategies, arguing that cluster policies are based on a technological and production Key, and therefore, are no less efficient than other investment plans.

Examining the clustering strategy, researchers determine that the interdependence of internal needs of consumers of the clustering investment category is associated with competition, while external needs directly depend on cooperation. In addition, within the framework of the implementation of relationships, certain communication connections arise in the cluster, also aimed at the formation of personal, internal-cluster official and unofficial connections, which usually occur between its participants, which ensures the proper functioning of this strategy and contributes to the effective adaptation of clustering enterprises to external positive and negative phenomena. A number of studies conducted by other authors explain that it is on the basis of innovative aspects that the development of marketing and information security relationships between clustering participants takes place. A substantial role in the formation of effective marketing actions is played by general standards of production activities, building the effective cost of products on the part of firms included in the cluster and ensuring the development of relevant brands (Andriamampiandra *et al.*, 2021).

Based on a number of reasoned studies on the effectiveness of the clustering strategy, it can be concluded that the cost activity of clusters is also based on the establishment of network interaction, cooperation, coordination of joint work activity, and the development of competitiveness of organisations. In addition, the relevant authorities, which are focused on the area where clustering occurs, can also ensure the functioning of such a clustering grid. Clustering can take place depending on the initiative of characteristic government figures and enterprises of privatised links. Considering the first case, it can be stated that investment in clustering will take place with the participation of the government, in the second case, such a prospect may not happen. The government can take the initiative only if the merger of enterprises causes substantial development of the territory where clustering is developing. Clustering requires attracting investments from the state since this provides a certain foundation for the financial security of enterprises. According to an opinion expressed by Z. Cai *et al.* (2023), the introduction of production technology and the implementation of credit security policies for agricultural enterprises is a very important element in the process of developing a strategy that will contribute to improving the efficiency of their activities. Some studies also show that the presence of organisations with very low coefficients of production capacity and profitability, due only to poor indicators of the operating part of these enterprises' economy (Anh *et al.*, 2019; Zogbassè *et al.*, 2023). Thus, entrepreneurs should pay special attention to the introduction of modern production strategies to increase the volume of output and ensure a reduction in the unit cost. Considering the substantial level of danger of conducting agricultural business operations caused by the consequences of natural and climatic factors and seasonal phenomena, it is necessary to conduct further modernisation and expansion of the range of production procedures.

According to some studies, it has been established that with the presence of a statistically substantial level of easy availability of food resources in states, compliance with the principles of agricultural production development is also the most substantial link in the issue of economic criteria for the production and development of the food sector (Andriushchenko *et al.*, 2021; Poltorak *et al.*, 2022). However, in countries with medium and low economic availability of food, this relationship does not gain sufficient statistical significance. In addition, according to another separate study by A. Poltorak *et al.* (2023), there is a substantial relationship between the level of technological development and the financial security of agricultural enterprises. This proves that the use of an appropriate strategy that includes the aspect of innovation support provokes investors to introduce monetary resources into the agro-industrial business. A. Berxolli *et al.* (2023) determined that with the introduction of innovative aspects in the investment strategy, it is possible to ensure the sustainable development and functioning of the agricultural sector even in martial law. However, according to some papers, it is determined that not all investment strategic actions are useful for the agro-industrial business and for other activities in general. O. AitElMekki (2020), establish that with the attraction of foreign direct investment, there may be some difficulties with the land ownership of the agricultural sector. Similar conclusions were drawn in the study on the importance of building an investment strategy for small and medium-sized businesses (Emmanuel *et al.*, 2024).

The above-mentioned researchers raise issues related to the fundamental principles of implementing financial activity, and in particular: the basics of implementing an investment strategy, creating favourable

innovative and profitable integration, and legislative norms that contribute to the development and strengthening of the investment mechanism. However, a study by A. Kliuchnyk *et al*. (2023) shows that the level of well-being of the population of rural areas can increase by attracting tourists to the territory of agricultural production, farms, etc. It is determined that an important role in the formation of financial security of agro-industrial production, an important role is played by attracting state support, which ensures the sustainable and sustainable development of agricultural activities (Abba & Demarso, 2020).

Thus, with the application of a legal framework that regulates investment sectors, there is an incentive to attract additional financial resources to facilitate economic development. However, agro-industrial associations can be used as an alternative for investing funds. Land plots of agriculture are focused on profitability due to rental income, in accordance with the growth of production costs. Thus, investing in an agro-industrial business can function as promotional dividends, or as ordinary leased property with a profitable income. Unlike how volatile stock campaigns can be, demand for food products among consumers is always present, regardless of the period in which the business environment unfolds. Therefore, if investments are made in agricultural plots, they are defined as stable and resistant to crisis states and will never fall into disrepair, although the monetary fund is subject to repression.

CONCLUSIONS

In this study, a systematic review of scientific materials was conducted, searching for effective strategies for attracting investment in the agro-industrial sector of production. With the analysis and comparison of indicators from the sources used, this study determined that effective strategic action, first of all, should include all possible risks that may arise in crisis conditions of the economy. Such risks should also include the shortcomings of the agro-industrial business: dependence on weather conditions and seasonal phenomena, high time spent on production and a substantial need for energy costs on the part of the labour force. In crisis conditions of the economy, representatives of the agro-industrial business should give preference to effective strategies that provoke additional attraction of investments. The cluster strategic framework, which is based on innovative shifts for clustering participants, was identified to be the most effective for this purpose. Attention was focused on the possible shortcomings of the cluster strategy, namely: the dependence of numerous clustering participants on one firm, which may provoke their tendency to imitate managerial influences from the management of this firm, there may not be flexibility in changing innovative technologies, that is, participating firms may be less proactive in developing and implementing new developments and technologies, because they believe that the strategy of following the leader works for them. However, the cluster strategy identified more advantages than disadvantages. The positive aspects of clustering for agro-industrial business were the focus of the strategy on increasing the competitiveness of firms, using external investment resources, and building strong relationships and organisation between potential clustering participants, which increases their ability to ensure their own financial stability. Identifying aspects that provoke attracting additional investment, this study focused on the following criteria: ensuring the competitiveness of enterprises in the market, constant demand for products, innovation, and flexibility to crisis conditions. Thus, in determining the most effective strategic plan for agro-industrial production, it is necessary to consider the cluster strategy since it is advisable to review all aspects that contribute to attracting investment in agriculture.

This study formed a number of recommendations for future investors in the agro-industrial sector and identified the positive and negative aspects of investing in the agricultural sector. Among the main negative aspects of agricultural production, it is determined that there may be insufficient insurance reserves necessary for the sale of products. In other words, certain unexpected circumstances may negatively affect the competitiveness of goods in the sales market. Such circumstances usually include such criteria as: a decrease in labour productivity, an increase in depreciation charges and expenses for updating equipment necessary for production. In turn, among the advantages of the agro-industrial sector, this study observed: constant demand for goods, an increase in the cost of the product of agricultural business, a favourable effect for the development of the economy, and rather low competitiveness in comparison with other areas of activity.

The limitations of this study were the uncertainty of a sufficient number of reasons that would explain the aspect of reducing the impact of domestic investment in crisis periods of the economy, given that the attraction of external investment resources often becomes unavailable with the growth of complicated economic and financial shifts. The results and conclusions of this study can serve to further explore aspects of clustering in its broader manifestation. Based on the aspects on which the cluster approach is founded, for further research, it is possible to investigate the subject of possible cooperation of enterprises in clustering and identify the boundaries that clustering can cover.

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CONFLICT OF INTEREST

None.

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Інвестиційні стратегії розвитку аграрних формувань в умовах кризової економіки

Ольга Христенко
Кандидат економічних наук, доцент
Миколаївський національний аграрний університет
54008, вул. Георгія Ґонґадзе, 9, м. Миколаїв, Україна
https://orcid.org/0000-0003-0431-5328

Ірина Поточилова
Магістр, асистент
Миколаївський національний аграрний університет
54008, вул. Георгія Ґонґадзе, 9, м. Миколаїв, Україна
https://orcid.org/0000-0001-7785-4053

Валентин Кертичак
Аспірант
Миколаївський національний аграрний університет
54008, вул. Георгія Ґонґадзе, 9, м. Миколаїв, Україна
https://orcid.org/0009-0004-6522-546X

Анотація. Метою цього дослідження було визначення кластеризації підприємств агропромислового сектора як найбільш результативної інвестиційної стратегії розвитку сільського господарства у кризових економічних умовах. Це дослідження являє собою систематичний огляд наукових робіт, основою яких є питання пошуку стратегій розвитку для аграрної сфери діяльності у критичних умовах економіки, а також визначення найбільш ефективних з них для посилення дії аграрних формувань. Згідно з результатами цього дослідження, найбільш ефективною для розвитку аграрних підприємств визначено саме кластерну інвестиційну стратегію, однак на противагу цьому було встановлено ряд її негативних наслідків Було визначено необхідність побудови ефективної стратегії для залучення додаткових інвестиційних процесів. Досліджено негативні та позитивні сторони вкладень у сільське господарство, що допомогли встановити прояв можливих ризиків та прибутків від аграрно промислового сектору діяльності. Із використанням додаткових теоретичних матеріалів, у ході цього дослідження було оцінено кластерну інвестиційну стратегію, як таку, що виявляється більшою мірою стійкою до кризових умов. Було розглянуто окреме питання щодо важливості залучення зовнішніх інвестиційних ресурсів, оскільки саме такий вид вкладень виявився надійнішим у кризові фінансові та економічні періоди. Також було окреслено негативні наслідки впливу кризових умов на підприємства та організації різних секторів діяльності, надано ряд рекомендацій для потенційних інвесторів аграрно-промислової діяльності. Визначено, що кризові фінансові та економічні спектри являють собою ряд прогалин, які варто враховувати при виборі ефективної стратегічної політики, що має бути спрямована на посилення конкурентоспроможності аграрних підприємств та побудована на інноваційних аспектах високої активності. Варто зазначити, що саме кластерну політику було обрано як таку, що доцільно відповідала поданим критеріям відбору ефективної стратегічної дії

Ключові слова: кластер; конкуренція; інновації; індустріалізація; регресійна модель; матеріально-ресурсна структура

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The use of outsourcing in the public service delivery system to enhance the efficiency of agricultural production

Natalia Potryvaieva*
Doctor of Economic Sciences, Professor
Mykolaiv National Agrarian University
54008, 9 Georgiy Gongadze Str., Mykolaiv, Ukraine
https://orcid.org/0000-0002-9781-6529

Artem Palieiev
Postgraduate Student
Mykolaiv National Agrarian University
54008, 9 Georgiy Gongadze Str., Mykolaiv, Ukraine
https://orcid.org/0009-0005-2624-2504

Illia Moskal
Postgraduate Student
Mykolaiv National Agrarian University
54008, 9 Georgiy Gongadze Str., Mykolaiv, Ukraine
https://orcid.org/0009-0000-8114-8960

Abstract. Outsourcing in agriculture is a key tool for improving resource management efficiency, facilitating the implementation of innovative technologies, and reducing costs. In Ukraine, where the agricultural sector constitutes a significant share of the gross domestic product, evaluating the efficiency of such models is essential to ensuring the competitiveness of farms. This study focused on analysing the economic efficiency of outsourcing agrochemical soil services, satellite monitoring, and the adoption of precision farming, as well as assessing the impact of public-private partnerships. Statistical and comparative analyses were applied, including data from Ukrainian companies such as AgriLab and international practices. The analysis was based on data on costs, yields, and the efficiency of agricultural infrastructure over the period 2019-2024. The results indicate that soil maintenance costs decreased from 98 EUR/ha in 2019 to 84 EUR/ha in 2024, reflecting a 14% cost reduction. Administrative expenses fell by 25%, while overall agricultural infrastructure costs in Ukraine declined from UAH 5 billion to UAH 3.5 billion (a 30% reduction). The use of precision farming increased yields by 15-20%, depending on the crop, while fertiliser savings amounted to 20%. The implementation of outsourcing and innovative technologies ensures cost reduction and improved efficiency for farms. In particular, outsourcing significantly optimises production processes, as evidenced by an 18% increase in wheat and maize yields following the adoption of field zoning recommendations

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*Corresponding author

and precision fertiliser application. The findings can be used to develop government support strategies, implement outsourcing models, and promote the sustainable development of Ukraine's agricultural sector

Keywords: agricultural sector; cost optimisation; precision farming; farms; soil analysis; yield improvement

INTRODUCTION

With the rapid development of the agricultural sector and the need to enhance resource efficiency, outsourcing has become one of the key tools for optimising production processes. The trend towards adopting innovative technologies, particularly precision farming, significantly reduces the costs of maintaining agricultural infrastructure and ensures a steady increase in yields. This is particularly relevant for many countries, including Ukraine, where agricultural development plays a crucial role in the national economy. Studies highlight the significant economic potential of outsourcing in the agricultural sector. For instance, F. Andersson *et al.* (2019) emphasise the importance of balancing cost and quality in outsourcing services in agriculture, allowing for increased efficiency in production processes. Similarly, Q. Mi *et al.* (2020) found that engaging external service providers in production helps improve the well-being of small farmers by reducing their production costs and increasing profitability. The experiences of the Netherlands and China demonstrate the prospects of implementing outsourcing models to enhance agricultural sector productivity.

Ukraine is also actively adopting new approaches to managing agricultural infrastructure by incorporating outsourcing services. The potential of such changes is confirmed by N. Potryvaieva & A. Palieiev (2023), who highlight outsourcing as an effective tool for reducing operational costs and increasing business competitiveness. In the research of L.Z. Buranbaeva *et al.* (2020), the emphasis is placed on the importance of cooperation between enterprises to ensure sustainable development and reduce environmental impact. V. Shebanin *et al.* (2022) stress the significance of implementing closed-loop technologies for the sustainable development of socio-economic systems. The authors underline that adopting innovative approaches through outsourcing models contributes to cost reduction and enhances the environmental efficiency of agricultural enterprises.

The study by T. Reardon *et al.* (2024) focuses on outsourcing as a mechanism for transforming agricultural production on a global scale through access to cutting-edge technologies and increased productivity. The authors examine the role of outsourcing services in helping farmers adapt to new value-added chains. Research by L. Shi *et al.* (2024) suggests that with government support, the implementation of "green" technologies through outsourcing becomes more accessible for farmers, reducing their carbon footprint and increasing production efficiency. G. Nguyen *et al.* (2022) conducted a statistical analysis of outsourcing in France's agricultural sector, identifying it as a growing trend. Their study revealed that farmers are increasingly outsourcing tasks such as equipment maintenance, allowing them to optimise costs.

J. Jiafang & Y. Junxiao (2022) highlight the importance of socialising agricultural machinery services in China to improve the management of large land areas. They note that outsourcing technical services enables farmers to utilise resources more effectively and expand cultivated areas. S. Xie *et al.* (2023) explore the impact of farmers' participation in outsourcing services on production levels and risks. Using case studies of farms in China, they demonstrate that outsourcing increases production volumes through access to advanced technologies while also helping to mitigate agricultural risks. Thus, the aim of this study was to analyse the economic efficiency of outsourcing models in Ukraine's agricultural infrastructure, particularly in terms of reducing agrochemical service costs, increasing yields, and adopting innovative technologies.

MATERIALS AND METHODS

The study was conducted using an empirical approach to analysing outsourcing practices in the field of agricultural infrastructure maintenance, including soil analysis and consultancy on innovative technologies. The analysis was based on data on costs, yields and efficiency of agricultural infrastructure for the period 2019-2024. The key legislative acts of Ukraine have been considered: Law of Ukraine No. 922 (2015) – ensures transparency in the selection of private service providers. Law of Ukraine No. 2404-VI (2010) – regulates the principles of cooperation between the state and the private sector. Resolution of the Cabinet of Ministers of Ukraine No. 102 (2021) – promotes the introduction of innovations in agriculture. State support programmes for farmers, particularly the "Affordable Loans 5-7-9%" programme, encourage farmers to collaborate with private companies to implement innovations (Ministry of Finance..., 2022). Decentralisation Reform (n.d.) – allowed local communities to enter

into agreements with private companies for the maintenance of agricultural infrastructure. EU directives under the Association Agreement between the European Union and its Member States, on the One Part, and Ukraine, on the Other Part (2014), particularly the directives on environmentally sustainable agriculture, encourage the involvement of innovations through the private sector.

The experience of Ukrainian companies has been analysed, including: AgriLab – a leading Ukrainian company that offers comprehensive agrodiagnostic services, including agrochemical soil analysis, satellite monitoring, and fertilisation recommendations to increase crop yield based on geoinformation data. National Scientific Center "Institute for Soil Science and Agrochemistry Research named after O.N. Sokolovsky" – a state institution that collaborates with private companies within soil analysis programmes for precision agriculture. The "AgroRegion" group of companies – implements AgriLab's recommendations to optimise fertilisation, using field zoning and a differentiated approach to field processing.

The activities of European companies were studied, such as: SoilCares (AgroCares) (Netherlands) – an international company from the Netherlands that specialises in soil analysis, using advanced technologies such as Lab-in-a-Box and Soil Scanner. These portable solutions enable farmers to obtain real-time data on soil micro- and macro-elements. The company provides fertilisation recommendations, helping to optimise costs and increase crop yields. SoilCares also works on local adaptation of its technologies in various regions of the world, including countries in Africa, Latin America, and Asia. Société Générale de Surveillance (SGS) (Switzerland) – a Swiss company that is a global leader in inspection, verification, testing, and certification, offering a full range of agricultural services. Its agricultural division provides soil analysis, evaluates soil fertility and condition, and offers recommendations for precision agriculture. SGS uses advanced laboratories to quickly and accurately determine the physical and chemical properties of soils, optimising fertiliser use and reducing environmental impact.

Analysis methods: statistical analysis – applied to process data on the economic efficiency of outsourcing models. Official reports from the Reports on the work of the Ministry of Agrarian Policy (2025) were used. An analysis was carried out on changes in state expenditures on agricultural infrastructure before and after the implementation of outsourcing, as well as the impact of these changes on crop yields; comparative analysis – analysed Ukrainian and international experience to identify best practices for implementing outsourcing solutions.

Tools described in the study: satellite monitoring and geoinformation systems for assessing soil quality, specifically EOSDA Crop Monitoring; portable laboratories such as AgroCares SoilCares Manager (12-month licence) & Handheld Scanner; IT platforms, including "MyAg riLab", for agronomic planning. The methodology allowed for the assessment of outsourcing efficiency in agriculture, particularly reducing government spending and increasing crop yields through the rational use of resources.

RESULTS

Outsourcing of services in agricultural infrastructure significantly reduces government spending on maintenance and support of agricultural infrastructure, particularly in the context of soil analysis and the implementation of innnovative technologies. A comparison of expenses before and after the introduction of outsourcing models in Ukraine shows a significant reduction in costs for agrochemical services (Aranchii & Ihnatenko, 2021). Specifically, according to AgriLab, which provides agrochemical soil analysis and satellite monitoring services, the cost of soil maintenance using outsourcing services can be reduced by 20-30% compared to traditional management methods. This is achieved through precise and timely fertiliser application, field zoning, and optimisation of agronomic processes.

Additionally, according to the Reports on the work of the Ministry of Agrarian Policy (2025), the introduction of outsourcing allows for a reduction in administrative costs, as many functions previously handled by government agencies are transferred to the private sector. This includes not only soil maintenance but also consulting services for farmers, which reduces infrastructure costs by 25-30% through improved efficiency and better use of relevant technologies.

The implementation of outsourcing models for soil analysis and fertilisation recommendations significantly increases agricultural production efficiency, particularly in terms of increased crop yields. The application of innovative solutions allows for the acquisition of accurate data on soil conditions, enabling more precise fertiliser application and maximising the use of available resources. According to AgriLab and studies within precision farming programmes, yield increases of 15-20% have been observed across various crops after implementing recommendations based on soil analysis and satellite monitoring. For example, in the case of wheat and maize in Ukraine, the use of precision farming technology resulted in an average yield increase of 18%, while fertiliser savings amounted to about 20% (Ministry of Agrarian…, 2024). On the other hand,

international companies such as SGS (Switzerland) also demonstrate positive results when using advanced soil analysis technologies and fertilisation recommendations. For instance, the use of laboratories and accurate soil condition data led to a 15% increase in yield on fields where these technologies were applied, compared to traditional processing methods. This approach not only reduces fertiliser costs but also improves long-term soil fertility.

