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## **Influence of biological preparations on organic cultivation of vegetable plants**

**Abstract.** The introduction of organic technology for growing vegetable plants will help to reduce the environmental burden of pesticides and produce safe vegetable products with high yields. The purpose of the study was to investigate the effect of biological preparations on the organic cultivation of vegetable plants. Field, measuring and weighing, mathematical and statistical methods were used to determine the efficacy of the preparations. The study was conducted in 2018-2021 in different

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regions of Ukraine. It was established that the systemic use of biologics during the growing season of vegetable plants provided rapid growth and development, helped to increase immunity to diseases, reduced the activity of pathogenic microorganisms in the soil, and provided an increase in overall yield. The general use of biologic preparations in open ground conditions contributed to a total potato yield of 25.4 t/ha, and the complex use of preparations on Brussels sprouts forms a larger number of heads – 90 units. The Organic Balance biological product provided an increase in yield of up to 3.5 t/ha and 90% marketability of products when growing Chinese cabbage. Chemical analysis showed that the use of biologics increased the dry matter in tomato fruits by 1.03% – in the Rio Fuego variety and 1.39% – in the Missouri variety. The yield increase in the studied varieties of asparagus beans Laura and Purpurova was 0.5 and 0.6 t/ha compared to the variants without seed inoculation. The use of biological preparations provided a higher yield in tomato plants of the Asvon variety by 2.2 t/ha, significantly reduced the content of nitrates in fruits to 50–80 mg/kg, while in the control – 110–170 mg/kg, increased the content of dry matter by 1.03 and 1.39%, depending on the variety. The gross yield of winter garlic with the use of biologics increased by 5%, and the marketability of potato tubers increased by 5%. Organic technologies would allow farmers to minimise the use of pesticides, produce environmentally friendly products, and increase yields

**Keywords:** biologics; organic technology; vegetable plants; productivity; quality, yield

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## INTRODUCTION

Vegetables contain high concentrations of vitamins, antioxidants, minerals and dietary fibre, and are low in fat, soluble sugars, and calories, so they are a supportive component of a healthy diet. The consumption of vegetables rich in vitamins, antioxidants, minerals and dietary fibre, with a low content of fat, soluble sugars and calories, is relevant, as it contributes to human health and the favourable development of industry, avoiding the problem of insufficient consumption of vegetables of plant origin worldwide. Human health and sustainable industrial production are under threat due to the imbalance and scarcity of plant-based vegetable consumption around the world, as indicated in papers by B.R. Havalli & S.N. Pradeep (2020) and J. Dong *et al.* (2022).

Organic vegetable production is becoming increasingly important and is spreading in 162 countries. Their annual increase is about 2 million hectares. The largest increase in agricultural land certified under organic standards was noted in Europe. The International Federation of the movement for organic agriculture, which unites participants from 108 countries of the world, promotes the development of organic production. Moreover, it covers the agricultural and processing industry, and other areas of activity. The most important and main segment of

organic farming is the production of environmentally friendly, safe food. For this purpose, special agricultural land is allocated, and in particular, 37.2 million hectares of agricultural land have already been certified (Kundilovska, 2019).

Data from Organic Market in Ukraine (2020) indicate that high-quality organic products grown on agricultural land comply with the European Union regulation on organic production, and the areas respectively have the status of organic or transitional. Their total number is 309,100 hectares, including the area of agricultural land with a certified organic status – 233,500 hectares. The possibility of increasing the production of organic products is ensured by the fact that Ukraine can sell its products in Western countries. The main organic products supplied to Western markets are cereals, oilseeds and legumes, mushrooms, nuts, wild berries, and medicinal plants, but the variety of products is constantly growing.

Stress resistance of the variety is important when using organic vegetable products. V. Mazur *et al.* (2020) found that a variety should be characterised by high adaptability, which allows metabolic processes to be restored to an optimal level after a stress factor, which is especially important due to climate change and instability. The effectiveness of the organic technology

used on farms also depends on the quality of soil cultivation. Ultimately, proper tillage will help to preserve moisture in the soil and increase yields. The quality of tillage directly depends on agricultural machinery, as noted by O. Solona *et al.* (2020), O. Tkachuk & N. Telekalo (2020).

Since organic farming is a dynamic system that responds to internal and external requirements and conditions, T. Ilakiya *et al.* (2020) concluded that practicing organic agriculture contributes to increased efficiency and productivity, but this should not be at the expense of human health and well-being. Over nearly two decades, people have become aware of the harmful effects of chemical fertilisers on human health and have started to move towards organic farming.