Ukrainian laws have created a legal framework for effective interaction between state institutions and private companies. This is particularly important in the agricultural infrastructure sector, where the involvement of private service providers promotes increased productivity. Public procurement transparency: Law of Ukraine No. 922 (2015) ensures competitive conditions for selecting suppliers. The use of the electronic procurement system (Prozorro) reduced the average time to conclude contracts to 21 days in 2024, which is 15% faster compared to 2021 (Resolution of the..., 2021). This enables faster implementation of innovations in the agricultural sector. Public-private partnership mechanisms: Law of Ukraine No. 2404-VI (2010) stimulates investment in innovative technologies, for example, through the transfer of soil analysis services to private companies. These agreements reduce state administrative costs by 20-25%, as functions are delegated to more competent specialised organisations.

The contribution of the "Affordable Loans 5-7-9%" programme. This state support programme is an important tool for helping small and medium-sized agricultural enterprises in Ukraine, promoting their financial stability, the implementation of new agricultural technologies, and increasing agricultural production efficiency. It provides preferential loans with low interest rates (5-9%), allowing farmers to significantly reduce financial burdens and more effectively utilise resources for the development of their farms. Thanks to these preferential loan rates (5-9%), farmers have been able to reduce financing costs, which allowed them to increase investments in innovative technologies. This has been a key factor in ensuring economic growth and increased productivity for agricultural enterprises in various regions of the country.

A prominent example of successful programme implementation is Odesa region, where more than UAH 1.2 billion was allocated under the programme. This enabled local agricultural enterprises to implement innovative technologies to increase yields and farming efficiency. It has been noted that even small farms in the region were able to access advanced agro-technologies, such as precision farming systems, allowing them to achieve significant yield increases per unit area. This confirms that state-level support programmes are an effective tool for stimulating the development of agricultural enterprises even in rural areas, where small farmers do not always have the means to finance innovations independently.

"Affordable Loans 5-7-9%" not only support the development of technologies in the agricultural sector but also provide an economic benefit to the entire industry (Ministry of Finance..., 2022). Investments in agricultural machinery and innovations improve the competitiveness of Ukrainian farmers on both domestic and international markets. The programme also creates co nditions for the development of sustainable agriculture, reducing dependence on the import of technologies and equipment, and promoting the growth of agricultural product exports. Importantly, the implementation of such programmes contributes not only to the development of individual farms but also to strengthening the economies of regions where agriculture is the primary sector. Overall, this programme has proven to be an effective tool for stimulating the development of agriculture in Ukraine by providing access to financing and encouraging the implementation of innovations, which in turn enhances the competitiveness of agricultural enterprises in domestic and international markets.

The cooperation of AgroRegion with the state farmer support programme "Affordable Loans 5-7-9" has significantly eased access to financing, ensuring the purchase of precision farming technologies. The programme has demonstrated substantial results in Ukraine's agricultural sector. According to the Ministry of Agrarian Policy and Food of Ukraine, in 2024, approximately 7,600 agricultural enterprises received loans totalling UAH 39.4 billion. These funds were used to modernise technical infrastructure, develop precision farming, conduct soil analysis, and purchase new equipment. AgriLab has become one of the leaders in the field of agrochemical soil analysis, offering farmers efficient solutions for optimising costs and increasing crop yields. Thanks to accurate analysis of the physical and chemical properties of soils, its services allow for rationalising the use of fertilisers and resources. Specifically, field zoning and individual recommendations help reduce fertiliser costs by 20%. In projects such as soybean cultivation in western Ukraine, after agrodiagnostics, fertiliser costs dropped from EUR 98/ha to EUR 84/ha (Fig. 1). Furthermore, due to the implementation of AgriLab's approaches, there was a 15% increase in yield. The analysis showed that accurate fertiliser selection based on the actual needs of soils increases the effectiveness of nutrition systems and allows for consistently higher yields.

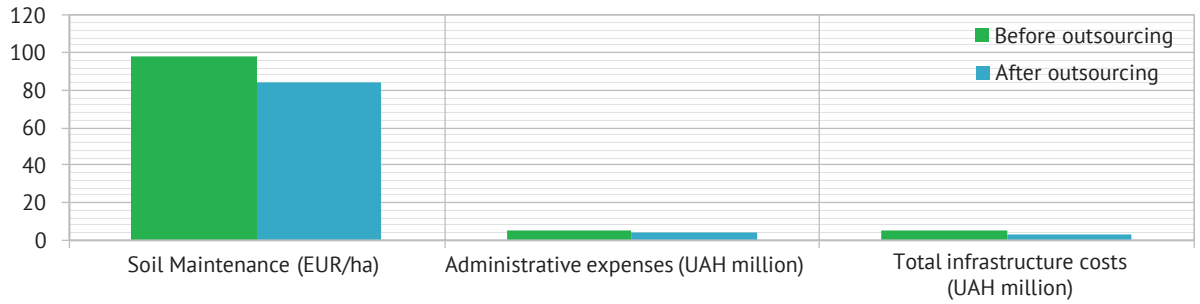

Figure 1. *Comparison of agrochemical service costs before and after outsourcing in Ukraine*
Source: *compiled by the authors based on Reports on the work of the Ministry of Agrarian Policy (2025)*

Project "Agrocultura Mostyska" In Lviv Region, AgriLab conducted agrodiagnostics on a 1,000 ha plot used for growing soybeans. The analysis revealed an issue with low soil pH in certain areas, which significantly impacted productivity. The use of GPS-linked zoning enabled the precise identification of problematic areas, and laboratory analysis indicated the need for soil liming to improve fertility. Recommendations for localised fertilisation were provided to reduce costs. Economic Results: excluding unprofitable areas from cultivation helped optimise production processes. Adhering to the recommendations reduced fertiliser costs, and as a result, overall yield on suitable areas increased by 3%. This case demonstrates the importance of field zoning as an economically effective tool for agriculture. Thanks to zoning, farmers were able to achieve higher productivity without increasing overall costs.

"Loretta Agro" in Khmelnytskyi Region focused on restoring long-neglected lands for active use. By using agrochemical soil analysis, the company obtained valuable information that helped develop an effective strategy. The lands, which had not been cultivated for a long time, had low nitrogen levels and significant erosion problems. A technological map was developed, which included recommendations for nitrogen and other micronutrient applications according to the needs of specific areas. The first harvests on the "restored" lands were high, even in adverse weather conditions. The correct proportions of fertiliser helped minimise the costs of crop nutrition while ensuring stable yield growth. The results of this case highlight the importance of using a comprehensive agrodiagnostic approach to cultivate land previously considered unsuitable. The innovative solutions provided by AgriLab allowed the restoration of productivity on these lands without excessive investment.

Both cases illustrate how the use of cutting-edge technologies and a scientific approach enhances the economic and ecological efficiency of agricultural production. They confirm that precision farming can bring not only economic benefits but also ensure sustainable management of natural resources. The technologies used by AgriLab include satellite monitoring of crop conditions and the creation of geographic information maps for agronomic planning. These tools allow for: identifying heterogeneities in soil structure and optimising fertiliser application by zones; reducing unnecessary field treatment costs; and obtaining real-time data for making quick decisions regarding nutrient systems. The additional economic efficiency is achieved by reducing the misallocation of resources through process automation and shortening the time required for decision-making, thanks to the prompt analysis of satellite data.

AgroRegion actively collaborates with AgriLab, implementing precision farming recommendations and optimising fertilisation practices. Their methods demonstrate significant improvements in financial and operational efficiency. Examples of this include increased farm profitability. Thanks to the introduction of a precision fertiliser application system based on agrochemical soil analysis, the profitability of farms increased by an average of 18%. This was made possible by using analysis data to create individual fertilisation maps and optimising field zoning, which allows for more efficient resource distribution and reducing costs on unjustified agrochemical operations. The use of satellite monitoring and geographic information systems reduced costs on agrochemicals by 20%, which was achieved through accurate calculation of soil nutrient needs and the rational use of natural resources. In turn, technologies like satellite monitoring and field zoning not only increased yield but also ensured sustainable land resource management. This approach enables high results even under adverse climatic and market conditions. Thus, AgroRegion serves as an example of successful innovation in agriculture, promoting increased profitability and ecological sustainability of farming operations.

The National Scientific Centre "Institute for Soil Science and Agrochemistry Research named after O.N. Sokolovsky" plays a key role in the development of precision farming programmes in Ukraine. Its activities

focus on integrating scientific research with the practical needs of the agricultural sector, particularly through collaboration with private companies. The centre conducts a wide range of soil research, including agrochemical analysis, evaluation of physico-chemical properties, and monitoring changes in soil structure. This research helps farmers adapt their technological approaches to local conditions, including optimising fertilisation systems by analysing the micro- and macro-element composition of soil, as well as using geographic information systems for field zoning, which reduces fertiliser costs by 15-20%. The centre collaborates with companies such as AgriLab to provide farmers with access to new soil analysis methods and precision farming recommendations. This allows for the scaling of precision farming practices throughout Ukraine, contributing to a 10-15% increase in yield, depending on the crop. Thanks to government support programmes, the centre coordinates between scientific institutes, farmers, and private companies, facilitating the integration of innovative technologies into the agricultural infrastructure. Therefore, outsourcing significantly reduces costs both in Ukraine and abroad. At the same time, such models contribute to yield growth by implementing precision farming and new technologies (Table 1). Data shows that state expenditures on soil maintenance under outsourcing have decreased from UAH 5.2 billion in 2019 to UAH 3.9 billion in 2024.

Table 1. *Comparison of costs, yield, and resource savings in different management models*

Indicator	Traditional mode	Ousourcing	Precision farming
Soil maintenance costs (EUR/ha)	98	84	78
Administrative costs for soil maintenance (million UAH))	5.2	3.9	3.2
Total costs for agricultural infrastructure (billion UAH)	5	3.5	3.1
Yield growth (average, %)	-	15-20%	18-25%
Fertiliser savings (%)	-	20%	25%
Data processing and planning time (days)	7-10	3-5	1-2

Source: *compiled by the authors based on data from AgriLab, Precision Farming Study based on Reports on the work of the Ministry of Agrarian Policy (2025)*

International experience. SoilCares (Netherlands) is part of the AgroCares group and specialises in the development of portable laboratories and scanners for real-time soil analysis. These technologies significantly simplify and reduce the cost of analysis. The company has developed devices such as Lab-in-a-Box and Soil Scanner, which provide data on the micro- and macro-element composition of soil in just minutes, reducing soil analysis costs by up to 40% compared to traditional methods. This is particularly relevant for small farms. SoilCares is implementing its solutions in Africa, Asia, and Latin America, where their technologies help significantly improve yields even in challenging climatic conditions. In the Netherlands, farmers report a 20-25% reduction in fertiliser costs thanks to recommendations created based on scanner data.

SGS (Switzerland) is a global leader in soil analysis, certification, and agrotechnologies. The company offers comprehensive services that optimise fertiliser use and reduce environmental impact. SGS uses laboratories for fast and accurate analysis of physical and chemical properties of soils. Their services help reduce excessive fertiliser use, cutting costs by 15-20% and promoting soil fertility preservation. SGS is actively implementing solutions to reduce environmental impact, such as soil monitoring and recommendations for eco-friendly land treatment technologies, and supporting organic farming programs through precise fertility analysis and natural fertilisation recommendations.

These examples demonstrate how innovative approaches and international experience can be integrated into Ukrainian agriculture to increase efficiency, save resources, and protect the environment. Analysis of Technology Efficiency. Satellite technologies, particularly EOSDA Crop Monitoring, significantly improve the accuracy of agrodiagnostics, positively affecting agricultural process management. Zoning accuracy is ensured by using vegetation indices such as NDVI, which allows the identification of uneven crop development across different areas of the field. This enables precise fertiliser and plant protection applications, reducing costs by 15-20%. Field condition data is updated every 1-3 days, allowing agronomists to quickly respond to changes, such as pest or disease outbreaks. Satellite monitoring also contributes to more accurate planning, reducing the risk of overspending or crop losses.

"MyAgriLab" is a leading example of a digital platform that provides farmers with analytical tools. It allows for fertiliser application planning, generating fertilisation maps based on soil analysis data, achieving fertiliser savings of up to 25%. Built-in algorithms also forecast yield depending on current conditions and past performance. The platform is compatible with precision farming systems such as GPS equipment for

automated machinery. New technological solutions not only enhance economic efficiency but also reduce environmental impact. Thanks to precise zoning and calculation of required fertiliser doses, agrochemical use is reduced by 20-30%. This decreases the risk of nitrates entering water resources and prevents soil degradation. Continuous monitoring of fertility indicators helps avoid soil overexploitation. Systems like EOSDA Crop Monitoring help maintain an optimal balance of mineral substances, preserving the long-term ecosystem of fields. The use of such tools facilitates the transition of farmers to organic farming, ensuring accurate identification of environmentally-friendly fertilisation and plant protection methods.

DISCUSSION

This study highlights the economic and agronomic potential of outsourcing in agricultural infrastructure. The results show significant cost reductions and improvements in efficiency and productivity. These findings contribute to expanding the discussion on the role of outsourcing in enhancing competitiveness and sustainable development in the agricultural sector. The study found that outsourcing services, such as soil analysis and precision agriculture technologies, reduce operational costs by 20-30% and increase yields by 15-20%. These findings align with the research by R. Du *et al.* (2024), which showed that production outsourcing contributes to the adoption of low-carbon technologies in China, reducing production costs and ensuring ecological sustainability. These results are particularly relevant for Ukraine, where the transition to innovative agricultural practices is critical for long-term competitiveness and resource optimisation.

These results are crucial in addressing systemic challenges in the agricultural sector. Outsourcing not only reduces financial barriers but also democratises access to advanced technologies. E. Vandergeten *et al.* (2016) in their meta-analysis noted that outsourcing in agriculture can bridge the gap between small farmers and technology providers, ensuring fair resource distribution. However, they also highlight the risks of "land grabbing," which need to be considered when developing policies. The findings of this study are consistent with the conclusions of G.M. de Oliveira & D. Zylbersztajn (2017), who examined outsourcing contracts in mechanised services for Brazil's coffee business and found that outsourcing enhances efficiency and better resource allocation. The similarity of results indicates the universal benefits of outsourcing in various agricultural contexts, despite differences in cultures and economic structures. However, there are some differences from the research by S.M. Mulewa (2019), who studied outsourcing in Kenya's food industry. S.M. Mulewa (2019) emphasises the importance of strategic management for the successful implementation of outsourcing, while this study in Ukraine achieved significant cost reductions even without advanced strategic approaches. This difference highlights the role of contextual factors, such as regulatory conditions and market dynamics.

The results are also consistent with the study by S. Yekimov *et al.* (2021), who analysed outsourcing accounting services for small agricultural enterprises in Ukraine. They found that outsourcing significantly reduces administrative costs, which supports the findings regarding cost savings. Meanwhile, the emphasis on financial management contrasts with the focus on operational aspects, indicating the complementary advantages of different forms of outsourcing. The strategic significance of outsourcing in agriculture goes beyond cost reduction. M. Charles & S.B. Ochieng (2023) note that outsourcing improves productivity by allowing businesses to focus on key competencies. This conclusion matches the findings of this study, which show that transferring soil analysis and consulting services allowed Ukrainian farmers to focus on optimising agricultural practices, positively impacting productivity.

The results also suggest that outsourcing soil and agrochemical analysis services and implementing innovative solutions by private companies lead to more rational resource use. This is supported by V.C. Materia *et al.* (2017), who state that outsourcing strategies facilitate the rapid implementation of innovations, especially in large enterprises where scale and efficiency are critical. The results of this study also align with the findings of F. Azizi *et al.* (2013), who investigated the impact of outsourcing on land preparation for sugarcane cultivation in Iran. The study showed that outsourcing reduced costs by 15-20% and increased productivity through the use of technology. The similarity of these results indicates the universality of outsourcing in optimising operational processes. On the other hand, research by H. Azadi *et al.* (2013) draws attention to outsourcing risks, such as increased dependency on large companies or uneven access to resources. This requires careful consideration of the social aspects of outsourcing when developing policies.

The results of this study also find support in the work of R.C. Yadav & J. Yadav (2013), who emphasise that outsourcing business processes in the primary sector of the economy improves natural resource management and contributes to the stability of farming enterprises. Meanwhile, comparisons with the study by M. Igata *et al.* (2008) show that the success of outsourcing depends on local characteristics. For example, in the Netherlands, this model is a common practice, while in

Japan, farmers tend to rely more on their own resources. The conducted study demonstrates that outsourcing allows farmers to focus on key aspects of their business while outsourcing specialised services to external contractors. This is consistent with the conclusions of P. Bębenek (2017), who notes that outsourcing is a development model for agricultural corporations focused on competencies. Engaging specialised suppliers enables companies to use their resources more efficiently.

J.B. Traversac *et al.* (2011) studied the impact of transaction costs and resource base on the integration of agricultural producers into additional stages of production. The authors emphasise that outsourcing services significantly reduce operational costs for farmers, especially in industries with high transaction costs, such as winemaking. These results align with the findings of this study regarding the economic efficiency of outsourcing to reduce operational costs in agriculture. The conclusions of A.A. Satybaldina *et al.* (2023) on outsourcing in Kazakhstan's agricultural sector are relevant to this study, which also highlights the need to create a favorable regulatory environment. The authors emphasise the potential of outsourcing to enhance the efficiency of agricultural enterprises and note that it can promote the transition to high-tech agriculture, but its implementation is limited by insufficient state support and institutional barriers.

The conclusions that outsourcing provides access to innovative solutions, especially for small farmers, align with the results of R. Tang & C. Chen (2022). The authors studied the impact of outsourcing services on the participation of elderly farmers in rice production in China and found that outsourcing reduces physical strain and encourages farmers to adopt updated technologies. L. Qian *et al.* (2022) analysed the use of farming machinery in comparison to outsourcing technical services in China and concluded that outsourcing allows large farmers to rent land more efficiently and expand cultivation scales. This is consistent with the findings that outsourcing creates conditions for large-scale production and optimal resource use.

The impact of outsourcing agronomy consulting programs on the income of small farmers in the Republic of South Africa was studied by L.J. Baiyegunhi *et al.* (2019). The research showed that farmers using outsourcing services earn higher net incomes due to rational resource use. This result resonates with the conclusions of this study regarding the economic benefits outsourcing provides for small agricultural enterprises. The results of this study align with the conclusions of J. Lin *et al.* (2023), who analysed the impact of outsourcing services provided by cooperatives in China. They found that such services improve farmers' technical efficiency through the use of shared infrastructure and access to professional recommendations. This matches the conclusions that the use of shared services, such as soil agrochemical analysis and field zoning, allows for cost reductions.

Implementing outsourcing models increases the efficiency of farms by optimising resource use and reducing soil maintenance costs, as found by A.J. Picazo-Tadeo & E. Reig-Martínez (2006) in their study on outsourcing in Spain's agriculture, particularly citrus production. The results confirm these findings, especially in the context of scaling up production through the adoption of innovative technologies. The study by L.J. Schulz *et al.* (2004) highlighted difficulties in implementing outsourcing models in extended partnership models within the TOPCROP program in Australia. They emphasise that the success of such models depends on proper management of partnerships and clear contractual agreements. This suggests the need to improve the legal regulation of outsourcing relations in Ukraine's agricultural sector.

The results of this study also find confirmation in the work of N. Zahid (2024), who studied the factors influencing the adoption of outsourcing services among corn farmers in Pakistan. The author notes that economic incentives, such as subsidies and access to credit, significantly increase farmers' willingness to adopt outsourcing services. This corresponds with the findings of this study on the need for state support to encourage outsourcing adoption. Outsourcing allows for the resolution of pressing issues faced by farmers, such as the high cost of maintenance and inefficient resource use. This makes outsourcing not only economically beneficial but also strategically important for enhancing the competitiveness of farming enterprises.

CONCLUSIONS

The research has achieved its objective, demonstrating that the implementation of outsourcing models in the agricultural sector, particularly in soil agrochemical analysis and satellite monitoring, has a significant economic impact. Reducing agrochemical service costs by up to 30% in Ukraine allows for a decrease in fertiliser costs and an increase in yield by 15-20%. The use of field zoning reduces fertiliser costs by 20%. State-private partnership programs, such as the electronic Prozorro system, have reduced contract signing time by 15% and lowered government administrative costs by 20-25%. This has facilitated the involvement of the private sector in providing services like agrochemical analysis. The "Affordable Loans 5-7-9%" program has helped reduce financial burdens on agricultural enterprises, leading to increased investments

in precision farming technologies. In 2024, farmers received loans amounting to UAH 39.4 billion, which allowed for a 15-20% increase in yield and a 20% reduction in fertilizer costs.

The implementation of precision farming practices, such as field zoning and agrodiagnostics, enables the optimisation of fertiliser costs and increased yield. For instance, in the "Agrocultura Mostyska" project, zoning reduced fertiliser costs by 14 EUR/ha, while yield on suitable plots increased by 3%. Similar results were achieved in the "Loretta Agro" project, where proper fertiliser application restored neglected lands and ensured a stable increase in yield. AgriLab demonstrated successful cases in optimising agrochemical processes, including a reduction in fertiliser costs from 98 EUR/ha to 84 EUR/ha and a 15% yield increase after agrodiagnostics in Western Ukraine. Satellite monitoring and GIS reduced agrochemical costs by 20%, confirming the effectiveness of precision farming technologies. One of the key limitations of this study is the focus on short-term economic indicators, which prevents a full assessment of the long-term consequences of outsourcing on the sustainability of the agricultural sector, particularly soil fertility and ecological balance. Additionally, the study primarily concentrated on large and medium-sized farms, while the specific challenges faced by small-scale farming enterprises under outsourcing conditions require deeper analysis. Given these aspects, promising areas for further research include exploring the social and ecological impacts of outsourcing, the influence of government policy and innovative technologies on its effectiveness, and analysing regional differences in the implementation of outsourcing models in agriculture.

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CONFLICT OF INTEREST

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Використання аутсорсингу у системі надання публічних послуг для підвищення ефективності сільськогосподарського виробництва

Наталя Потриваєва
Доктор економічних наук, професор
Миколаївський національний аграрний університет
54008, вул. Георгія Ґонґадзе, 9, м. Миколаїв, Україна
https://orcid.org/0000-0002-9781-6529
Артем Палєєв
Аспірант
Миколаївський національний аграрний університет
54008, вул. Георгія Ґонґадзе, 9, м. Миколаїв, Україна
https://orcid.org/0009-0005-2624-2504
Ілля Москаль
Аспірант
Миколаївський національний аграрний університет
54008, вул. Георгія Ґонґадзе, 9, м. Миколаїв, Україна
https://orcid.org/0009-0000-8114-8960

Анотація. Аутсорсинг у сільському господарстві є ключовим інструментом підвищення ефективності управління ресурсами, сприяючи впровадженню інноваційних технологій та зниженню витрат. В Україні, де аграрний сектор формує значну частину валового внутрішнього продукту, оцінка ефективності таких моделей є важливою для забезпечення конкурентоспроможності фермерських господарств. Дослідження було спрямоване на аналіз економічної ефективності аутсорсингу агрохімічного обслуговування ґрунтів, супутникового моніторингу та впровадження точного землеробства, а також на оцінку впливу державно-приватного партнерства. Застосовано статистичний і порівняльний аналіз, включаючи дані українських компаній, таких як AgriLab, і міжнародних практик. Аналіз проводився на основі даних про витрати, врожайність і ефективність аграрної інфраструктури за період 2019-2024 років. Результати показують, що витрати на технічне обслуговування ґрунтів знизилися з 98 євро/га у 2019 році до 84 євро/га у 2024 році, що відповідає скороченню витрат на 14 %. Адміністративні витрати зменшилися на 25 %, а загальні витрати на аграрну інфраструктуру в Україні знизилися з 5 млрд грн до 3,5 млрд грн (30 %). Використання точного землеробства підвищило врожайність на 15-20 % залежно від культури, а економія на добривах становила 20 %. Впровадження аутсорсингу та інноваційних технологій забезпечує скорочення витрат і покращення ефективності фермерських господарств. Зокрема, аутсорсинг дозволяє значно оптимізувати виробничі процеси, що підтверджується зростанням врожайності пшениці та кукурудзи на 18 % після впровадження рекомендацій із зонування полів і точного внесення добрив. Результати можуть бути використані для розробки стратегій державної підтримки, впровадження аутсорсингових моделей і стимулювання сталого розвитку аграрного сектора України

Ключові слова: аграрний сектор; оптимізація витрат; точне землеробство; фермерські господарства; аналіз ґрунтів; покращення врожайності

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Assessment of state supports and subsidies efficiency in ensuring financial security of Ukrainian agricultural enterprises

Denys Pylypenko*
Postgraduate Student
National University of Life and Environmental Sciences of Ukraine
03041, 15 Heroiv Oborony Str., Kyiv, Ukraine
https://orcid.org/0009-0001-3652-0134

Nataliya Shevchenko
PhD in Economic Sciences, Associate Professor
National University of Life and Environmental Sciences of Ukraine
03041, 15 Heroiv Oborony Str., Kyiv, Ukraine
https://orcid.org/0000-0001-8506-1782

Maksym Pylypenko
Lecturer
Classic Private University
69002, 70-B Universytetska Str., Zaporizhzhia, Ukraine
https://orcid.org/0009-0009-6955-0805

Abstract. The study aimed to assess the impact of state subsidies and loans on the financial stability and competitiveness of Ukrainian agricultural enterprises in the face of economic challenges. Comparative analysis, content analysis of reports and data on state support for the agricultural sector for 2025, and theoretical research methods were used to identify possible areas for improving existing financial instruments. An analysis of the budgetary allocations for state subsidies shows that UAH 4.726 billion is earmarked for the support of farmers in 2025, which will help reduce production costs and increase the competitiveness of agricultural enterprises. An assessment of tax privileges, particularly the special VAT regime, has shown its importance for reducing costs and maintaining the competitiveness of farmers. The study also included an analysis of concessional loans, in particular the Affordable Loans 5-7-9% programme, which is an important tool for supporting agricultural enterprises in Ukraine. In 2024, according to PrivatBank, more than 3,000 loans worth UAH 10.6 billion were granted to agricultural enterprises. The mechanisms of state support in Ukraine and Canada were compared. The Canadian experience demonstrates that certain mechanisms can be adapted, such as subsidies for machinery and support for small farms. The results showed that government subsidies, loans and tax privileges significantly impact the financial stability of agricultural enterprises in Ukraine, providing access to finance, reducing costs and increasing market competitiveness

Keywords: agriculture; infrastructure deficit; competitiveness; instability; loans

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*Corresponding author

INTRODUCTION

The research relevance is determined by the importance of ensuring the financial security of agricultural enterprises in Ukraine in the context of constant economic and social challenges. Agriculture is one of the main components of the national economy, and its stability directly affects food security, export potential and socio-economic development of the regions. However, the agricultural sector faces numerous challenges, including low levels of investment, market volatility, high production costs and limited access to financial resources. In such circumstances, state support and subsidies become important tools to maintain the financial stability of agricultural enterprises, increase their competitiveness and ensure their resilience to external and internal economic influences. Assessment of the effectiveness of these measures can identify both the positive and negative aspects of state aid and offer ideas for improving existing procedures. Financial support for the Ukrainian agricultural sector under martial law has become critical to ensuring economic stability. D. Titov & V. Oleksienko (2024) studied the impact of the war on the sector, pointing to the destruction of infrastructure and increased financial risks. The authors emphasised the importance of new financial instruments, such as international grants and insurance, to support businesses. The authors also identified the need for special financial products, such as soft loans and war risk insurance programmes. The development of new models of support for farmers and the adaptation of financing to war conditions are issues that require further study.

Ensuring the economic security and sustainability of the Ukrainian agricultural sector in the context of martial law and post-war is an important task for ensuring the stability of the economy. S. Herasymchuk (2023) explored the challenges faced by the agricultural sector, including limited access to resources, rising costs of defending against threats, and declining demand for products. The author emphasised the importance of developing strategies to support the stability and development of the agricultural sector, including improving legislation, providing access to credit for farmers, and investing in infrastructure. However, it is necessary to continue exploring mechanisms for more effective investment attraction and the use of new technologies in production. In terms of the effectiveness of state financial support instruments for agricultural enterprises in Ukraine, A. Osipova (2020) highlighted insufficient funding and inefficient use of available instruments. The author emphasised the need to improve support strategies and expand access to finance for small and medium-sized producers and stressed the need for additional research to improve oversight and evaluate the effectiveness of the use of public funds, as well as to create new financial instruments for farmers.

The main threats to the economic security of agricultural enterprises, such as climate change, volatility of agricultural prices and legal risks, were identified by Yu. Mykhnovetskyi (2024), proposes measures to improve security, including financial support, infrastructure investment, and innovation. Improvements in risk monitoring and legislative regulation in the agricultural sector require further study. Maintenance of financial subsidies for agriculture is important for increasing the efficiency of agricultural development. K. Chen & Z. Wang (2022) examined a model for evaluating agricultural subsidies based on a combined algorithm using analytical hierarchy and data mining techniques with constraints. Their study showed that income-based subsidies were the most effective, while technology subsidies were less effective. However, the authors noted the need to improve the allocation of financial resources and the subsidy system to ensure sustainable agricultural development.

The growth of crisis phenomena in the Ukrainian economy, such as military conflicts, inflation, and declining investment, has led to a deterioration in the financial security of agriculture. M. Kunytska-Iliash (2023) studied the methodology for assessing the financial security of the agricultural sector, focusing on an integral approach and the need to improve methods through additional indicators. The results demonstrated the importance of enhanced monitoring for effective management decisions. New elements such as tax and innovation indicators should be introduced to improve risk assessment. The decline in the effectiveness of agricultural subsidies globally has become an important issue for food security. C. Li *et al.* (2022) investigated the effectiveness of agricultural subsidies, finding that they significantly increased cropland, grain production, and farmers' incomes, which contributed to improved production capacity and higher incomes. However, some studies have shown that in the long run, the effect of subsidies may be limited. Further research is needed on the long-term effects of subsidies and their role in poverty reduction.

In the context of martial law, financial support for agribusiness has become critical to the stability of the agricultural sector. T.V. Kurman (2023) studied the legal support of agrarian relations in the field of financial support, identifying key problems such as the lack of an effective legal regulation mechanism and the need for urgent changes in legislation to support agribusiness. The author emphasised the importance of urgently introducing financial support measures, such as grants

and compensation for agricultural enterprises, as well as the need to adapt legislation to wartime conditions. The development of effective programmes for the recovery of agribusiness after the war and the improvement of grant support procedures are shortcomings that require further study. The study aimed to analyse the impact of state support on the financial stability of Ukrainian agricultural enterprises and to determine the effectiveness of subsidies in ensuring their competitiveness in the face of economic challenges. The objectives of the study were to assess the impact of state subsidies on the economic sustainability of agricultural enterprises in Ukraine; and to identify factors that affect the effectiveness of state financial support in the agricultural sector.

MATERIALS AND METHODS

The study covers the period of 2024-2025, assessing the impact of state subsidies and loans on the financial stability of Ukrainian agricultural enterprises. The comparative analysis was used to evaluate the mechanisms of state support for the agricultural sector of Ukraine and identify the advantages and disadvantages of existing programmes (Koznova, 2024). Generalisation was used to process data on budgetary funds for subsidies and loans through a simple description, which included an analysis of the amount of funding and an assessment of their impact on the agricultural sector (Budget 2025: What..., 2024). Content analysis of analytical articles identified key aspects of financial support for farmers (Subsidies for farmers..., 2024). This determined the scale of financial support and the main areas of its use, including such areas as compensation for humanitarian land demining and financing the development of land reclamation systems.

The research also included an analysis of tax privileges, in particular, the special regime of value-added taxation (Kyiv School of Economics, 2017). The assessment of this mechanism determined the impact of tax policy on reducing production costs and maintaining the competitiveness of agricultural enterprises. An analysis of tax changes that could reduce the administrative burden and stimulate the development of the agricultural sector, based on comparative analysis and descriptive research methods for assessment of the effectiveness of tax changes and their impact on the sector, was a substantial part of the study. The study also analysed concessional lending mechanisms, the "Affordable Loans 5-7-9%" programme, which is substantial for the support of agricultural enterprises in Ukraine. Under this programme, the number of loans disbursed, through PrivatBank (2024a; 2024b) was studied to assess the role of both the public and banking sectors in providing access to finance for farmers and other agricultural enterprises.

Comparison of subsidy and credit mechanisms in Ukraine and Canada, where the agricultural sector is supported through government programmes that include financial assistance, insurance and agricultural development strategies, was emphasised. The Canadian experience was selected due to its successful practices in supporting farmers, which could be useful for improving Ukrainian programmes. The comparison has identified potential areas for improvement of Ukrainian state funding programmes that could increase the effectiveness of support to Ukraine's agricultural sector. Based on the results obtained, recommendations were formulated to improve subsidy and lending programmes aimed at increasing the financial stability of agricultural enterprises. Possible areas for the development of new forms of support that could help increase the efficiency of public funds and ensure the long-term sustainability of the agricultural sector were identified. This includes expanding access to concessional loans for small farms, improving the process of registration and distribution of funds through automated platforms, and reducing administrative barriers to financial support, which will reduce the time for paperwork and speed up access to the necessary resources for farmers.

RESULTS

Assessment of the impact of subsidies and loans on the financial performance of companies is an important part of their operations, as these financial instruments directly affect the ability of companies to operate, develop and achieve their strategic goals. In the context of the ongoing economic changes and crisis in the agricultural sector, analysing the effectiveness of government subsidies and loans is particularly important. In this situation, it is necessary to consider how these instruments increase the financial stability of companies and affect their competitiveness and ability to adapt to new economic conditions. One of the main mechanisms of state support is subsidies, which are intended to stimulate the growth of agricultural enterprises, reduce costs and increase financial stability. The impact of subsidies on farms' financial performance is significant and complex. Subsidies reduce production costs, which can significantly increase the profitability of companies. The analysis of state support mechanisms for the agricultural sector identified some problems, such as inefficient allocation of funds and unequal access to subsidies, as well as opportunities to improve financing mechanisms, in terms of transparency of the allocation of public resources and ensuring equal access for small and medium-sized enterprises. An analysis of open-source publications has revealed a trend of growth in the number of loans and their volume, which indicates an increase in demand for financing in the agricultural

sector, especially during the period of full-scale invasion, when farmers need additional resources to restore production capacity (Budget 2025: What..., 2024).

This is achieved by stimulating investment in new technologies and infrastructure, as well as subsidising the cost of raw materials and energy. Lowering production costs and allowing for competitive product prices, increases the competitiveness of companies both domestically and internationally.

Subsidies also improve the financial stability of agricultural enterprises. State support liquidity of enterprises and ensure necessary investments in development. This allows companies to introduce new technologies, expand production and improve infrastructure, which is important for development. At the same time, subsidies can have undesirable effects. For example, indirect subsidies, such as tax debt write-offs, can encourage companies to hope for additional government assistance, which sometimes leads to a reduction in incentives for good management and productivity (Wu *et al*., 2022). Loans are another substantial for financing agricultural enterprises, especially when it comes to raising resources for production or expansion. Loans allow enterprises to quickly raise the necessary financial resources, which speeds up the production process and prevents delays in production. Thus, loans are necessary for stability of cash flow and production. Loans can also encourage companies to increase productivity. Companies need to constantly control costs, optimise processes and increase productivity to repay the loan on time. This can be a strong incentive to innovate, improve management practices and increase production. However, loans carry certain risks for companies. The main risk is the debt burden, which can lead to increased financial instability. In the event of unfavourable economic conditions or a decline in revenues, companies may face problems with debt repayment, which may lead to bankruptcy or forced production cuts (Lebid, 2016). In addition, credit may be restricted by laws and regulations. For instance, certain enterprises may not be able to access concessional loans due to poor funding or a poor credit history. In addition, high interest rates on loans, especially for small and medium-sized enterprises with limited access to financial resources, may make them inefficient.

Subsidies and loans are important instruments in the process of improving the financial stability of agricultural enterprises. Increasing competitiveness, obtaining additional financial resources and stimulating investments in development are the results of these measures. While these instruments have many advantages, they also have some risks that require careful management. Misuse of loans or subsidies can lead to increased debt or reduced management efficiency. To use credits and subsidies effectively, enterprises should regularly analyse their financial position to assess the potential consequences for their financial stability. In addition, government programmes should aim their support for innovation in the long-term perspective, focusing on improving the technological level of enterprises and increasing their production capacity. These instruments can significantly improve the financial performance of agricultural enterprises and contribute to their sustainable development only if properly managed and controlled. In the context of economic instability, climate change, and external challenges such as war and economic sanctions, effective government support for farmers is becoming substantial for ensuring national food security and rural development. Given this, determination of the effectiveness of state support is a critical task for formulating a strategy for the development of the agricultural sector. Subsidies provided to agricultural producers to stimulate production and increase the competitiveness of products are one of the main forms of state support. In 2025, UAH 4.726 million is to be allocated to support farmers and other agricultural producers. This money will be used to provide subsidies per unit of cultivated land, especially in areas where the hostilities have ended. In addition, UAH 1,000 million has been allocated to cover the costs of humanitarian demining of agricultural land. The restoration of production facilities and agricultural land through these measures is an important step in the recovery of the agricultural sector (Koznova, 2024).

Another important component of state support is programmes aimed at developing reclamation systems. The programme provides for up to 50% compensation for the cost of reconstruction or construction of new reclamation systems, with a maximum amount of assistance of up to UAH 26,500 per hectare of cultivated land (Subsidies for farmers..., 2024). These measures improve water supply in agricultural regions, which in turn increases yields and sustainability of agricultural production, especially in the context of climate change. Concessional loans are also an important aspect of state support. Farmers can receive concessional interest-free loans, which promotes agricultural development, without having to accumulate in-house funds to implement production plans. This allows agricultural enterprises to respond more quickly to changes in the market and modernise their production facilities.

The effectiveness of subsidies and loans is ensured by reducing production costs, which allows for competitive prices in domestic and foreign markets. In the context of inflation and rising raw material prices,

reducing the cost of agricultural production is a key factor in maintaining the financial stability of agricultural companies. In addition, compensation for humanitarian land demining and support for land reclamation systems allow farmers to restore damaged or degraded land, which contributes not only to production growth but also to improving the environmental situation in agricultural regions. All these aspects contribute to increased production efficiency and ensure a stable cash flow. Tax privileges are also an important aspect of state support for farmers. Ukraine has various forms of tax privileges, including a fixed agricultural tax, a simplified taxation system and a special regime for value-added tax (VAT). The fixed agricultural tax allows farmers to reduce their tax burden, while the simplified taxation system reduces administrative costs for small and medium-sized businesses. Before its abolition in 2016, the special VAT regime allowed farmers to retain a part of the VAT to compensate for input costs, which amounted to approximately UAH 14 billion in 2014 (Kyiv School of Economics, 2017).

Tax privileges mitigate the costs of farm upkeep and increase competitiveness of their products both domestically and internationally, as they reduce the cost of final products, making them more affordable for consumers. This allows agricultural enterprises not only to maintain their market share, but also to increase sales on foreign markets, which in turn increases revenues and financial stability. The draft budget for 2025 envisages 9 billion UAH in expenditures for the Ministry of Agrarian Policy and Food of Ukraine, of which 5 billion UAH is planned to be allocated to support farmers. This is a significant increase of 4 billion UAH compared to 2024, reflecting the government's growing focus on supporting the agricultural sector. It is worth noting that part of these funds is earmarked for lending, which allows farmers to receive concessional loans for the development and modernisation of production. Table 1 shows a comparison of the impact of subsidies, soft loans and tax privileges on the financial security of agricultural enterprises, in the context of reducing production costs and their interaction with each other.