In the traditional cultivation method, as noted by B. Alaoui & R. Hamimaz (2023), excessive use of pesticides and fertilisers leads to an imbalance of nutrients in the soil, an increase in pests and diseases, and a decrease in the quality and yield of vegetables. Therefore, the demand for organic food is mainly motivated by health and nutrition issues. Much attention is paid to biological control methods as an alternative to traditional chemical fungicides against plant diseases. A. Allayarov *et al.* (2021) showed that one of the most promising new areas of crop protection against phytopathogens is to increase the induction of plant resistance to pathogens and adverse environmental factors provided by the use of biologics.

The development of organic farming is observed in almost all countries of the world. The demand for organic products is growing, which has led to people's awareness to consume eco-friendly products. The technology has been developed to produce fresh food in both off- and on-season, while maintaining traditional agriculture and organic production, but export markets are increasingly demanding organic products for further sale.

The purpose of the study was to investigate the effect of biological preparations on organic cultivation of vegetable plants in various soil and climatic conditions of Ukraine.

## MATERIALS AND METHODS

The research on the effective action of biological products was conducted in 2018-2021 at

farms in Vinnytsia, Odesa and Volyn oblasts and at the experimental plots of Vinnytsia National Agrarian University (Vinnytsia Oblast), Mykolaiv National Agrarian University (Mykolaiv Oblast), Uman National University of Horticulture (Cherkasy Oblast) and the Institute of Vegetable and Melon Growing of the National Academy of Agrarian Sciences of Ukraine (Kharkiv Oblast).

In particular, the investigation of the effect of biologics on the growth, development and yield of garlic was carried out in the conditions of LLC NZCh of the Volyn Oblast (Ukraine). The Lyubasha winter garlic variety was used in the experiment. The design of the experiment involved the use of the existing technology on the farm, which was taken as a control, and a technology with the introduction of biological products. Biological preparations were applied during the growing season of plants in the phase of 2-4 leaves: Fitocide 2.0 l/ha, Azotofit 0.3 l/ha, HelpRost Vegetables 2.0 l/ha. Organic balance 0.5 l/ha, Bitoxibacillin BTU 10.0 l/ha, Lepidocide 7.0 l/ha, Lyposam 0.5 l/ha; phase 8-9 leaves – Fitohelp 2.0 l/ha, HelpRost Vegetables 2.0 l/ha, Organic Balance 0.5 l/ha, Bitoxibacillin BTU 10.0 l/ha, Lepidocide 7.0 l/ha, Lyposam 0.5 l/ha; head development and growth – Mycohelp 2.0 l/ha, HelpRost Boron 2.0 l/ha, Organic Balance 0.5 l/ha, Bitoxibacillin BTU 10.0 l/ha, Lepidocide 7.0 l/ha, Lyposam 0.5 l/ha; leaf yellowing – technical ripeness – Mycohelp 2.0 l/ha, HelpRost Boron 2.0 l/ha, Organic balance 0.5 l/ha, Bitoxibacillin BTU 10.0 l/ha, Lepidocide 7.0 l/ha, Lyposam 0.5 l/ha. The predecessor was winter wheat, grey podzolic soil, soil pH: 6.6.

In the conditions of the farm of M.M. Shkuryna, Odesa Oblast (Ukraine), the effect of biological products was studied during the cultivation of the Tiras potato variety. The design of the experiment included the following variants: no biological products were used (control) and a variant with the introduction of biological preparations. Biological products were applied during the following periods: pre-sowing tillage – Groundfix 5.0 l/ha, Mycohelp 2.0 l/ha; before planting – Mycofrend 1 l/t; during the growing season of the plant in the phase of 5-6 leaves – Fitohelp 2.0 l/ha, Humifrend 0.6 l/ha, Lyposam 0.3 l/ha; the period of growth of vegetative mass – Fitohelp 2.0 l/ha, Humifrend 0.6 l/ha, Lyposam 0.3 l/ha;

before flowering – Mycohelp 3.0 l/ha, Humifrend 0.6 l/ha, Lyposam 0.3 l/ha; after flowering – Mycohelp 3.0 l/ha, Humifrend 0.6 l/ha, Lyposam 0.3 l/ha. The predecessor was barley, grey podzolic soil, soil pH: 6.6.