Table 1. *Comparison of financial support for agricultural enterprises*

Type of financial support	Description	Percentage reduction in costs	Impact on financial stability	Interaction with other mechanisms
Subsidies	Reduction of costs per unit of cultivated land, increasing product competitiveness	10-15%	Maintains stability by keeping prices competitive	Amplifies the impact of soft loans and tax breaks, reducing production costs
Concessional loans	The ability to obtain financing without having to accumulate funds reduces capital investment costs	20-25%	Increases stability by being able to quickly adapt to changes in the market	Helps modernise production facilities and increases efficiency by reducing capital expenditure.
Tax benefits	Reduced tax burden, and reduced administrative costs for small and medium-sized businesses	5-10%	Reduces financial costs and increases profitability	Increases financial stability by reducing the tax burden, which has a positive impact on profits

Source: *compiled by the authors based on Subsidies for farmers. Who is eligible for assistance and how to get it? (2024), Budget 2025: What will farmers have enough money for? (2024)*

Table 1 demonstrates that all three types of financial support – subsidies, soft loans and tax privileges significantly impact the financial stability of agricultural enterprises, but each of them works in different ways. Subsidies reduce production costs, which is important for maintaining product competitiveness. Concessional loans provide enterprises with the opportunity to invest in modernisation, which helps to increase production and improve efficiency. Tax privileges, in turn, reduce the tax burden and increase the profitability of enterprises, allowing them to maintain financial stability. All these mechanisms interact with each other, reinforcing each other's effect and helping agricultural enterprises to adapt more quickly to changes in the market, reducing costs and increasing productivity. The budget of the Ministry of Agrarian Policy provides for the following major assistance: 200 million UAH has been allocated for the restoration and construction of reclamation systems. This is an important step in restoring land affected by hostilities or environmental degradation. For family farmers, UAH 5 million will be allocated to compensate for the unified social tax, which will help to stabilise their finances. Furthermore, UAH 80 million will be allocated for preferential interest-free loans to farms, which will enable farmers to obtain financial capital for development. In addition, a significant portion of the budget, amounting to UAH 4.7 billion, will be allocated to pay subsidies to farmers for each hectare of land, as well as for the maintenance of cows, sheep and goats. This area received additional funds of UAH 3.93 billion compared to 2024, which significantly supports agricultural producers (Budget 2025: What..., 2024).

In addition, the Ministry of Economy of Ukraine plans to provide grants for the development of

horticulture, berry growing, viticulture and greenhouses in the amount of UAH 1.4 billion, as well as compensation for the costs of humanitarian demining of agricultural land in the amount of UAH 1 billion. However, no direct funding from the budget is envisaged to partially compensate for the cost of agricultural machinery and equipment manufactured in Ukraine. In addition, by 2025, UAH 18 billion will be allocated for the "Affordable Loans" programme (PrivatBank, 2023a). Under this programme, the maximum loan amount that agricultural producers could receive was increased to UAH 90 million. This provides additional financial resources to develop and modernise their enterprises. The programme also includes preferential loans for the restoration of war-damaged assets of enterprises in the high-high-risk zone (Budget 2025: What..., 2024). The distribution and proper organisation of state support in the 2025 budget will determine its effectiveness. To maximise the impact of public resources on the development of the agricultural sector and food security, it is necessary not only to increase spending but also to guarantee transparency and control over their use. Despite how important it is for the state to support the agricultural sector; certain problems need to be addressed. One of the main ones is the inefficient use of the budget. There are still problems with the transparency of loans and subsidies, which sometimes leads to uneven distribution of resources among enterprises. In addition, systems for overseeing how public money are spent need to be improved to prevent misuse. Another problem is the need to develop a more balanced agricultural policy that considers the real needs of farmers and their readiness for innovation and changes in the market. It is also necessary to account for international experience in agricultural policy to integrate best practices and ensure sustainable development of the sector.

Subsidies provided to farmers directly reduce the cost of agricultural production, which helps to maintain competitive prices on the market. This is an important factor for the financial stability of enterprises, as it allows them to maintain profits even in the face of rising raw material and energy costs. In addition, the availability of concessional loans enables agricultural enterprises to obtain financing for the development and modernisation of production facilities. This allows companies to adapt to market changes more quickly, increase production efficiency and reduce the risks associated with lagging technological development. Concessional lending allows farmers to modernise machinery and purchase new equipment, which in turn helps to increase productivity and reduce production costs. In turn, compensation for the costs of humanitarian land demining and reclamation systems allows farmers to return to use land that has been damaged by hostilities or environmental problems. Land reclamation is an important step in stabilising agricultural production and increasing yields, which directly affects the financial performance of companies. Tax privileges, such as the simplified taxation system and the fixed agricultural tax, allow agricultural enterprises to reduce their tax burden. This reduces the financial costs of enterprises and contributes to their profits, which is important for ensuring financial stability. In the future, state support should be aimed not only at recovery from crisis situations, but also at the long-term stability and development of the agricultural sector through the introduction of innovations, the provision of soft loans and the creation of favourable conditions for the development of new areas of agriculture, such as horticulture and viticulture. Table 2 illustrates the problems and prospects for the development of state aid to agriculture in Ukraine.

Table 2. *Problems and opportunities for the development of state support for the agricultural sector of Ukraine*

Issues	Opportunity
Low efficiency in the use of funds	Improving the mechanisms for allocating budget funds to ensure their uniform and targeted use
Uneven distribution of subsidies and loans	Optimisation of the subsidy and credit system, targeting the highest priority enterprises and regions
Need to improve mechanisms for controlling the use of public funds	Strengthening control and transparency in the use of public resources to avoid their misuse
Lack of adaptation to international standards in agricultural policy	Implementation of high-quality international practices to improve the effectiveness of agricultural policy
Low innovation in agriculture due to lack of incentives for investment	Developing programmes to support innovation and modernisation of farmers' production facilities
Poor development of new areas of the agricultural sector (horticulture, viticulture)	Expanding financial support programmes to develop new areas of agriculture
Insufficient integration of agricultural policy with other sectors of the economy	Develop an integrated strategy for the development of the agricultural sector that considers the interests of other economic sectors
The need to balance policy with the needs of farmers and new economic conditions	Formation of a clear and balanced agricultural policy that meets new market requirements and technological progress

Source: *compiled by the authors based on O. Mysnyk (2022)*

State support for the agricultural sector is a key factor in the development of agriculture in Ukraine. It reduces production costs, increases the competitiveness of products and guarantees company stability. Effective programmes of subsidies, loans and tax privileges can significantly improve the financial stability of the agricultural sector and contribute to its long-term development. Nevertheless, to increase the effectiveness of state aid, it is necessary to further improve policies, reduce administrative obstacles and encourage more efficient use of resources. Only if state support is used effectively will Ukraine's agricultural sector be able to achieve sustainable growth, competitiveness and food security. Lending is necessary for the development of the agricultural sector, providing access to the necessary financial resources for modernisation and expansion of production capacity. One of the main programmes is the "Affordable Loans 5-7-9%", which provides concessional loans to farmers on favourable terms (PrivatBank, 2023a). These loans can be used for business development, purchase of machinery, purchase of seeds, and modernisation of production facilities. Ukrainian banks are also actively developing programmes to support farmers. PrivatBank is one of the leaders among Ukrainian banks in supporting small businesses and entrepreneurs. According to the Ministry of Finance of Ukraine, PrivatBank (2024b) provided 36.7 thousand loans worth UAH 52.3 billion, most of which were used to support the agricultural sector and important businesses during the war. In 2024, the bank provided financing to more than 3,000 agricultural companies in the amount of UAH 10.6 billion, ranking 3rd among all banks in terms of credit support to the agricultural sector.

PrivatBank's credit support includes both working capital loans and investment loans for business development. In 2024, 40% of agricultural loans were investment loans for business development and purchase of fixed assets, and 60% were working capital loans. The Bank actively supports all programmes, both by raising funds from international partners and through government support, so that clients can obtain loans on the most favourable terms. The "Affordable Loans 5-7-9%" programme has become an important tool for financial support to agricultural enterprises in Ukraine, especially in times of economic difficulties and martial law. Since the launch of the programme in February 2020, more than 92,000 loans have been issued for a total amount of about UAH 317.7 billion. This has allowed businesses, including agricultural enterprises, to access credit resources on favourable terms. The programme is an important tool to support small businesses, as it provides an opportunity to obtain loans on favourable terms, which reduces the financial burden and ensures the stability of production activities, especially in times of economic difficulties. In 2024, the distribution of public funds between large agricultural companies and small farmers in Ukraine revealed a significant imbalance. Small farmers received support through special programmes aimed at farms that cultivate up to 120 hectares or keep up to 100 cows. They could receive UAH 4,000 for each hectare of land, UAH 7,000 for each cow, and UAH 2,000 for each goat or sheep. In total, about UAH 4.7 billion was earmarked from the state budget to support small farmers. At the same time, large agricultural companies received a much larger share of public funds through the mechanisms of VAT refunds on agricultural exports and other programmes. Given historical practice, large companies receive a much larger share of total state support for the agricultural sector (Prasad, 2024).

The programme significantly affected the development of small farms, enabling them to obtain financing on favourable terms. In 2024, more than 8,750 loans worth UAH 46.9 billion were disbursed to support farmers, which underscores the high demand for the programme among agricultural businesses. Since the beginning of 2025, 944 loans worth UAH 4.5 billion have been disbursed (Cherkasy Regional State Administration, 2025). However, the programme also has certain limitations. The average loan size is about UAH 3.5 million, which can be too large for small farms, especially those with limited resources. In addition, the availability of credit for large agricultural companies is much higher, as they are better able to secure loans and usually receive larger loan amounts on more favourable terms. For small farms, this can create inequalities in access to financial resources, although the programme contributes to the development of small enterprises through the provision of concessional loans (Krytska, 2023). Overall, the "Affordable Loans 5-7-9%" programme had a significant positive impact on the development of agricultural enterprises, especially small farms, by facilitating access to loans on favourable terms. It allows small agricultural enterprises to stabilise production, expand their business and create new jobs, which is important for rural development. However, to achieve maximum effect, further improvement of the availability of credit to small farmers is needed, especially given their limited financial capacity compared to large agricultural companies.

There are also several mechanisms in place in Ukraine to help small farms gain equal access to finance. One of these mechanisms is the Partial Guarantee Fund for Agricultural Loans, which allows small farmers to receive loans under state guarantees, which

reduces risks for banks and simplifies access to finance (A large-scale awareness-raising..., 2024). In addition, the Ukrainian government provides subsidy programmes and grants to small farms for cultivated land and other activities. For example, in 2025, a subsidy of UAH 4,000 per hectare is envisaged for farms that cultivate between 1 and 120 hectares of land. In addition, microfinance organisations provide loans to small entrepreneurs who have limited access to traditional bank loans, which is especially useful for those who are just beginning their business. These mechanisms contribute to equal access to finance for small farms, although they still face certain obstacles and imbalances compared to large agricultural companies. To expand the definition of agricultural sector financing, a comparison was made with Canada, one of the most developed agricultural countries. Canadian farm support programmes are an example for many countries around the world, including programmes such as AgriInvest (Government of Canada, 2024), Sustainable Canadian Agricultural Partnership (Government of Canada, 2023c), Canadian Agricultural Loans Act (Government of Canada, 2022; 2025). Table 3 shows the main differences between the subsidy and credit mechanisms in Ukraine and Canada.

Table 3. *Comparison of subsidy and credit mechanisms in Ukraine and Canada*

Mechanism	Ukraine	Canada
Main subsidy programmes	Subsidies per hectare of land, livestock support, subsidies for agricultural equipment	AgriInvest, Sustainable Canadian Agricultural Partnership
Credit programmes	"Affordable Loans 5-7-9%" programme, preferential loans through OTP Bank and PrivatBank	Canadian Agricultural Loans Act, Farm Credit Canada, AgriInvest
Maximum loan amounts	Up to 5 million UAH per hectare of land, up to 3 million UAH for the purchase of equipment	Canadian Agricultural Loans Act: up to 500 thousand USD for land and construction, up to 350 thousand USD for other purposes
Interest rates	5-7% (for the "Affordable Loans" programme)	Canadian Agricultural Loans Act: Prime + 1% or Residential Mortgage Rate + 1%
Conditions of receipt	Business in the agricultural sector, activity in agriculture	Business registration, experience in agriculture (less than 6 years for Canadian Agricultural Loans Act)
Peculiarities	Reimbursement of part of the costs of agricultural products, preferential terms for small enterprises	Programmes for beginning farmers, cooperatives, regional support programmes, development grants
Challenges	Limited budget funds, unequal access to finance for small farmers	Limitations on the size of loans, lack of sufficient information among potential participants

Source: *compiled by the authors*

While Ukrainian subsidy and credit mechanisms contribute to the development of the agricultural sector, there are certain limitations and challenges. While the "Affordable Loans 5-7-9%" programme is an important instrument of financial support for farmers, the effectiveness of these initiatives may depend on limitations on the maximum loan amount, as well as on the lack of information about available support programmes. Canada has a more developed system of lending to farmers than Ukraine, through the Farm Credit Canada and Canadian Agricultural Loans Act programmes, which provide more flexible terms of financing. Ukraine can learn from Canada's experience to improve access to credit for large agricultural companies and increase government support in other regions. The Canadian agricultural support programme is an important part of the national economic policy. Canada annually provides significant support to agricultural enterprises, including subsidies worth about USD 12.5 billion (Kevany *et al.*, 2024). Overall, the Canadian agriculture sector contributes about 1.8% of the country's gross domestic product, with a direct contribution of agriculture to the gross domestic product of USD 36.3 billion in 2022. Considering the sector's impact on other related industries, its economic importance is substantial, although the relationship between subsidies and gross domestic product growth is complex and indirect (Canadian Federation of Agriculture, 2024). In terms of access to credit, Canada has an advance payment programme that provides farmers with interest-free loans based on the value of their agricultural products. As of 2023, the interest-free loan limit has been temporarily increased to USD 350,000, but after 2023 it will drop back to USD 100,000 unless further adjustments are made. Farmers have expressed concern that the current limit is too low given the rising costs of production. General requirements for participation in such programmes include being actively engaged in agriculture and having a viable business unit, although requirements may vary depending on the specific programme.

Canada has a developed system of government subsidy controls that includes a variety of regulatory mechanisms, including a demand management system for dairy, poultry and eggs. This system includes tariffs and production quotas to maintain domestic prices above international levels. The level of government support for agriculture in Canada is assessed by the Organisation for Economic Co-operation and Development,

which uses indicators such as the Producer Support Estimate and the General. Services Support Estimate to monitor the effectiveness and structure of agricultural support (Bombrun, 2024). Canada's state support mechanisms demonstrate high adaptability to global challenges. For example, the increase in the limit of interest-free advances was a direct response to the rising production costs faced by farmers. Canada's Sustainable Canadian Agricultural Partnership initiative includes a five-year, USD 3.5 billion plan to support sustainability, innovation and risk management in the agricultural sector (Government of Canada, 2023c). It aims to help farmers adapt to climate change and market fluctuations. In addition, programmes such as the Agricultural Climate Solutions Programme (Government of Canada, 2023a) and Living Labs (Government of Canada, 2023b) promote sustainable practices and technologies that assist farmers in adaptation to climate change.

An analysis of Canadian state support mechanisms demonstrates that they are highly efficient and flexible, allowing for a quick response to changes in economic and environmental conditions. However, for Ukraine, it is necessary to address the specifics of the national economic situation, in particular the high level of risks due to military operations and adapt these mechanisms to the specifics of the Ukrainian agricultural sector. Canadian mechanisms, such as interest-free loans and concessional financing programmes, can serve as a model for improving state support for agricultural enterprises in Ukraine, especially in the context of small farm development and climate change adaptation. It is necessary to increase access to finance for small farmers, improve awareness of government programmes, and create more flexible lending conditions for large agricultural enterprises to help Ukraine become more competitive in the global market. Reduction of interest rates on loans to farmers is a key area for improving state support. The "Affordable Loans 5-7-9%" programme is effective, but for investments that take longer to make, the terms of concessional loans should be extended to ten years. This would allow small and medium-sized farms to make long-term investment commitments without overburdening them in the short term. It is also necessary to continue and expand concessional lending opportunities, including the possibility of partially offsetting the cost of the loan. This will reduce the burden on businesses, which is especially important in times of economic instability. The process of obtaining loans will be more transparent and faster if digital platforms are used to register and assess the creditworthiness of businesses. Automation of such processes will help management to reduce the workload they have and reduce the time required to review applications.

Expanding grant programmes for the development of innovative projects is another way to improve state support. In Ukraine, there is a growing interest in technological solutions in agriculture, including agricultural innovation and organic farming. With state support for such projects through grants and low-interest loans, farmers will be able to obtain the funds necessary to implement new technologies that will improve production efficiency. Support for horticulture, berry growing, and viticulture is particularly important. For 2025-2026, it is necessary to expand and extend grant programmes for planting and developing processing plants for agricultural products. By 2025, there is a significant deficit of infrastructure in Ukraine that could facilitate agricultural development. Primarily, it concerns land reclamation systems, as well as the development of systems for storing and processing fruits and vegetables. The creation of new crop storage facilities and the modernisation of existing systems should be the main objectives of state aid in this area. This will allow farmers to reduce storage losses and become more stable in the market. In addition, the development of transport infrastructure is crucial for farmers. Building and repairing roads and reducing customs barriers for exports will allow farmers to transport their products faster and cheaper. To increase the effectiveness of support programmes, it is necessary to strengthen control over their implementation. The introduction of new automated systems for the provision of state support to the agricultural sector will help to increase the transparency of this process. Automatic allocation of funds and registration of enterprises in the system will increase the trust of farmers and prevent misuse of funds, as demonstrated by the experience of the State Agrarian Register in Ukraine. The involvement of the Accounting Chamber in the audit of budget expenditures and activities of state-owned enterprises optimises the process of tracking the effectiveness of financial expenditures on agricultural support. This can be a significant step towards increasing the transparency of financial transactions with public funds and eliminating corruption schemes.

To ensure access to new markets for Ukrainian agricultural products, it is also necessary to develop international cooperation. Supporting exports by participating in international events and signing new trade agreements will help farmers diversify their markets and earn more money from exports. Expanding opportunities for attracting international investment and grants will provide farmers with additional resources that they can use to develop their companies. Therefore, state support for the agricultural sector should include not only financial measures, but also a comprehensive

approach to infrastructure development, reduction of administrative obstacles, increased control and transparency, involvement of partners from other countries, and introduction of automated systems that are an effective tool for improving the agricultural economic situation. Improving subsidy and loan programmes, creating new forms of support and stimulating innovative solutions will be an important step towards increasing the competitiveness of the Ukrainian agricultural sector in the global market.

DISCUSSION

State support to the agricultural sector through subsidies is an important means of ensuring financial stability and development of agriculture. Effective support for farmers is vital for maintaining food security, increasing competitiveness and sustainable development of agricultural enterprises in the face of global economic challenges, including military conflicts, climate change and economic crises. In such circumstances, government subsidies become even more important as they help to provide access to finance, reduce production costs and promote technological innovation in agriculture. The study assessed the impact of government subsidies and loans on the financial stability of agricultural enterprises in Ukraine, while C.M. Viana *et al.* (2022) examined financial mechanisms to support the agricultural sector at the global level. Both approaches to the analysis of financial support for farmers as an important element of the sector's stability and development are similar. The study highlighted specific state support programmes in Ukraine, such as soft loans and tax exemptions, while C.M. Viana *et al.* (2022) addressed general international mechanisms and strategies for supporting agriculture.

The study by L. Marmul *et al.* (2021) and the current study used similar methods to examine how the agricultural sector is supported through subsidies, loans, and tax breaks. Both studies emphasised the importance of these instruments for maintaining the financial stability of agricultural enterprises. On the other hand, this study covered the Ukrainian context, in particular the war and its impact on the financial stability of the agricultural sector, while L. Marmul *et al.* (2021) analysed general support mechanisms in the context of international trends. Current research and the study by C. Bernini & F. Galli (2024) both address subsidies on agricultural enterprises, on their economic and environmental performance. Both papers emphasised how subsidies can reduce production costs and contribute to sustainable development. However, this paper analysed the full-scale invasion environment in which Ukraine is currently operating, evaluating budgetary funds, loans, and tax privileges. In contrast, the study by C. Bernini & F. Galli (2024) focused on Italy's experience with the EU's Common Agricultural Policy, analysing the impact of subsidies on spatial effects and their economic consequences for the agricultural sector.

The impact of subsidies on the efficiency of the agricultural sector, in particular on the financial stability and competitiveness of enterprises, was addressed both in the current study and by F. Liu *et al.* (2024). Both studies emphasise how subsidies reduce production costs. However, this paper analyses budgetary funds, credits and tax privileges, focusing on Ukraine and the impact of the war on the agricultural sector. On the other hand, the study by F. Liu *et al.* (2024) addressed the experience of rapeseed cultivation in China and used alternative methods of analysis. The current study and M.W. Barbosa (2024) both addressed the impact of government subsidies on the agricultural sector. Both studies emphasised the importance of financial support for agricultural efficiency. However, this study covered support mechanisms in Ukraine during the war, such as subsidies, loans and tax exemptions, while M.W. Barbosa (2024) studied sustainable agriculture policies internationally. In addition, M.W. Barbosa (2024) assessed the spatial effects of subsidies, which differs from the approach in this study, which was based on the context of the war in Ukraine.

V. Piñeiro *et al.* (2020) analysed the importance of using economic, regulatory and environmental incentives to encourage the transition to sustainable agricultural practices. The authors noted that soft loans, subsidies, and tax breaks are important mechanisms to support farmers, particularly in the context of global environmental change. The main similarities between the studies were in the focus on financial instruments as the main mechanisms for stimulating farmers, as well as in the comparison of national approaches to international experience. However, an important difference was that V. Piñeiro *et al.* (2020) addressed the sustainability of agricultural practices through environmental and economic incentives, while this study assessed the mechanisms of support for farmers through the prism of economic stability in times of war focusing on the crisis in Ukraine and the need for urgent financial instruments. J.A. Pérez-Méndez *et al.* (2019) and the current study both covered the effectiveness of subsidies for agricultural enterprises. Both papers emphasised the importance of subsidies to reduce costs and maintain competitiveness. However, this study focused on Ukrainian realities, considering the impact of full-scale invasion and analysing not only subsidies but also tax privileges and credits. Whereas J.A. Pérez-Méndez *et al.* (2019) addressed European subsidy mechanisms, within the EU's Common Agricultural Policy.

S. Khalmirzayeva (2023) and the current study both analysed state support mechanisms for the agricultural sector, in particular subsidies. However, S. Khalmirzayeva (2023) analysed international experience, comparing the practices of state support for agriculture in different countries, such as the US, Canada, and the EU, and adapting these mechanisms to the conditions of Uzbekistan. In turn, this study covered the specific conditions of Ukraine on supporting farmers in the context of a full-scale invasion. The present study and D. Amaglobeli *et al.* (2024) both addressed subsidies for the agricultural sector. They both emphasised the importance of state support for increasing production efficiency. However, this study focused on the global experience of subsidies, with an emphasis on environmental and social development. At the same time, D. Amaglobeli *et al.* (2024) addressed economic subsidies and political aspects of support in individual countries. C. Edwards (2023) analysed the effectiveness of government support programmes for agriculture in the UK, focusing on subsidies that promote sustainable development and environmental efficiency. The study also considered the impact of subsidies on agricultural adaptation to climate change. Both papers emphasised the importance of subsidies to support the agricultural sector and increase efficiency. However, this study focused on Ukrainian realities and the war, while C. Edwards (2023) analysed environmental aspects in the UK.

This study and P. Lal *et al.* (2023) both address government support for the agricultural sector through subsidies to improve economic stability. Both assess the role of subsidies in promoting agricultural efficiency and development. However, this study covered the situation in Ukraine under the conditions of war, analysing subsidies, credits and tax privileges, while P. Lal *et al.* (2023) analysed global approaches to agricultural policy, sustainable development and environmental aspects. This paper addressed national challenges, while P. Lal *et al.* (2023) analysed agricultural policy in an international context. Both studies confirm the importance of supporting farmers, but the approaches differ depending on the specifics of the region and conditions. K. Mazur & L. Tetenyi (2022) and the current study both covered the impact of subsidies on agriculture. K. Mazur & L. Tetenyi (2022) analysed Sub-Saharan Africa, examining the impact on productivity and labour, while this study assessed the impact of subsidies and credit on the financial stability of agricultural enterprises in Ukraine. Both studies emphasised the importance of subsidies for development but differed in their approaches: one used equilibrium modelling, while the other used budgetary analysis and international comparisons.

J.A. Garner *et al.* (2023) addressed the macroeconomic effects of subsidies, analysing their impact on the economy, while this study covered the specific subsidy mechanisms in Ukraine, under full-scale invasion. Both papers emphasised the role of subsidies in reducing production costs and maintaining the financial stability of agricultural enterprises, but J.A. Garner *et al.* (2023) analysed global macroeconomic effects, while this study focused on specific support mechanisms for Ukrainian farmers. S. Zaharco & E. Petreanu (2023) covered subsidy management and efficiency audits in the agricultural sector, while this study focuses on agricultural financing and sustainable development mechanisms through subsidies. Both studies emphasise the importance of supporting the competitiveness of agricultural enterprises, but S. Zaharco & E. Petreanu (2023) addressed infrastructure development and support for small farmers, while this study analysed subsidy mechanisms in the context of full-scale invasion and their impact on the economic stability of the agricultural sector in Ukraine.

C. Akbay & A. Bilgiç (2023) analysed the impact of subsidies on the economic efficiency of dairy farms in Turkey, using econometric analysis to estimate the profitability and impact of financial support. Both studies covered the effectiveness of subsidies in the agricultural sector, but this study addressed wider range of financial mechanisms and compares them with international experience, while C. Akbay & A. Bilgiç (2023) analysed Turkey and the dairy sector. T. Bhandari (2023) studied the impact of the political ideology of People's Multiparty Democracy on agriculture in Nepal, covering technological development and economic stability through government subsidies. Both studies acknowledge the importance of state support for the stability of agricultural enterprises, but this paper analysed financial aspects, while T. Bhandari (2023) addressed political factors. S.F. Anzia *et al.* (2022) addressed the political aspects of subsidies in the United States, in particular, how receiving government assistance affects farmers' political beliefs. The authors studied how participation in subsidy programmes changes farmers' attitudes towards the government depending on their ideology. Both studies analysed the impact of state aid on agriculture, particularly through subsidies. They both recognised the importance of these programmes in supporting farmers. This paper analysed the economic effect of subsidies on farms, while S.F. Anzia *et al.* (2022) covered the political effect, particularly the impact on farmers' political views depending on their ideology.

The current study and I. Dinis (2024) both analysed the impact of state support on the agricultural sector but from different approaches. Both studies analysed

the impact of state subsidies on the agricultural sector, how these subsidies affected farmers. The authors highlighted the uneven distribution of support depending on various factors, such as farm size or type of agricultural product. This article focused on the economic impact of subsidies on enterprises in Ukraine, while I. Dinis (2024) focused on the distribution of direct subsidies between different farming systems in Portugal under the European support policy. This study highlights the importance of financial support for the stability of the agricultural sector, particularly in times of war. Comparison with other studies suggests that although subsidies play an important role in supporting farmers in different countries, there are specific aspects in each case, including the political situation, types of subsidies and economic conditions that affect the effectiveness of these programmes.

CONCLUSIONS

A study of the effectiveness of state support for the Ukrainian agricultural sector shows that financial support through subsidies, loans and tax breaks is substantial for ensuring the development of agricultural enterprises and increasing their competitiveness. The draft budget for 2025 allocates a significant amount of money to support farmers, which will not only restore the agricultural sector but also stimulate its further development. The envisaged increase of 4 billion UAH in expenditures to support farmers compared to 2024 demonstrates the importance of agricultural policy for the Ukrainian government. Different types of financial support for agricultural enterprises significantly affect their financial stability. Subsidies reduce production costs by 10-15%, which supports the competitiveness of products. Concessional loans reduce the cost of capital investments by 20-25%, which facilitates rapid adaptation to market changes and increases efficiency. Tax privileges reduce the tax burden by 5-10%, increasing the profitability of enterprises and strengthening financial stability. All these mechanisms are interconnected and reinforce each other, allowing agricultural enterprises to adapt to market changes more effectively, reducing costs and increasing productivity.

One of the main forms of support is subsidies, which allow agricultural enterprises to reduce production costs, increasing their competitiveness in domestic and foreign markets. In 2025, UAH 4,726 million is planned to be allocated to support farmers and agricultural producers, which will help ensure the financial stability of enterprises, especially in regions where active hostilities are not currently taking place. In addition, UAH 1,000 million was allocated for humanitarian land demining, which will help restore agricultural land and improve the environmental situation. Concessional loan programmes, such as "5-7-9%", provide farmers with access to finance for development and modernisation without high interest rates. With the help of concessional loans, agricultural enterprises can adapt more quickly to market changes and improve their production base. The development of reclamation systems, especially through compensation for rehabilitation and construction costs, is an important step towards ensuring financial stability. All these measures improve the conditions for agricultural production, especially in the face of environmental change, and ensure production growth and stable cash flow for enterprises.

The increase in funding for concessional loans and subsidies for farmers has significantly expanded access to finance. According to PrivatBank, more than 3,000 agricultural loans totalling UAH 10.6 billion were disbursed in 2024. This shows that the demand for loan programmes for agribusiness development is growing. Equally important is ensuring transparency in how public funds are allocated. Automated systems, such as the State Agrarian Register, should significantly improve the process of registering enterprises and allocate funding more efficiently. To increase the stability of the agricultural sector, the system of control over the use of public funds and the fight against misuse of resources should be improved. Although there is still considerable potential for developing state support for farmers in Ukraine, a comparison with Canada shows that Ukraine needs to learn from other countries that have more efficient methods of distributing financial assistance and innovative problem-solving. Canada is increasing loans to large enterprises and supporting farmers through grants, which provides greater financial stability in the agricultural sector. The efficiency of the agricultural sector in Ukraine can be significantly improved by increasing financial assistance to farmers, improving soft loans and subsidies, and introducing new types of assistance and technological innovations. To do this, it is necessary to control its expenditures and create optimal conditions for innovative rural projects.

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CONFLICT OF INTEREST

None.

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Оцінка ефективності державних підтримок та субсидій у забезпеченні фінансової безпеки аграрних підприємств України

Денис Пилипенко
Аспірант
Національний університет біоресурсів і природокористування України
03041, вул. Героїв Оборони, 15, м. Київ, Україна
https://orcid.org/0009-0001-3652-0134
Наталія Шевченко
Кандидат економічних наук, доцент
Національний університет біоресурсів і природокористування України
03041, вул. Героїв Оборони, 15, м. Київ, Україна
https://orcid.org/0000-0001-8506-1782
Максим Пилипенко
Викладач
Класичний приватний університет
69002, вул. Університетська, 70-Б, м. Запоріжжя, Україна
https://orcid.org/0009-0009-6955-0805

Анотація. Метою цього дослідження було оцінити вплив державних субсидій і кредитів на фінансову стабільність та конкурентоспроможність аграрних підприємств України в умовах економічних викликів. У ході дослідження використовували методи порівняльного аналізу, контент-аналіз звітів та даних про державну підтримку аграрного сектора на 2025 рік, а також методи теоретичного дослідження для виявлення можливих напрямків вдосконалення існуючих фінансових інструментів. Аналіз бюджетних коштів на державні субсидії показав, що у 2025 році на підтримку аграріїв передбачено 4,726 млрд грн, що сприятиме зниженню витрат на виробництво та підвищенню конкурентоспроможності агропідприємств. Оцінка податкових пільг, зокрема спеціального режиму оподаткування податком на додану вартість, виявила його важливість для зниження витрат і підтримки конкурентоспроможності аграріїв. Дослідження також включало аналіз пільгових кредитів, зокрема програми «Доступні кредити 5-7-9 %», що є важливим інструментом підтримки аграрних підприємств в Україні. У 2024 році, за даними ПриватБанку, аграрним підприємствам було надано понад 3 000 кредитів на суму 10,6 млрд грн. Особливу увагу було приділено порівнянню механізмів державної підтримки в Україні та Канаді. Канадський досвід демонструє можливості адаптації певних механізмів, таких як субсидії на техніку та підтримка малих фермерських господарств. Отримані результати показали, що державні субсидії, кредити та податкові пільги мають суттєвий позитивний вплив на фінансову стабільність аграрних підприємств в Україні, забезпечуючи доступ до фінансування, зниження витрат і підвищення конкурентоспроможності на ринку

Ключові слова: сільське господарство; дефіцит інфраструктури; конкурентоспроможність; нестабільність; кредити

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Performance of grain and leguminous crops under resource saving cultivation technology in the Southern Steppe of Ukraine

Anna Tereshchenko*
Postgraduate Student
Mykolaiv National Agrarian University
54008, 9 Georgiy Gongadze Str., Mykolaiv, Ukraine
https://orcid.org/0000-0001-6698-8697

Alona-Mariia Tarabrina
Postgraduate Student
Mykolaiv National Agrarian University
54008, 9 Georgiy Gongadze Str., Mykolaiv, Ukraine
https://orcid.org/0000-0002-4783-3988

Abstract. The study aimed to investigate the impact of conventional and no-till cultivation on crop productivity, particularly the efficiency of water and nutrient use, and to assess the impact on plant resistance to extreme weather conditions. The study presented the results of the impact of no-till technology on corn and soybean yields in the Southern Steppe of Ukraine, including a comparison of efficiency with the traditional method of tillage. The study included an analysis of agronomic indicators such as yield, plant height, plant density, survival rate and other physiological characteristics of crops. Two soybean varieties (Bettina and Fortress) and two corn hybrids (DCS 4795 and DCS 3730) were used to assess the impact of no-till technology and compare the results for the three years of the study, 2022-2024. The study determined that the use of no-till technology contributed to an increase in both corn and soybean yields. For corn, the yield increase in no-till plots was 13.9-15.1%, and for soybeans – 15.2-17.5% compared to conventional cultivation. These results indicate that the use of minimal tillage helped to retain moisture, improved structure and reduced the risk of erosion, which contributed to better plant growth and increased the ability to withstand stressful weather conditions such as drought. The analysis of the results demonstrated that the height of corn and soybean plants in the no-till plots was higher than in the control plots with conventional technology. However, this demonstrates the long-term benefits of no-till in maintaining soil sustainability and increasing productivity. The study established that no-till technology is an effective method for increasing yields and preserving soil fertility, which is important for the sustainable development of agricultural production in the southern regions of Ukraine

Keywords: soya; corn; no-till technology; plant height; plant density; survival; yield

INTRODUCTION

Minimum tillage technologies, such as no-till, are gaining popularity in modern agriculture due to their potential to preserve soil fertility, reduce erosion, improve soil water retention and reduce tillage costs. These technologies are especially important for the southern regions of Ukraine, where agricultural and climatic conditions

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*Corresponding author

are often characterised by droughts, high temperatures and water shortages. In such conditions, no-till can not only improve the environmental situation but also significantly increase the yield of crops such as corn and soybeans. The research relevance of no-till technology in southern Ukraine is determined by the need to adapt agricultural technologies to climate change, to increasing periods of drought, which is becoming one of the biggest challenges for agricultural producers. At the same time, traditional tillage methods, such as ploughing and cultivation, can lead to soil degradation, reduced water retention and increased risk of erosion. In this regard, no-till technology, which involves minimal tillage, can be an effective way to address these issues while also improving crop productivity.

The problem of the study is that traditional methods of soil cultivation, such as ploughing and cultivation, cause soil degradation and, a decrease in soil fertility and water retention properties, which in turn leads to lower yields of crops such as corn and soybeans in the southern regions of Ukraine. This is becoming particularly critical considering climate change, droughts and other extreme weather events that negatively impact agricultural production. The lack of scientific data on the impact of no-till on the productivity of major crops in these specific agricultural and climatic conditions creates a need for experiments to assess the feasibility and benefits in detail.

I. Honcharuk & H. Pantsyreva (2021) studied the efficiency of pulse cultivation in Ukraine, highlighting the integration of traditional and innovative methods to improve productivity and preserve soil fertility. The researchers emphasise the importance of modern agronomic approaches in ensuring sustainable production in the face of climate change. S. Sheoran *et al.* (2022) investigated the latest technologies to improve the productivity of pulses, focusing on innovations in water conservation and the use of technological inputs to increase yields. The researchers emphasise the importance of intensive use of modern methods, such as no-till, to optimise agricultural practices. Z.Z. Qodirov *et al.* (2022) studied water-saving irrigation technologies for soybeans, particularly the role of such technologies in increasing yields in arid regions. The researchers highlight the importance of proper water management for the sustainable development of crops. H. Tiwari *et al.* (2022) analysed the effectiveness of innovative technologies for increasing productivity in rice-wheat systems focusing on improving resource conservation and water retention. The authors of this paper also highlight the importance of using technologies such as no-till to improve the efficiency of agronomic systems, which reduces water consumption and increases crop resilience to drought.

S.S. Walia *et al.* (2022) considered the design of resource-efficient and environmentally sound crop rotations for sustainable energy use and economic benefits. They investigated how crop rotation optimisation can contribute to increased productivity and resource conservation. L.P. Amgain *et al.* (2022) analysed soil conservation technologies to improve the resilience of agricultural systems in Nepal. The researchers emphasise the importance of applying minimum tillage techniques to preserve fertility and improve structure, which is critical for food security. A. Nurbekov *et al.* (2024) studied the effectiveness of no-till technology for growing wheat in arid regions. The authors also noted that minimum tillage technologies help preserve soil moisture, reduce erosion risks, and improve the overall resilience of agricultural systems to climate change. X. Liu *et al.* (2024) assessed the efficiency of water use in agriculture, particularly in arid regions, focusing on no-till technologies to conserve water and increase use efficiency. They noted that these technologies can help reduce water consumption and reduce negative environmental impacts.

N. Suleimenova *et al.* (2021) studied soil conservation technologies for adapting agroecosystems to climate change in southeastern Kazakhstan. The scientists note that the use of the no-till system helps to preserve the natural structure of the soil, reduce erosion, and increase crop resilience to drought. T.K. Das *et al.* (2021) studied the impact of soil conservation technologies on productivity and resource use efficiency in agriculture. The authors note that no-till technology helps to increase water use efficiency, preserve soil fertility, and reduce negative environmental impact. The study aimed to evaluate the effectiveness of no-till technology for increasing corn and soybean yields in the southern regions of Ukraine, for preserving soil fertility, improving water retention properties and increasing crop resistance to stressful conditions. The objectives of the study were to compare the impact of no-till and conventional tillage on corn and soybean yields; assess growth characteristics; and determine the impact of no-till on soil ecological properties.

MATERIALS AND METHODS

The research was conducted in 2022-2024 in the conditions of Olena Farm, Voznesenskyi district, Mykolaiv region. Several agronomic approaches were used to evaluate the effectiveness of different technologies, including no-till technology for corn and soybean cultivation, as well as classical cultivation technology. Observations of plant development were conducted during the following phases of plant growth and development: during the germination phase (June), during the period

of active growth (July-August) and the ripening and harvesting phase (September-October). The weather conditions in 2022 were characterised by moderate rainfall at the beginning of the season, but a lack of rainfall in August, which affected plant development. In 2023, the spring was rainy, but August was dry, which also had an impact on the growth and development of crops. The year 2024 was defined as extremely dry, which affected the growth and development of plants and their productivity. During the growing season, plant height, plant density, and survival rate were measured, and the crops were harvested in late autumn. The study complied with the ethical standards set out in the Convention on the Trade in Endangered Species of Wild Fauna and Flora (1973) and the Convention on Biological Diversity (1992).

Plots with two soybean varieties were used to assess the impact of no-till technology on soybean yields: Bettina and Fortress. No-till sowing was carried out using a Sich-4.2 direct seed drill produced in Ukraine. This seed drill ensures precise seed placement without preliminary tillage and is equipped with disc elements that sow seeds to a depth of 3-5 cm with minimal soil mixing. Seeds were sown according to the recommended rates for each crop (Growing soybeans. Sowing..., 2024). Yields were measured by harvesting the entire crop in each plot after the crops were ripe. Yields were estimated in t/ha. The analysis of the impact of no-till on maize yields was conducted on hybrids DKS 4795 and DKS 3730. Yields were measured using the same standards as for soybeans, which made it possible to determine the yield increase with no-till. To measure the yield of corn using conventional and no-till technologies, the amount of grain harvested per 1 m^2 was calculated, after which these figures were converted into tonnes per hectare. Harvesting was conducted after the crop had reached full maturity, which accurately determined the amount and weight of grain.