The study of the influence of biological preparations on the development of the Brussels sprouts crop took place in the Vinnytsia National Agrarian University (Ukraine) for growing hybrids Franklin F<sub>1</sub>, Diamant F<sub>1</sub>, Bokser F<sub>1</sub>, and Dolores F<sub>1</sub>. The design of the experiment considered the following options, namely: without the use of biological preparations – control; introduction of the products at the recommended dose – in the phase of 5-6 leaves: Fitohelp 2.0 l/ha, Organic Balance 0.5 l/ha, Bitoxibacillin BTU 10.0 l/ha, Lepidocide 7.0 l/ha, Lyposam 0.3 l/ha; before the development of heads – Mycohelp 3.0 l/ha, HelpRost Boron 2.0 l/ha, Azotofit 0.5 l/ha, Organic Balance 0.5 l/ha, Actoverm formula 8.0 l/ha, Lepidocide 7.0 l/ha, Lyposam 0.3 l/ha; during the development of heads – Mycohelp 3.0 l/ha, HelpRost Boron 2.0 l/ha, Organic Balance 0.5 l/ha, Actoverm formula 8.0 l/ha, Lepidocide 7.0 l/ha, Lyposam 0.3 l/ha; growth of heads – Mycohelp 3.0 l/ha, HelpRost Boron 2.0 l/ha, Azotofit 0.5 l/ha, Organic Balance 0.5 l/ha, Actoverm formula 8.0 l/ha, Lepidocide 7.0 l/ha, Lyposam 0.3 l/ha. The predecessor was sweet pepper, podzolized chernozem, soil pH: 6.6.

The study of the effect of biological preparations on the yield of Chinese cabbage was carried out in the Uman National University of Horticulture when growing the Willie F<sub>1</sub> hybrid. Predecessor: winter garlic. Soil type: podzolized chernozem, soil pH: 6.3. The design of the experiment included the following options: without the introduction of biologics (control); foliar top dressing was carried out with organic balance 0.5 l/ha, Bitoxibacillin 8 l/ha, Lepidocide 7.0 l/ha, Lyposam 0.3 l/ha; foliar top dressing in the phase of head development – HelpRost Vegetables 2.0 l/ha, Bitoxibacillin 8 l/ha, Lepidocide 7.0 l/ha, Lyposam 0.3 l/ha; foliar top dressing during head growth – HelpRost Vegetables 2.0 l/ha, Organic Balance 0.5 l/ha, Bitoxibacillin 8.0 l/ha, Lepidocide 7.0 l/ha, Lyposam 0.3 l/ha.

A study on the influence of biologics on the yield of carrots was conducted during 2019-2021 at the Organic-D farm in the Vinnytsia Oblast for hybrids Olympus F<sub>1</sub>, Abaco F<sub>1</sub>, Bolivar F<sub>1</sub>,

Miroflores F<sub>1</sub>. Biologic preparations were applied in the following stages: 1) pre-sowing tillage – Groundfix 5.0 l/ha, Mycohelp 2.0 l/ha; 2) during the growing season of the plant in the phase of 2-5 leaves – Fitohelp 1.0 l/ha, Azotofit 0.3 l/ha Organic Balance 0.5 l/ha, Lyposam 0.3 l/ha; 3) in the phase of 6-9 leaves – Fitohelp 1.0 l/ha, Azotofit 0.3 l/ha ha, Organic Balance 0.5 l/ha, Actoverm formula 6.0 l/ha, Lepidocide 7.0 l/ha, HelpRost Boron 1.0 l/ha, Lyposam 0.3 l/ha; 4) during molting of the root crop – Azotofit 0.3 l/ha, Organic Balance 0.5 l/ha, HelpRost Vegetables 2.0 l/ha, Actoverm formula 6.0 l/ha, Lepidocide 7.0 l/ha, Fitohelp 1.0 l/ha, Lyposam 0.3 l/ha; 5) during root fruit development – Azotofit 0.3 l/ha, Organic Balance 0.5 l/ha, HelpRost Vegetables 2.0 l/ha, HelpRost Boron 2.0 l/ha, Actoverm formula 6.0 l/ha, Lepidocide 7.0 l/ha, Mycohelp 3.0 l/ha, Lyposam 0.3 l/ha. The control was based on the technology used on the farm.