To measure the density of plants and the degree of plant survival, the method of counting the number of plant sprouts per 1 m^2 was used. The assessment was conducted at each stage of the growing season: after germination, during the period of active growth and after maturation. The survival rate was defined as the ratio of the number of remaining plants to the number of seeds sown at the initial stages. This method accurately assessed the effectiveness of no-till and conventional cultivation technology in terms of plant survival and adaptation to stressful conditions. The dynamics of plant height were recorded by regular measurements at each study site. Plant height was determined using measuring rulers on standard 1 m^2 plots every 10-15 days during the growing season. The measurements were carried out during the main phases of plant growth and development, particularly the germination phase, active growth and before grain filling. Analysis of variance (ANOVA) was used to determine the statistical significance of the differences between the groups (conventional and no-till). This method was used to assess whether there are statistically significant differences between different crop cultivation technologies. The data were processed using Microsoft Excel statistical software for basic calculations and graphical presentation of the results.

RESULTS

To create a highly productive crop, it is necessary to determine an optimal plant density and ensure proper growth and development. At the same time, the initial period of plant development is crucial, as it determines the plant density, their growth in the future and the yield potential of the crop. To create a highly productive sowing, it is necessary to obtain the optimal number of plants per unit area, accounting for the variety, water supply, etc. The objective of this research was to study the plant density and survival rate of soybean and corn plants of different varieties and hybrids, depending on the technology of growing crops. The research demonstrated that, regardless of the year of soybean cultivation, the density of plants in the germination phase did not depend on varietal characteristics but was determined by the cultivation technology (Table 1).

Table 1. *Soybean plant density and survival depending on varietal characteristics and cultivation technology (average for 2022-2024)*

Technology	Variety	Plant density, thousand plants/ha		Survival rate, %
		Germination phase	Phase of full seed ripeness	
Classic	Bettina	383.9	339.8	88.5
	Fortetsia	375.9	328.7	87.4
No-till technology	Bettina	141.4	128.2	90.6
	Fortetsia	139.3	124.4	89.2

Source: *compiled by the authors*

The researchers determined that, regardless of the year of soybean cultivation, the plant density in the germination phase did not depend on varietal characteristics but was determined by the technology of growing the crop. Notably, soybean seeds were sown at a rate of 400 thousand units/ha under conventional cultivation technology and 150 thousand units/ha under no-till technology. On average, over the years of research, when Bettina was grown using classical technology, there were 383.9 thousand soybean plants per hectare in the germination phase and 375.9 thousand plants per 1 hectare of Fortetsia soybean. When growing soybeans using no-till technology, the number of soybean plants in the germination phase ranged from 139.3-141.4 thousand plants/ha. The calculation of the density of soybean plants in the phase of full seed maturity showed that the density of soybean plants of Bettina variety was 128.2-339.8 thousand units/ha, and Fortetsia variety – 124.4-328.7 thousand units/ha, depending on the cultivation technology. Notably, on average, Bettina plants had a slightly higher plant density in the phase of full seed maturity (234 thousand units/ha), which exceeded Fortetsia plants by 7.45 thousand units/ha or 3.2%. The study revealed that the survival of soybean plants during the growing season was influenced by the varietal characteristics of the crop and the cultivation technology. When growing soybeans using no-till technology, more plants survived than under the classical cultivation technology. On average, over the years of research, the majority of soybean plants survived for the period of full seed maturity under no-till technology 89.2-90.6%, which exceeded the indicators of the variant of the classical technology of growing the crop by 1.8-2.1%, depending on the variety under study. Notably, the survival rate of Bettina plants during the growing season was slightly higher than that of Fortetsia by 1.3% on average over the years of research and by the factor of cultivation technology. Plant density is one of the most important elements in regulating water consumption during the growing season of maize hybrids to ensure a high level of grain productivity under conditions of insufficient and unstable moisture. These studies showed that the density of maize plants depended on the characteristics of the hybrid under study (Table 2).

Table 2. *Influence of varietal characteristics and cultivation technology on the density of maize plants and their survival (average for 2022-2024)*

Technology	Variety	Plant density, thousand plants/ha		Survival rate, %
		Germination phase	The phase of full-grain ripeness	
Classic	DKC 4795	65.5	56.9	86.9
	DKC 3730	66.4	58.6	88.3
No-till technology	DKC 4795	65	59.5	91.5
	DKC 3730	65.5	60.4	92.2

Source: *compiled by the authors*

Thus, on average, during the years of research, when growing the hybrid DKS 3730, the density of plants in the germination phase, depending on the cultivation technology, was 65.5-66.4 thousand units/ha, which exceeded the figures for the hybrid DKS 4795 by 0.8-1.4%. The same trend was observed in the phase of full-grain ripeness. Notably, in the germination phase, a slightly higher density of maize plants was observed under conventional tillage, which may be due to the fact that no-till contributed to fewer germinations due to the preservation of a denser surface soil structure, which sometimes hinders seed germination. Due to better conditions for the growth and development of maize plants during the growing season, less damage and death of plants from pests when growing maize using no-till technology in the phase of full grain ripeness, the plant density under this technology was 59.5-60.4 thousand units/ha, depending on the hybrid, which exceeded the indicators of the classical cultivation technology by 3-4.4%.

The best results in the preservation of maize plants during the growing season, on average over the years of research, were provided by no-till technology 91.5-92.2%, depending on the hybrid under study, which exceeded the indicators of the classical technology variant by 3.9-4.6%. It should be noted that on average over the years of research and by the factor of cultivation technology, during the growing season, more plants of hybrid DKC 3730 were preserved at 90.3%, which exceeded the survival rate of plants of hybrid DKC 4795 by 1.1%. The obtained results demonstrate that the use of no-till technology compared to conventional sowing technology does not lead to significant losses in plant density or plant survival. At the same time, the degree of plant survival remains high and stable for both soybeans and corn, which confirms the effectiveness of no-till technology for maintaining plant viability (Tsyliuryk & Tyshchenko, 2024).

The formation of soybean productivity is influenced by plant height, so, depending on the dynamics of this

indicator during the growing season, it is possible to conclude the conditions of plant growth and development in ontogeny. The research data showed that the height of soybean plants depended on the weather conditions of the year of cultivation, varietal characteristics, as well as on the variant of the crop cultivation technology. In the dry years of 2022-2023, the height of plants of both studied soybean varieties in the budding phase reached 50.7-62.6 and 46.9-58.4 cm, depending on the variant of cultivation technology. In 2024, when a very severe drought was observed, similar indicators varied between 41.9-43 and 40.6-42.5 cm, respectively, depending on the factors studied.

In 2022, at the end of the flowering phase, the plants of the soybean variety Bettina were taller, reaching values of 61.7-63.2 cm, depending on the variant of crop cultivation technology, which is 4.7-5.6 cm or 8.2-9.1% higher than the height of the Fortetsia variety. In all subsequent years of research, plants of the Bettina variety were also determined to be slightly taller than the Fortetsia variety. Thus, depending on the variant of cultivation technology, in 2023 the excess was 2.8-4.3 cm (3.8-6.1%), and in 2024 – 2.1-2.4 cm (4.1-4.5%).

In the phase of seed filling, the linear height of plants of both studied varieties reached its maximum. At the same time, it was determined that the plants of the Bettina variety, as in the previous phases of plant growth and development, were slightly taller than the Fortetsia variety, regardless of the year of cultivation. On average, over the years of research, growing soybeans using no-till technology contributed to the formation of larger linear dimensions of plants of the studied varieties at all stages of plant growth and development (Fig. 1).

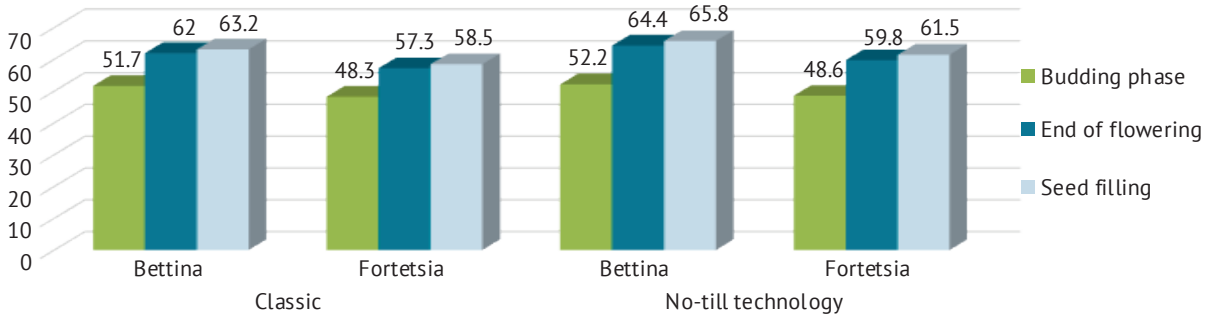

Figure 1. *Influence of varietal characteristics and cultivation technology on soybean plant height (average for 2022-2024), cm*

Source: *compiled by the authors*

Important manifestations of plant life are their growth processes, which are associated with quantitative changes (Vozhegova *et al.*, 2020; Mokrienko *et al.*, 2024). According to the results of research in 2022-2024 in the southern Steppe of Ukraine, the height of maize plants of the studied hybrids increased depending on the growing technology and weather conditions of the region. The best results were obtained in 2023. According to the results of the research, the highest height index for no-till cultivation technology was 240 cm (2023) in the full ripeness phase for the DKC 3730 hybrid, and 235 cm (2022) for the classic technology. On average, over the years of research, the highest plant height was determined in the variant of growing the studied hybrids using no-till technology (Fig. 2).

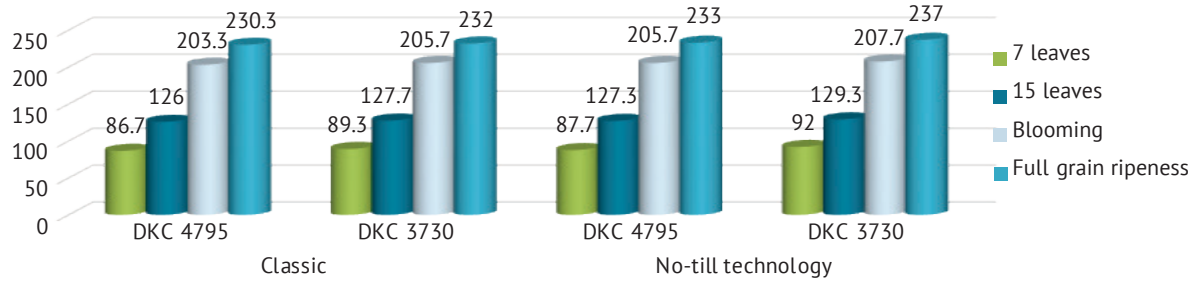

Figure 2. *IInfluence of cultivation technology on the height of maize hybrids (average for 2022-2024), cm*

Source: *compiled by the authors*

Thus, on average, according to the hybrid factor, the height of maize plants under the classical cultivation technology ranged from 88-231.2 cm, depending on the phase of growth and development, which was 1.4-3.8 cm or 1.1-1.6% less than the no-till technology variant. At the same time, regardless of the studied technology of crop cultivation, plants of hybrid DKC 3730 had slightly higher linear dimensions at all stages of growth and development. The use of no-till technology for growing soybeans in the Southern Steppe of Ukraine has shown a significant increase in yields compared to conventional cultivation. According to the study, on average, in 2022-2024, soybean yields were 15.2-17.5% higher in areas where no-till technology was used, depending on the variety under study, compared to conventional technology.

One of the main factors that contributed to the increase in yields is the preservation of moisture in the soil. No-till technology has significantly reduced moisture losses compared to conventional cultivation, as minimal tillage prevents soil loosening, which reduces water evaporation from the surface. This is crucial in the southern regions of Ukraine, where rainfall deficits are a common concern, especially during periods of active plant growth. No-till helps to retain moisture in the upper layers of the soil, which is crucial for plant growth during dry periods (Zabolotnyi *et al*., 2020). In areas where no-till technology was used, moisture was retained 20% longer than in conventionally cultivated areas.

Another important aspect of no-till technology is the improvement of soil structure. This method helps to preserve organic matter on the soil surface, which is key to improving physical properties. The presence of organic matter forms a natural protective layer that not only reduces erosion but also contributes to better soil moisture retention. This, in turn, allows for more stable conditions for plant development, especially during periods of drought, when moisture is a limited resource (Tsyryulyk, 2020). The study noted that the root system of soybeans in plots with no-till technology was more developed, which contributed to increasing plant resistance to stress factors.

Another important aspect of no-till technology was the improvement of soil biological activity. Minimal tillage does not disturb the natural environment for beneficial microorganisms, such as nodule bacteria, which play an important role in stimulating nitrogen fixation in the roots of plants, including soybeans. Nitrogen fixation provides the plants with the necessary nitrogen, which reduces the need for chemical nitrogen fertilisers. This, in turn, reduced fertiliser costs and contributed to a more sustainable use of natural resources. Preserving the natural microflora of the soil is critical to maintaining the ecological balance in the agroecosystem. Since no-till does not disturb the soil structure, it promotes the development of beneficial microorganisms that maintain soil health and improve fertility. In addition, the activity of these microorganisms contributes to better absorption of other important nutrients, such as phosphorus and potassium, which also reduces the need for mineral fertilisers. Preserving the biological activity of the soil helps to create a sustainable and productive farming system, which is an important factor for achieving long-term results in agriculture (Draganchuk, 2023). No-till technology has helped to preserve the top fertile layer of soil, which results in more sustainable plant development and improved product quality. Reduced erosion also has a long-term positive effect on soil fertility (Tereshchenko, 2024).

The cultivation of pulses, including soybeans, in Ukraine and high grain yields are key for agriculture and the economy, as they are strategic crops for food security, export potential and sustainable development of the agricultural sector (Drobitko *et al*., 2024; Mokrienko *et al*., 2024). The dynamics of yields of pulses, including soybeans, over the period 2015-2023 are marked by fluctuations. Soybean yields increased from 18.4 c/ha in 2015 to 25.8 c/ha in 2023. The choice of soybean variety and cultivation technology plays an important role in increasing soybean yields. Increasing soybean yields by 0.22-0.35 t/ha or 15.2-17.5% on average over the years of research using no-till technology is an important economic and environmental result that allows farms to reduce tillage costs, improve soil fertility and obtain consistently high soybean yields (Table 3).

Table 3. *Soybean yields using conventional and no-till technology, t/ha*

Variety	Technology		Yield increase from no-till technology	
	Classic	No-till	t/ha	%
		2022		
Bettina	1.81	2.17	0.36	16.6
Fortetsia	1.4	1.63	0.23	14.1
		2023		
Bettina	2.05	2.5	0.45	18
Fortetsia	1.58	1.89	0.31	16.4

Table 3, Continued

Variety	Technology		Yield increase from no-till technology	
	Classic	No-till	t/ha	%
		2024		
Bettina	1.09	1.32	0.23	17.4
Fortetsia	0.71	0.83	0.12	14.5
		Average for 2022-2024		
Bettina	1.65	2	0.35	17.5
Fortetsia	1.23	1.45	0.22	15.2

Source: *compiled by the authors*

The next task of the research was to study the impact of classical and no-till technology on the yield of maize hybrids DKC 4795 and DKC 3730 in the Southern Steppe of Ukraine (Table 4).

Table 4. *Influence of cultivation technology on corn yield, t/ha*

Hybrid	Technology		Yield increase from no-till technology	
	Classic	No-till	t/ha	%
		2022		
DKC 4795	3.73	4.32	0.59	13.6
DKC 3730	3.99	4.71	0.72	15.3
		2023		
DKC 4795	3.87	4.51	0.64	14.2
DKC 3730	4.21	4.98	0.77	15.5
		2024		
DKC 4795	2.89	3.28	0.39	13.8
DKC 3730	3.26	3.82	0.56	14.9
		Average for 2022-2024		
DKC 4795	3.73	4.03	0.3	13.9
DKC 3730	3.82	4.5	0.68	15.1

Source: *compiled by the authors*

In 2022, in areas where no-till technology was used, a yield increase of 0.59 t/ha or 13.6% was recorded for the hybrid DKC 4795 compared to the classical technology of growing the crop. In 2023, the increase was 0.64 t/ha or 14.2%, and in 2024, 0.39 t/ha or 13.8%. This demonstrates the significant advantage of no-till technology for increasing corn yields in the Southern Steppe of Ukraine, where soil moisture is an important factor in high crop productivity. No-till technology reduces water evaporation from the soil surface, which allows moisture to be retained 20% longer compared to conventional cultivation. This has become a crucial factor in the growth and development of corn plants, which is a water-dependent crop. Minimal tillage also improves the development of the root system, which allows plants to obtain nutrients from deeper soil layers.

The hybrid DKC 3730, which is highly resistant to stressful conditions such as drought and high temperatures, showed an even greater increase in yields when using no-till technology. In 2022, the increase in grain yield of the hybrid under study was 0.72 t/ha or 15.3%, in 2023 0.77 t/ha or 15.5%, and in 2024 0.56 t/ha or 14.9%. This data confirms that no-till technology is effective not only for high-yielding hybrids but also for crops that are highly resistant to adverse conditions. By preserving moisture in the soil, no-till contributes to the stable development of plants even in drought conditions, which is an important aspect for southern regions where precipitation can be irregular (Tereshchenko, 2024). A comparison of the yield increase between the two hybrids showed that for the hybrid DKC 4795, the average increase over the years of research was slightly lower than for DKC 3730, but still significant at 13.9%. DKS 3730 showed a greater increase due to its high resistance to stressful conditions, which once again confirms the effectiveness of no-till technology in ensuring stable growth and development of plants even in extreme conditions. In addition to increasing yields, no-till technology has helped to reduce tillage costs. Scientists have determined that the absence of ploughing and cultivation has reduced fuel and time costs, making this technology economically viable for farmers (Demydenko, 2024). Minimal intervention in the soil also reduces the probability of degradation,

which has a positive effect on soil structure and helps to preserve biological activity.

In general, no-till technology has a positive impact on preserving soil structure, reducing erosion and preserving moisture, which is an important aspect for southern regions where a lack of precipitation can significantly affect crop development. No-till technology allows for the preservation of organic matter on the soil surface, which improves physical properties such as aeration and water retention (Tsyliuryk & Tyshchenko, 2024). This is important for maintaining stable plant development even in dry conditions. The cultivation of the studied crops using no-till technology provided better conditions for plant growth and development in all years of research, while the plants had better conditions for the formation of linear dimensions and survival during the growing season, including due to the preservation and accumulation of moisture in the soil.

DISCUSSION

The study evaluated the effectiveness of no-till technology for growing corn and soybeans in the Southern Steppe of Ukraine. This study showed a significant increase in yields compared to conventional tillage methods, which confirms the effectiveness of no-till in ensuring stable plant development and increasing productivity in the southern regions. O.O. Fostachenko (2022) optimised the placement of crops in the field crop rotation on the example of the private enterprise "Lyon" in the Kamianskyi district of the Dnipro region. The researcher notes that the right choice of tillage method and optimal use is an important factor in increasing crop yields. This study is in line with the findings of the present study, where no-till technology also showed a significant increase in corn and soybean yields. However, unlike this study, the researcher also focuses on the role of proper crop placement in crop rotation and agronomic practices to increase land use efficiency and improve fertility. This experiment focuses more specifically on no-till, which demonstrates greater yield gains for specific crops, regardless of placement in the rotation.

O.O. Tsokalo & D.V. Tkachenko (2022) studied the adaptation of crop production to climate change, emphasising the importance of using conservation tillage, in particular no-till, to preserve soil moisture and adapt crops to stressful conditions such as drought. This study showed similar results to the current one, where no-till technology also showed increased plant resistance to drought conditions. However, the scientist focuses more on the general principles of plant adaptation to climate change, while this study focuses on the specific results of no-till to increase corn and soybean yields. This experiment also showed significantly higher yield gains, highlighting the more specific approach to no-till technology.

M.V. Veremiev (2023) evaluated the effect of Quantum micro fertiliser on the growth and development of grain sorghum plants. The author emphasised the importance of microfertilisers for stimulating plant growth, increasing resistance to stressful conditions and improving the general condition of plants. The research of the scientist does not fully coincide with the results of the current study, as it focuses on the use of biological products and microfertilisers, while this work focuses on no-till technology. Nevertheless, both studies confirm the significant impact of agricultural technologies on improving plant growth and stress tolerance. This experiment differs in that it analyses the impact of tillage without the use of additional fertilisers, which compared the effectiveness of the methods in the context of natural soil conservation.