The efficacy of the preparations in tomato cultivation technology was investigated at the Institute of Vegetable and Melon Growing in the Selektsiyne village, Kharkiv Oblast, during the cultivation of Topaz tomato variety. The design of planting seedlings was 140×25 cm, they were planted in the 3rd ten days of May using drip irrigation. The design of the experiment included the application of the recommended cultivation technology for Kharkiv Oblast (control), the variant where humus 10 t/ha, wood ash 1 t/ha were used; during the growing season, treatment with Actophyt 1 l/ha, Mycohelp 3 l/ha; a variant with an optimised nutrition system, namely humus 10 t/ha, wood ash 1 t/ha in pre-sowing soil tillage, Roundup 3.0 l/ha, Mycohelp 3.0 l/ha. During the growing season of the plant in the phase of 5-6 leaves – Fitohelp 1.0 l/ha, HelpRost Vegetables 2.0 l/ha, Organic Balance 0.5 l/ha, Bitoxibacillin BTU 7.0 l/ha, Lepidocide 7.0 l/ha, Lyposam 0.3 l/ha; before flowering – Mycohelp 3.0 l/ha, HelpRost Boron 2.0 l/ha Azotofit 0.3 l/ha, Organic Balance 0.5 l/ha, Bitoxibacillin BTU 7.0 l/ha, Lepidocide 7.0 l/ha, Lyposam 0.3 l/ha; at the beginning of fruiting – Mycohelp 3.0 l/ha, HelpRost Boron 2.0 l/ha, Azotofit 0.3 l/ha, Organic Balance 0.5 l/ha, Bitoxibacillin BTU 7.0 l/ha, Lepidocide 7.0 l/ha, Lyposam 0.3 l/ha; during the period of mass fruiting – Mycohelp 3.0 l/ha, HelpRost Boron 2.0 l/ha, Azotofit 0.3 l/ha, Organic Balance 0.5 l/ha, Bitoxibacillin BTU 7.0 l/ha, Lepidocide 7.0 l/ha, Lyposam 0.3 l/ha.

The effect of biological preparations on the yield of seedling tomatoes was studied in the conditions of the farm private enterprise Trebukin of the Vinnytsia Oblast during the cultivation of hybrids Asvon F<sub>1</sub> (Kitano seeds), Bobcat F<sub>1</sub> (Syngenta), Solerosso F<sub>1</sub> (Nunhems). The design of the experiment provided for Ecostern 2.0 l/ha in autumn tillage; and pre-sowing tillage with Groundfix 5.0 l/ha and Mycohelp 2.0 l/ha. During the growing season of plants in the phase of 5-6 leaves – Organic Balance 0.5 l/ha, Azotofit 0.3 l/ha, Actoverm formula 6.0 l/ha, Lepidocide 7.0 l/ha, Fitohelp 1.0 l/ha, HelpRost Vegetables 2.0 l/ha, Lyposam 0.3 l/ha; before flowering – Azotofit 0.3 l/ha, Organic Balance 0.5 l/ha, Actoverm formula 6.0 l/ha, Lepidocide 7.0 l/ha, Mycohelp 2.0 l/ha, HelpRost Boron 2.0 l/ha, Lyposam 0.3 l/ha; in the phase of the beginning of fruiting – Azotofit 0.3 l/ha, Organic Balance 0.5 l/ha, Actoverm formula 7.0 l/ha, Lepidocide 7.0 l/ha, Mycohelp 2.0 l/ha, HelpRost Boron 2.0 l/ha, Lyposam 0.3 l/ha; during mass fruiting – Azotofit 0.3 l/ha, Organic Balance 0.5 l/ha, Lepidocide 7.0 l/ha, Mycohelp 3.0 l/ha, HelpRost Boron 2.0 l/ha, Lyposam 0.3 l/ha.

Studies on the development of the bean yield depending on seed inoculation were conducted in the experimental fields of the Uman National University of Horticulture. The treatment was carried out with Anderiz preparation. The soil was characterised by the following agrochemical indicators: humus content – 3.91%; pH – 6.1; mobile phosphorus – 110 mg/kg of soil; exchange potassium – 195 mg/kg of soil. Inoculation of bean seeds was carried out on the day of sowing at the rate of 1 litre of the biological preparation per 1 tonne of seeds.