O.M. Vuyko & Y.M. Shkatula (2020) substantiated the technological methods of spring wheat cultivation in the conditions of Promin Limited Liability Company (LLC) in the village of Suslivtsi village, Letychiv district, Khmelnytskyi region. The main focus of the study was on the selection of optimal agronomic measures to improve wheat yields, in particular, the correct placement of crops in crop rotation and the selection of effective tillage methods. This study has certain parallels with the present study, as it also deals with optimising crop cultivation technologies to increase productivity. However, in contrast to these results, which focused on comparing no-till and conventional tillage, the researchers' studies focus more on wheat practices, such as variety selection and seeding methods, without a focus on no-till technology. These results showed that no-till technology yielded higher yields, particularly for soybeans and corn, compared to the O.M. Vuyko & Y.M. Shkatula (2020) study on conventional planting methods.

O.Yu. Mokoychuk (2021) conducted a comparative assessment of soybean varieties by grain productivity in the conditions of AgroFirm "Khliborob" LLC in the village of Nalyvaika, Kirovohrad region. The scientist focused on the study of different soybean varieties and their ability to use resources efficiently with different sowing methods. The researcher determined that the choice of variety is an important factor that directly affects yields and that the right choice of variety can significantly increase the efficiency of growing the crop. This coincides with the present study, which also determined that no-till technology can increase yields, but in this case, the study examined sowing technology on the same varieties, which allows for more accurate comparisons of yields for each tillage method. The

results of a study by O.Y. Mokoychuk (2021) demonstrated a significant role for the variety, but in this study, the effect on yields was more due to tillage methods than to varieties.

O.V. Averchev & T.S. Kovshakova (2022) studied the effect of biostimulants and trace elements on the phenological characteristics of pea varieties in the South of Ukraine. The researchers determined that the use of biostimulants and micronutrients improves plant development and increases resistance to stress factors such as drought and low temperatures. This study partially coincides with these results, as each study examines the effectiveness of different agronomic practices to increase crop productivity. However, this study focuses on comparing no-till and conventional seeding methods without the additional use of biostimulants, which is an important distinguishing factor. In this case, the yield increase was achieved through no-till technology, while O.V. Averchev & T.S. Kovshakova (2022) focused on the improvement of phenological parameters using biostimulants, which may be an additional factor for increasing efficiency in future studies.

M.P. Kovalchuk (2020) studied and analysed the impact of agronomic practices on spring barley productivity in the experimental field of Vinnytsia National Agrarian University. The researcher studied different methods of tillage, fertilisation and sowing to determine the optimal conditions for increasing spring barley yields. This study is in some ways similar to the present results, as both studies examine the impact of agronomic practices on crop yields. However, in contrast to this study, which compared no-till and conventional tillage, the researcher focuses more on an integrated approach to agronomic practices. The results showed a greater increase in yields due to no-till. O.V. Kozak (2023) studied the impact of basic tillage on pea productivity in the conditions of Agrosvit LLC in the Synelnykivskyi district of the Dnipro region. The study focused on different methods of tillage, in particular, on the comparison of traditional and modern technologies. The author's conclusions partially coincide with the data, as the studies examined the impact of tillage on legume yields. However, this study focuses on comparing no-till and conventional tillage, while O.V. Kozak (2023) work examines different types of basic tillage. These results showed a greater yield increase with no-till.

A.I. Kibziy & I.I. Palamarchuk (2020) studied the influence of sowing dates on the yield of vegetable pea grain in the conditions of the Podillia Botanical Garden of Vinnytsia National Agrarian University. The researchers emphasise that sowing dates are one of the key factors affecting yields, especially when using minimum tillage technologies. This study also focuses on the impact of agronomic factors on yields. However, unlike current research that focuses on no-till as a tillage method, the researchers focus more on the optimal sowing time to increase yields. These results showed a greater yield increase with no-till technology, indicating the specificity of tillage methods compared to sowing dates. R.O. Shylo & Y.M. Shkatula (2020) studied the influence of mineral fertilisers and precursors on the formation of winter wheat productivity in the conditions of Podillya Agroproduct LLC in Brailiv village, Zhmerynka district. The researchers found that the right choice of predecessors and the use of mineral fertilisers significantly improved wheat productivity. This study has some similarities with the present study, as it also focuses on increasing crop yields. However, contrary to the work of the authors mentioned above, which addresses the optimisation of fertiliser application and choosing predecessors, this study focuses on comparing tillage technologies, including no-till. These results demonstrated a greater yield increase with no-till, without the use of additional mineral fertilisers, which confirms the effectiveness of minimal tillage in increasing productivity.

Y.O. Alexandrov (2021) studied the peculiarities of winter wheat grain yield formation depending on cultivation methods in the conditions of the Eldorado farm in the Pavlohrad district of the Dnipro region. The researcher highlighted the importance of choosing the right agronomic practices, particularly the importance of tillage technology for optimising yields. This study is similar to the current one, as it also examines the impact of tillage methods on wheat productivity. However, the study by Y.O. Alexandrov (2021) addressed the combination of tillage and fertiliser, while this study is more focused on comparing no-till and conventional no-till seeding technology. These results showed significantly higher yield increases with no-till, which demonstrates the greater efficiency of minimum tillage technology compared to other agronomic practices.

Comparing the results of this study with other studies shows that no-till technology is an effective strategy for increasing corn and soybean yields and for maintaining ecological balance in agriculture. Most studies confirm the importance of proper tillage for high yields, but these results demonstrate significantly higher yield increases with no-till, making this study an important contribution to the development of efficient and sustainable agricultural technologies. Differences in research methods and results could be determined by different experimental conditions, soil types and crops, but the overall conclusion shows the advantage of no-till for increasing crop productivity in the southern regions of Ukraine.

CONCLUSIONS

The study assessed the impact of no-till technology on corn and soybean yields in the Southern Steppe of Ukraine, in comparison with the classical technology of growing the crops under study. The use of no-till showed a significant increase in yields for both crops: for corn by 13.9-15.1% and for soybeans by 15.2-17.5%. These results confirm that no-till technology contributes to better water retention in the soil, which is especially important for the southern regions where water shortages are a pressing issue. In addition, this cultivation technology reduces soil erosion and improves soil structure, which creates optimal conditions for the development of the plant root system. The formation of linear plant dimensions in all phases of growth and development was better with no-till technology compared to conventional technology, which subsequently affected crop yields. This indicates that although the root system of plants develops somewhat slower in the initial stages, no-till technology contributes to an increase in overall crop productivity due to better conservation of soil resources in the long term. One of the most important aspects of the study was the finding that no-till technology increases crop resilience to stressful weather conditions such as drought. Preserving organic matter on the soil surface and improving its water-holding properties enables plants to better withstand periods of moisture deficit. This is an important factor for agricultural production in the context of climate change and extreme weather events typical for the southern regions of Ukraine. Thus, the results of this study show that no-till technology is an effective method for increasing corn and soybean yields, improving soil sustainability and conserving resources. The use of this technology can reduce tillage costs, improve soil structure and ensure stable productivity in difficult agroclimatic conditions. Based on the results obtained, no-till can be recommended for widespread adoption in agricultural enterprises of the Southern Steppe of Ukraine. For further research, it is recommended to expand the range of crops and investigate the long-term impact of no-till technology on other agronomic indicators and soil types in different climatic zones.

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CONFLICT OF INTEREST

None.

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Продуктивність зернових та зернобобових культур за ресурсозберігаючої технології вирощування в умовах Південного Степу України

Анна Терещенко
Аспірант
Миколаївський національний аграрний університет
54008, вул. Георгія Гонгадзе, 9, м. Миколаїв, Україна
https://orcid.org/0000-0001-6698-8697
Альона-Марія Тарабріна
Аспірант
Миколаївський національний аграрний університет
54008, вул. Георгія Гонгадзе, 9, м. Миколаїв, Україна
https://orcid.org/0000-0002-4783-3988

Анотація. Метою дослідження було вивчення впливу класичної технології вирощування та технології no-till на продуктивність сільськогосподарських культур, зокрема на ефективність використання водних та поживних ресурсів, а також оцінка впливу на стійкість рослин до екстремальних погодних умов. У статті було наведено результати впливу технології no-till на врожайність кукурудзи та сої в умовах Південного Степу України, зокрема порівняння ефективності з традиційним методом обробітку ґрунту. Дослідження включало аналіз таких агрономічних показників, як врожайність, висота рослин, густота стояння, ступінь виживання та інші фізіологічні характеристики культур. Для оцінки впливу технології no-till було використано два сорти сої (Беттіна та Фортеця) та два гібриди кукурудзи (ДКС 4795 та ДКС 3730), а також порівняння результатів за три роки дослідження 2022-2024 рр. В результаті дослідження було виявлено, що застосування технології no-till сприяло підвищенню врожайності як кукурудзи, так і сої. Для кукурудзи приріст врожайності на ділянках за no-till становив 13,9-15,1 %, а для сої – 15,2-17,5 % порівняно з традиційною технологією вирощування. Ці результати свідчать, що застосування мінімального обробітку ґрунту сприяло збереження вологи, покращило структуру та знизило ризик ерозії, що сприяло кращому росту рослин і підвищенню здатності протистояти стресовим погодним умовам, таким як посуха. Аналіз результатів показав, що на ділянках за no-till висота рослин кукурудзи та сої була більшою, ніж на контрольних ділянках з класичною технологією. Однак це свідчить про довгострокові переваги no-till у збереженні екологічної стійкості ґрунтів та підвищенні продуктивності. Встановлено, що технологія no-till є ефективним методом для підвищення врожайності та збереження родючості ґрунтів, що має важливе значення для сталого розвитку сільськогосподарського виробництва в південних регіонах України

Ключові слова: соя; кукурудза; технологія no-till; висота рослин; густота стояння; виживаність; урожайність

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Modern agricultural enterprise management methods

Elti Shahini*
Postgraduate Student
Simon Kuznets Kharkiv National University of Economics
61166, 9A Nauka Ave., Kharkiv, Ukraine
https://orcid.org/0009-0004-8299-4236

Abstract. The study aimed to identify innovative approaches in the field of personnel management of agricultural enterprises in the context of active implementation of digital technologies. The study highlighted key aspects of implementing modern methods of managing agricultural enterprises using digital technologies. Optimisation of HR management processes through automated systems that significantly simplify recruitment, onboarding and HR records management was prioritised. As demonstrated, automation of routine tasks allows managers to focus on strategic aspects of management. The study described modern digital technologies for monitoring fields and analysing data on weather conditions, yields and market trends to improve the management of agricultural processes. The use of analytical platforms to monitor management processes was used to assess the effectiveness of the changes implemented and identify possible weaknesses. Automated financial transaction accounting systems and digital platforms for managing remote teams were integrated, which increased efficiency and reduced resource costs. In addition, the importance of using e-learning and distance learning programmes to ensure the continuous professional development of employees was emphasised. Results obtained can become the basis for the development of new management strategies that will help increase the competitiveness of agricultural enterprises in the digital economy. The practical significance of the study is determined by the possibility of applying the obtained results to improve the efficiency of management processes at agricultural enterprises through the introduction of modern digital technologies. Automated systems, analytical platforms and e-learning tools can improve employee productivity, optimise work processes, increase staff motivation and adapt to the digital transformation of the market

Keywords: innovation; leadership; motivation; adaptation; efficiency

INTRODUCTION

Human resources (HR) management in the digital age has undergone significant changes due to the rapid development of innovation and automation. Modern agricultural businesses are increasingly integrating digital solutions such as artificial intelligence, data management systems and big data analytics to optimise recruitment processes, assess productivity and improve staff performance. This not only improves internal processes but also improves response to changing market conditions and agribusiness needs. However, along with the positive aspects of digitalisation, new challenges arise, including ethics, data security and employee adaptation to new technologies.

The research relevance is determined by the rapid digitalisation of business processes in agriculture, which requires new approaches to the organisation of HR. Agricultural companies face the need to quickly adapt to changes, including the automation of

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*Corresponding author

routine tasks, the use of big data for decision-making, and the introduction of artificial intelligence to improve the efficiency of HR management. Given the global trends in technology, the integration of digital solutions into HR practices in the agricultural sector is becoming critical to increasing the productivity, engagement and competitiveness of these businesses.

Many contemporary scholars addressed this issue and provided many perspectives. For instance, O. Hryvkivska *et al*. (2024) considered innovative production risk management in agricultural enterprises, offering new methods of risk assessment and management. The study highlighted the importance of using technology to identify risks on time and implement measures to mitigate them, which in turn increases the resilience of enterprises to external shocks. In the context of global trends in the use of information technology in management, the study by M. Kryshtanovych *et al*. (2019), which analysed strategic HR management in companies, is noteworthy. They explored how modern digital tools can be used to assess and improve the effectiveness of HR management, in strategic planning and staff development.

In modern agriculture, the management of agricultural enterprises is becoming an important aspect in the context of globalisation and the introduction of the latest technologies. V. Hmyria *et al*. (2023) highlighted the current state of agricultural management, noting that enterprises must adapt their strategies to meet the challenges of the globalised economy. The authors emphasise the need to develop innovative approaches to improve the efficiency and competitiveness of agricultural enterprises, accounting for the specifics of local markets and resources. G. Chen (2021) also studied how information technology can optimise the HR management processes of agricultural enterprises, increasing the efficiency of companies by automating key functions and improving communication. H. Liu & G. Hu (2020) and C. Li (2022) highlighted the integration of artificial intelligence into automated personnel management systems. Their research demonstrated how intelligent systems can help with the financial management of HR by simplifying routine processes and providing more accurate planning.

K. Hushvakhtzoda (2023) discussed the role of management accounting in the information systems of agricultural enterprises. The author emphasised that modern information technologies increased the efficiency of management decisions through data analysis, which improved the accuracy of the assessment of the financial condition of the enterprise and developed strategies for its development. Lastly, J. Hu & X. Li (2022) analysed the management of the green supply chain of agricultural enterprises in the digital economy. The authors proposed optimisation of the supply chain as a key factor in ensuring the sustainable development of agricultural enterprises, emphasising the importance of introducing environmental practices and technologies. For instance, H. Nazarova *et al*. (2022) analysed digital technologies are changing approaches to the management strategy of agricultural enterprises and their development. Y.W. Park *et al*. (2019) studied how companies use digital transformation technologies to improve management processes and increase competitiveness. They studied the impact of digital solutions on firms' adaptation to market changes. K. Pryshliak & Yu. Semenenko (2024) analysed the role of artificial intelligence in the process of selecting personnel for an agricultural enterprise.

Even though the above studies cover many important aspects of HR management of agricultural enterprises in the digital age, some issues require further research. In particular, the impact of digital technologies on the ethical aspects of HR management in the agricultural sector remains insufficiently studied. It is also necessary to address the effectiveness of digital solutions for HR management in small and medium-sized agricultural enterprises, where resources for innovation are limited. In addition, the issue of the impact of digital transformation on the psycho-emotional state of agricultural workers and their ability to adapt to new technologies remains open. Intercultural aspects of digitalisation in agricultural HR management, which is important in light of globalisation and the growing diversity of the workforce, are also understudied. The study aims to develop recommendations for optimising management processes in agricultural enterprises using digital technologies.

MATERIALS AND METHODS

The study was conducted on a comprehensive approach. Each stage of the research provided a detailed overview of various aspects of digitalisation in HR. The first step was to analyse a sample of organisations and technologies. A comprehensive analysis of enterprises of various sizes was carried out, including Agro Iliria Group, Agrocon Albania and Alba Green. To analyse the management of agricultural enterprises, technologies such as artificial intelligence, cloud technologies and analytical platforms were selected based on the following criteria: enterprise-scale; need to increase efficiency; flexibility and mobility; analysis and transparency; and readiness to implement technology.

A SWOT analysis was conducted in the second stage to identify the strengths and weaknesses, as well as potential opportunities and threats arising from the

introduction of modern technologies in the management and development of agricultural enterprises. After that, recommendations were made to optimise the management processes of agricultural enterprises using digital technologies. These recommendations were used to introduce automation of routine HR tasks, such as recruitment and HR records management, which significantly increased the efficiency of HR departments at agricultural enterprises.

Equally important, the study addressed the use of digital technologies, not only in terms of HR management but also in collecting and analysing large amounts of data on weather conditions, yields, market prices and logistics capabilities of agricultural enterprises. Technologies for monitoring the condition of fields using modern tools, such as drones, satellite images and sensors, were described, which allows to assess the condition of crops and detect diseases or pests.

RESULTS

HR management in agricultural enterprises is undergoing significant transformations under the influence of digital technologies, which are radically changing traditional approaches to HR. From automating routine processes to implementing artificial intelligence, new solutions are changing not only recruitment methods but also approaches to employee training and development, which is especially relevant for the agricultural sector, which requires employees with new digital skills to operate modern equipment and technologies. Automation of routine tasks such as *curriculum vitae* processing, HR management and record keeping allows HR professionals in agricultural enterprises to focus on more strategic aspects of HR management, such as upskilling employees in innovative agricultural technologies. Thanks to talent management systems, agricultural companies can effectively track the progress of employees, identify their strengths and work on areas for improvement, which contributes to the development of new competencies required to work with modern agricultural machinery and innovative approaches to land cultivation. This helps create individualised development plans that meet not only the company's overall goals but also the specific requirements of agricultural production. The introduction of artificial intelligence into HR processes in the agricultural sector opens new opportunities for forecasting staffing needs, analysing productivity data, and optimising workflows. With the help of machine learning algorithms, agricultural enterprises can analyse large amounts of employee data and identify patterns that indicate the possibility of staff turnover or the need for additional agricultural knowledge, especially in the context of the introduction of the latest technologies to increase yields and efficient use of resources.

Employee engagement is also a significant aspect of agricultural enterprises. Modern agricultural companies must provide an environment that encourages the active participation of employees in decision-making and the development of corporate culture. This is especially important in the agricultural sector, where the effective use of modern technologies and innovative solutions requires close cooperation between employees from different departments. Creating platforms for feedback and open communication allows employees to feel valued by the company, which increases their motivation and loyalty, particularly during periods of seasonal work or the introduction of new agricultural technologies. In this context, HR management at agricultural enterprises is becoming not just an administrative function, but a strategic partner in shaping the business development strategy. HR managers play an important role in developing initiatives that increase productivity, improve the working climate and ensure the long-term success of the enterprise, especially when considering the impact of external factors such as weather conditions or changes in agricultural policy. They should work closely with management to introduce innovations that foster human capital development, including training staff to work with modern agricultural technologies. The digitalisation of HR management is also significantly changing the traditional way HR departments of agricultural enterprises work, offering effective solutions with the help of modern technologies. Automation of routine operations, such as recruitment, performance monitoring and leave management, allows for optimised administrative processes. For instance, attendance and time management systems automatically record employee work schedules during the harvest season, which frees HR professionals from routine work and allows them to focus on strategic tasks.

One of the most commonly used technologies in agricultural enterprises is Applicant Tracking Systems, which simplify the hiring process by automatically filtering resumes, scheduling interviews and tracking the status of candidates. This is especially useful for the agricultural sector, where there is often a need for seasonal workers or specialists with narrow technical qualifications. By implementing such systems, HR departments of agricultural enterprises can focus on strategic tasks, such as talent development and assessment of the HR required to work with innovative agricultural technologies. Another important component of the digitalisation of agricultural enterprises is HR information system, which combines all employee data into a single database (Chygryn *et al.*, 2019;

Makhmetova *et al.*, 2023). This facilitates the analysis and access to information, allowing management to make quicker decisions on promotions, transfers, or dismissals, especially in the face of changing seasonal labour demand. In addition, such systems can include tools for tracking employee performance at different stages of the agricultural production process, which allows for more effective management of staff development and planning of training activities to improve skills.

The digitalisation of management processes at agricultural enterprises improves the efficiency of HR departments by reducing the amount of routine work and increasing the transparency and accessibility of employee information. Thus, agricultural companies can adapt to changes more quickly, increase competitiveness and attract the best staff with the necessary agricultural and technical skills to implement the latest agricultural technologies. Digitalisation not only automates routine operations but also changes the structure and functions of HR departments at agricultural enterprises. Due to new technologies, HR professionals are becoming strategic partners responsible for the development of human capital in the agricultural sector. Using analytical tools, companies can analyse employee productivity data, plan their career trajectories, anticipate training needs for new agricultural technologies, and proactively manage the risks associated with staff turnover in seasonal operations.

With the changing role of HR professionals in agricultural enterprises and the development of analytical functions, the use of big data in HR management is becoming an important step. Agricultural companies can use digital technologies not only to automate processes but also to analyse employees' activities and potential, in particular in the context of seasonal work and the use of the latest agricultural technologies (Xue, 2022; Makovoz & Lysenko, 2024). Big data analytics in HR is becoming significant in making informed decisions based on evidence. For instance, agricultural enterprises can analyse historical data on employee turnover during peak seasons, employee productivity at different stages of the agricultural cycle, or even external factors such as weather conditions and market trends to predict future staffing needs. This can be used to effectively plan HR and prevent employee shortages at critical points in the production cycle. The use of big data also helps to manage staff turnover in agricultural enterprises, especially due to seasonal employment. Analytical tools can be used to predict when employees are likely to leave the company and take preventive measures to retain them, including offering additional training programmes or better working conditions. This reduces the cost of recruiting new employees and increases the stability of the team, which is highly relevant during critical harvest periods.

Modern digital technologies have a significant impact on other aspects of agricultural enterprises. For instance, the use of big data and artificial intelligence can optimise supply chain management processes. By collecting and analysing data on weather conditions, yields, market prices and logistics capabilities, agricultural companies can more accurately forecast demand, and plan harvesting and transport, reducing losses and increasing efficiency. Technology is being introduced into land management and field monitoring. The use of drones, satellite imagery and sensors in the fields can monitor soil moisture levels, and crop conditions, and detect diseases or pests at early stages, which significantly improves crop management. Hence, agricultural enterprises not only increase production efficiency but also reduce the cost of resources such as water or fertilisers. An important aspect is the integration of automated systems for accounting and controlling financial transactions. Cloud-based digital platforms allow for transparent accounting of expenses, income, and investments and provide access to real-time analytics.

Artificial intelligence in agricultural enterprises is used to conduct preliminary interviews through chatbots or virtual assistants, which becomes especially relevant during peak hiring seasons. These systems can interact with candidates, ask standard questions about their agricultural experience, analyse the answers and offer recommendations for further steps. This facilitates the efforts of agricultural HR specialists, quickly identifying unsuitable candidates and focusing on those who best meet the company's requirements. Artificial intelligence can also analyse the behavioural aspects of candidates during online interviews or tests, predicting their future performance in the field or with animals. For instance, machine learning algorithms can identify hidden characteristics that are not apparent during a regular interview but are relevant for efficiency in the agricultural sector, such as endurance or the ability to quickly adapt to changing working conditions. Automating the hiring process also increases the objectivity of the selection process. Artificial intelligence algorithms work with large amounts of data to evaluate candidates based on clearly defined criteria, such as experience in specific agricultural processes or special skills, reducing the risk of subjective errors. This allows agricultural companies to improve the quality of their hiring by focusing on candidates with the greatest potential to work in the challenging agricultural environment.

Automation and artificial intelligence contribute to the formation of corporate culture at agricultural

enterprises, especially in the context of active digitalisation of the industry. Using technology for recruitment, agricultural companies are adapting their management strategies to keep employees motivated and engaged. At agricultural enterprises, workshops can cover a wide range of topics aimed at improving labour efficiency and increasing profitability. One important area is the use of digital platforms to manage remote and seasonal teams. These seminars will discuss the implementation of collaboration software such as Slack or Microsoft Teams, which can be used to organise communication, distribute tasks and monitor their progress in real-time. The use of digital platforms not only simplifies the management process but also helps to maintain team spirit, which is especially important for seasonal workers who often work separately from the main office. This reduces the cost of organising and coordinating work while increasing staff productivity and motivation. Another important area is precision farming seminars, which will cover technologies for using drones, sensors and satellite systems to monitor fields. The practical aspects of implementing these technologies to control soil moisture, detect diseases or pests at an early stage and optimise fertiliser use will be discussed (Veeraiah *et al.*, 2022). This will allow farmers to minimise input costs and improve yields, which will directly affect the profitability of the enterprise. At the supply chain management seminars, participants will learn how to optimise the supply, transportation and storage of agricultural products using market data and logistics capabilities. This will help reduce product losses, respond more quickly to changes in demand and improve inventory management, which will have a positive impact on the company's economic performance. Agricultural enterprises can benefit from seminars on financial planning and risk management. This could include tools for analysing and forecasting prices on the agricultural market, as well as strategies for minimising risks associated with adverse weather conditions or changes in market conditions. By improving financial planning, businesses can better allocate their resources, avoid losses and increase profits. Such workshops will not only help to develop the professional skills of staff but will also help to increase the overall efficiency of the agricultural enterprise, allowing for more efficient use of available resources, minimising risks and improving process management.

Cybersecurity at an agricultural enterprise goes beyond HR management and is critical to protecting all aspects of operations. Agricultural enterprises are increasingly using modern digital technologies, such as automated farm management systems, drones for crop monitoring, and the Internet of Things to track the condition of soils, crops, and machinery. All these technologies generate huge amounts of data that need to be protected from cyber threats. Agricultural companies collect and analyse information about crops, fertiliser use, yield forecasts and other data that is the basis of their competitiveness. The loss or theft of this information can lead to serious financial losses or even bankruptcy, as strategic data can be used by competitors or criminals to manipulate the company's market position. Agricultural businesses often use automated systems to control equipment, such as tractors or other machines, that are connected to a network. Failure to properly protect these systems can lead to equipment malfunctions or, in the worst-case scenario, hacking and complete paralysis of production processes. Such attacks can cause damage to both equipment and the crop itself, resulting in significant economic losses. Another important aspect is the protection of financial transactions. Agricultural enterprises carry out many transactions, from the purchase of equipment to the sale of products. Lack of proper protection can lead to fraud, theft of funds, or manipulation of bank data, which can jeopardise the financial stability of the enterprise. Cybersecurity helps agricultural businesses ensure compliance with international standards and legal requirements governing the protection of personal and commercial data. Failure to comply with these requirements can lead to fines or market restrictions, especially if the company operates internationally. Cybersecurity is an important tool for protecting data, technology and financial operations of agricultural enterprises. Its implementation helps to increase business resilience to cyber threats, protect production processes and maintain market reputation, which contributes to the overall efficiency and profitability of the enterprise.

HR management in agricultural enterprises in the digital age also requires the active development of employees' skills and their adaptation to an ever-changing environment. As the agricultural sector increasingly integrates modern technologies, continuous learning is becoming an important condition for maintaining productivity and competitiveness. Agricultural companies should create opportunities to develop the digital skills of their employees, which not only improves their efficiency but also increases job satisfaction. The introduction of specialised training programmes focused on the use of new technologies in agriculture is becoming an important component of HR management. These can include courses on the use of drones for field monitoring, precision farming systems, or digital farm management platforms. Training programmes should consider the level of training of individual employees and provide an individual approach to their development.

This allows each employee to feel their importance in the process, increasing motivation and promoting career growth. Creating conditions for continuous staff development helps maintain high performance and team engagement (Ye, 2020; Zhang, 2022). In addition to digital skills, it is also important to develop critical thinking and problem-solving skills, which are becoming key in the context of the rapid evolution of agricultural technology. Participation in project teams, where employees can learn new techniques and interact with colleagues, fosters a culture of continuous learning and collaborative problem-solving. Effective HR management in agriculture should focus not only on the introduction of digital technologies but also on the development of human capital. Preparing employees for future challenges, actively integrating training programmes and creating conditions for their personal development help businesses maintain their competitiveness and build an adaptive, innovative team.

Social media can significantly contribute to the development of agricultural enterprises beyond HR management. They can open opportunities to promote products, increase brand awareness and establish communication with customers and partners. Social media is a powerful tool for promoting the brand of an agricultural enterprise. Publishing visual content about production processes, plant and animal care, or technological innovations allows businesses to build a positive image and raise awareness of their products. Platforms such as Instagram and YouTube help to create engaging visual content that can attract the attention of consumers and partners, increasing demand for products and potential investment. In addition, social media can highlight a company's environmental initiatives, which helps build trust among customers who increasingly prefer sustainable and environmentally responsible products. Social media can also be used to engage with customers. Platforms such as Facebook and Twitter enable businesses to maintain direct communication with their audience, answer questions, and receive feedback and suggestions, which helps to improve product quality. Such openness in communications helps farmers respond to market demands more quickly, which leads to a better understanding of consumer needs and optimisation of production processes. It also helps to strengthen the loyalty of customers who value transparency and accessibility of information. Social media can be an effective tool for finding new markets and partners. Agricultural enterprises can use the platforms to establish contacts with potential distributors or retailers, expanding their sales geography. In addition, participation in thematic groups or forums can help businesses share experiences with peers and learn about new business opportunities.

Social media also provides an opportunity for direct sales of products. Many platforms offer integrated e-commerce tools, allowing farmers to sell their products directly through social media, shortening the supply chain and increasing profits. This is especially useful for small farms that can offer their products to end consumers through platforms such as Facebook Marketplace or Instagram Shop. Social media can be a platform for education and outreach. Agricultural enterprises can share their experience, and conduct online trainings or seminars for farmers, which will contribute to the development of the industry. Publishing materials about new technologies, farm management methods or market research can be a useful tool for attracting specialists, which will increase the efficiency of enterprises and the overall level of knowledge in the industry. The use of social media can enhance the capabilities of agricultural enterprises, helping not only with internal communication and talent acquisition, but also with brand building, establishing relationships with customers and partners, and increasing sales.

Real success in the development of agricultural enterprises is possible only if modern technologies are properly implemented in their business processes. This applies not only to increasing the efficiency of operations but also to optimising the use of resources, improving planning and enhancing the management of the entire production cycle. Agromino, IMK and Nibulon have integrated the technologies shown in Table 1.

Table 1. *The impact of the introduction of modern technologies on personnel management in agricultural companies*

The company and the implemented technology	Before implementation	After implementation
Agro Iliria Group, artificial intelligence	Decision-making on crops and yields was based on traditional methods of analysis, which increased the risk of inefficient use of resources and crop losses	The introduction of artificial intelligence improved field data analysis accuracy, increasing yields and reducing the cost of agrochemicals through accurate forecasting and planning
Agrocon Albania, cloud technologies	Information on land cultivation and field conditions was stored on local servers, which complicated management at various levels of the company and delayed decision-making	Cloud technologies have provided access to real-time data from anywhere, which has improved land management and reduced administrative costs

Table 1, Continued

The company and the implemented technology	Before implementation	After implementation
Alba Green, analytical platforms	Assessment of global markets and supply chains was carried out manually, which increased risks and delayed decision-making, increasing the cost of transporting products	Analytical platforms automated the collection and analysis of market data, which optimised logistics routes and reduce transport costs, as well as increase export efficiency

Source: *compiled by the author*

The introduction of digital technologies in the field of HR management in agricultural enterprises brings significant benefits but also comes with certain challenges. To analyse these technologies in detail, a SWOT analysis was conducted to help identify strengths and weaknesses, as well as potential opportunities and threats. Table 2 summarises the key findings of the analysis.

Table 2. *SWOT analysis of modern technologies in the field of management and development of agricultural enterprises*

Technology	Advantages	Disadvantages	Possibilities	Threats
Artificial intelligence	Optimisation of production processes yields forecasting and automation of routine tasks	High implementation costs need for qualified personnel for setup	Expanding the use of artificial intelligence to improve production efficiency	Competition from other businesses that are rapidly adopting new technologies
Cloud technologies	Real-time data storage, accessibility from anywhere, collaboration	Dependence on internet connection, data security risks	Growing popularity of cloud solutions among small and medium-sized enterprises	Changes in legislation that may restrict the use of certain technologies
Analytics platforms	Analyse large amounts of data, improve decision-making and get quick access to analytics	High need for staff training, difficulty in implementing new analytical tools	Integration of new analytical platforms to improve agronomic decisions	Cyber threats that may affect data security

Source: *compiled by the author*

Optimising the management processes of agricultural enterprises with the use of digital technologies is an important step towards increasing efficiency and competitiveness. The introduction of automated HR management systems can significantly facilitate the processes of recruiting, onboarding new employees and maintaining HR records. Automating these routine tasks reduces the time required to complete them and allows HR professionals to focus on more strategic issues. Developing and implementing programmes to increase employee motivation through the introduction of flexible working arrangements is another important aspect. The agricultural sector often faces challenges due to the seasonality of its operations, so the ability to customise working hours to meet the individual needs of employees can significantly increase their engagement and productivity. Flexibility in workflows will also contribute to a better work-life balance, which in turn will increase employee satisfaction. The use of analytical platforms to monitor the efficiency of management processes is another important area. Collecting and analysing data will allow agricultural enterprises to assess the results of implemented changes and identify weaknesses in management. Active implementation of e-learning and distance learning programmes for employees is also worthy of attention. The use of modern technologies in training will allow agricultural enterprises to ensure the continuous professional development of their employees, improving their skills and adaptability to new market conditions. These steps will contribute to the creation of an innovative and adaptive management environment in the agricultural sector. Overall, these recommendations can significantly improve the management processes in agricultural organisations and contribute to their successful functioning in the digital age.

DISCUSSION

The study demonstrates the significant impact of information technology on HR management in agricultural enterprises, indicating the need to integrate modern technologies. This issue has become especially relevant in the context of rapid digitalisation, which is observed in many sectors of the economy. The study emphasised the importance of introducing new management strategies, such as digitalisation, risk management and sustainable development. The study determined that agricultural enterprises that integrate new technologies demonstrate greater efficiency in the use of resources. This correlates with the findings of W. Chen (2023),

who studied cost management methods in agricultural supply chains and emphasised the use of heuristic algorithms to optimise costs, which can be extremely important in a competitive market. The results are also consistent with the study by N. Dalisova *et al*. (2020), who emphasised the importance of strategic management for the development of agricultural enterprises. The researchers argued that a systematic approach to strategic management can have a positive impact on the financial performance of enterprises. This is consistent with observations on the importance of integrating new management practices. The study by N. Davydenko *et al*. (2024), which examined the mechanisms of risk neutralisation in the financial management of agricultural enterprises, is also noteworthy. The results of the study show that enterprises often underestimate the risks associated with financial security, which is also noted in the authors' work. These results emphasise the need to create effective risk management mechanisms to improve the financial stability of agricultural enterprises. In particular, the results of the study confirm the findings of V. Hmyria *et al*. (2023) on the management of production risks in the agricultural sector. The researchers pointed out the need to apply innovative risk management methods, which is critical for enterprises to adapt to a changing environment. According to a study by J. Hu & X. Li (2022), the introduction of green management models in the digital economy is important for the agricultural sector. This emphasises the need for environmental innovation in the management strategies of enterprises, which coincides with the results of the study, which indicate the importance of sustainable development.

S.S. Gadzali *et al*. (2023) emphasised the importance of HR management in the context of digitalisation. The results show that agricultural enterprises should invest in human capital development to ensure competitiveness. Important aspects are not only hiring but also training and retraining of employees, which confirms the importance of HR management strategies in the context of change. A study by O. Hryvkivska *et al*. (2024) on innovative risk management in the agricultural sector highlighted the need for flexibility in the application of management strategies. The study confirms this idea, as enterprises that quickly adapt to new conditions are more likely to succeed. The study by D. Makhmetova *et al*. (2023) emphasised the importance of waste management for improving the efficiency of rural development. This indicates that agricultural enterprises should consider environmental aspects in their management, which is important for increasing their competitiveness. Y. Luo & L. Xiong (2023) investigated the optimisation of financial management of wastewater treatment enterprises. The study shows that agricultural enterprises should also consider financial aspects in terms of environmental requirements, which is important for their sustainable development. A study by S. Yekimov *et al*. (2021) on improving the corporate governance of agricultural enterprises highlighted the need to introduce new management practices that contribute to efficiency. The results support this view, as they show that new management practices can have a significant impact on the productivity and financial stability of enterprises.

The obtained results open new opportunities for further research in the field of management of agricultural enterprises. In the context of digitalisation, it is important to study the impact of the latest technologies on various aspects of management, including decision-making and optimisation of production processes. The study by J. Zhang (2022) on strategies for the digital development of agricultural enterprises using smart sensors may become a key area for improving management practices in the future. It is worth exploring the social aspects of introducing new technologies, in particular, how digital solutions affect the motivation and adaptation of employees to change. This will help to create more effective HR management strategies, which in turn will help to increase the productivity of enterprises. It is also worth addressing the environmental aspects of management in the agricultural sector, as noted by D. Makhmetova *et al*. (2023), focusing on waste management to improve the efficiency of rural development. The study of such strategies can help agricultural enterprises to adapt to the new requirements of society. Thus, the results of the study confirm the importance of introducing modern management methods in agricultural enterprises to ensure their competitiveness. The analysis of the results shows that they are consistent with many studies, but also reveal certain discrepancies that require further study.

CONCLUSIONS

The study of modern HR management technologies in the agricultural sector determined that their implementation is critical for increasing the efficiency of management processes, improving employee interaction and adapting to a dynamic labour market. The integration of automated HR management systems allows agricultural companies to significantly reduce recruitment costs, simplify the onboarding of new employees and improve the accuracy of their performance assessment. Automation of such processes not only saves time but also reduces the risk of errors that can occur when manually maintaining documentation. This is especially true in a seasonal and rapidly changing production environment,

where responsiveness to change is a key success factor. The introduction of digital platforms for monitoring labour efficiency in the agricultural sector helps to identify weaknesses in management processes, which allows them to be addressed promptly. This underlines the importance of investing in digital solutions that can significantly improve management practices and ensure the competitiveness of agricultural companies.

The results highlight the significant potential of new technologies in the agricultural sector, but more empirical research is needed to better understand their impact. The success of technology adoption in agricultural companies depends not only on the technical equipment but also on the organisational culture and the readiness of employees to change. Notably, technologies should be implemented with due regard to the specifics of the agricultural business, as this can have a significant impact on their efficiency. To optimise the results in the future, it is important to pay more attention to practical aspects, expand the range of cases studied and consider regional peculiarities. This will allow agrarian enterprises to more accurately assess the effectiveness of the implemented measures and develop recommendations for their further optimisation, ensuring sustainability and development in the face of current challenges.

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CONFLICT OF INTEREST

None.

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Сучасні методи управління сільськогосподарськими підприємствами

Елті Шахіні
Аспірант
Харківський національний економічний університет імені Семена Кузнеця
61166, просп. Науки, 9А, м. Харків, Україна
https://orcid.org/0009-0004-8299-4236

Анотація. Метою дослідження було визначення інноваційних підходів у сфері управління персоналом сільськогосподарських підприємств в умовах активного впровадження цифрових технологій. У дослідженні висвітлено ключові аспекти впровадження сучасних методів управління сільськогосподарськими підприємствами з використанням цифрових технологій. Пріоритетним напрямком була визначена оптимізація процесів управління персоналом за допомогою автоматизованих систем, які значно спрощують підбір персоналу, його адаптацію та ведення кадрового діловодства. Як було продемонстровано, автоматизація рутинних завдань дозволяє керівникам зосередитися на стратегічних аспектах управління. У дослідженні описано сучасні цифрові технології для моніторингу полів та аналізу даних про погодні умови, врожайність і ринкові тенденції для покращення управління сільськогосподарськими процесами. Використання аналітичних платформ для моніторингу управлінських процесів дозволило оцінити ефективність впроваджених змін та виявити можливі слабкі місця. Були інтегровані автоматизовані системи обліку фінансових операцій та цифрові платформи для управління віддаленими командами, що дозволило підвищити ефективність та зменшити витрати ресурсів. Крім того, було підкреслено важливість використання електронного навчання та програм дистанційного навчання для забезпечення безперервного професійного розвитку співробітників. Отримані результати можуть стати основою для розробки нових стратегій управління, які сприятимуть підвищенню конкурентоспроможності сільськогосподарських підприємств в умовах цифрової економіки. Практичне значення дослідження визначається можливістю застосування отриманих результатів для підвищення ефективності управлінських процесів на сільськогосподарських підприємствах за рахунок впровадження сучасних цифрових технологій. Автоматизовані системи, аналітичні платформи та інструменти електронного навчання дозволяють підвищити продуктивність праці працівників, оптимізувати робочі процеси, підвищити мотивацію персоналу та адаптуватися до цифрової трансформації ринку

Ключові слова: інновації; лідерство; мотивація; адаптація; ефективність

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54008, вул. Георгія Ґонґадзе, 9, м. Миколаїв, Україна,
тел.: +38(0512) 70-93-54
E-mail: info@bsagriculture.com.ua
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