The influence of biological products on the yield of tomato was investigated in the Mykolaiv National Agrarian University with the cultivation of Rio Fuego (Lark Seeds) and Missouri (Seminis vegetable seeds) varieties. The design of the experiment provided for the use in pre-sowing

tillage: Groundfix 5.0 l/ha + Mycohelp 2.0 l/ha + Metawhite 8 l/ha; during the growing season of plants in the phase of 5-6 leaves: Fitohelp 1.0 l/ha + HelpRost Vegetables 2.0 l/ha + Organic Balance 0.5 l/ha + Lyposam 0.3 l/ha; before flowering: Mycohelp 2.0 l/ha + HelpRost Vegetables 2.0 l/ha + Azotofit 0.2 l/ha + Organic Balance 0.5 l/ha + Actoverm formula 7.0 l/ha + Lepidocide 7.0 l/ha + Lyposam 0.3 l/ha; beginning of fruiting: Mycohelp 3.0 l/ha + HelpRost Boron 2.0 l/ha + Azotofit 0.3 l/ha + Organic Balance 0.5 l/ha + Actoverm formula 7.0 l/ha + Lepidocide 7.0 l/ha + Lyposam 0.3 l/ha; mass fruiting: Mycohelp 3.0 l/ha + HelpRost Boron 1.0 l/ha + Azotofit 0.3 l/ha + Organic Balance 0.5 l/ha + Actoverm formula 7.0 l/ha + Lepidocide 7.0 l/ha + Lyposam 0.3 l/ha.

All studies were carried out in accordance with generally accepted modern methods in crop production by A.O. Rozhkov *et al.* (2016), and the Greentest device (China) was used to determine the total nitrate content in the product organs of tomato and carrot roots. Based on the existing instructions for the device and the established recommendations, the permissible nitrate content in tomato berries should not exceed 300 mg/kg of product, and in carrot roots – 400 mg/kg. All values above the specified value are considered to be exceeded and must not be used for further consumption.

The study complied with all the requirements set out in the Convention on Biological Diversity (1992) and Convention on the Trade in Endangered Species of Wild Fauna and Flora (1973).

## RESULTS AND DISCUSSION

Based on the results of studies conducted to study the effect of a complex of biologics, their positive effect on the growth, development and formation of the crop of vegetable plants was established. The effect of biological preparations on the growth, development, and yield of garlic is shown in Table 1.

**Table 1.** Yield of the Lyubasha garlic variety using a complex system of biological preparations in the Volyn Oblast (Ukraine), t/ha

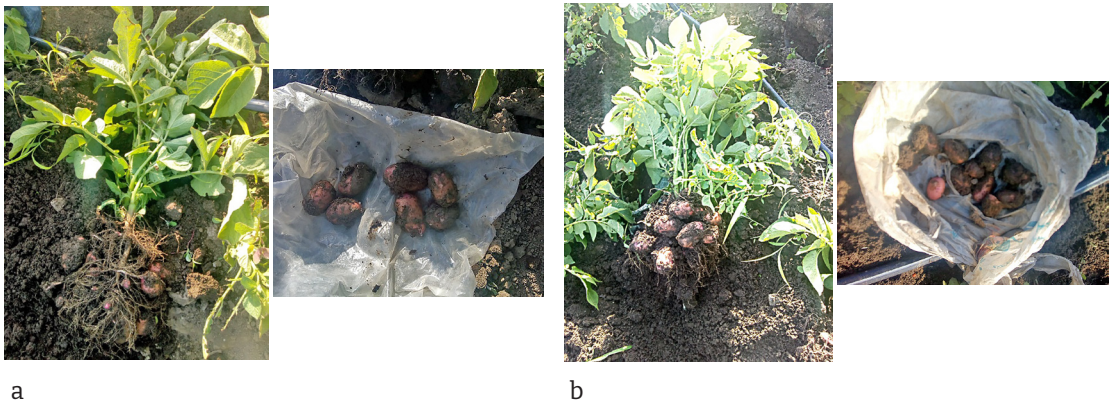
Control			Experimental			Yield increase, t/ha
Area, ha	Gross harvest, t	Yield, t/ha	Area, ha	Gross harvest, t	Yield, t/ha	
0.5	3.6	7.2	0.5	3.8	7.6	0.4

Source: compiled by the authors

Systemic use of biological preparations during the growing season of garlic plants of the Lubasha variety ensures rapid growth and development, helps to increase immunity to diseases, reduces the activity of pathogenic microorganisms in the soil, and provides an increase in overall yield. On the variant with the use of a complex of biological preparations, a yield of 7.6 t/ha was obtained, which is 0.4 t/ha more compared to the control version. The gross yield at the study site was 3.8 t/ha, which is 0.2 t/ha (5%) more than the control. The activity of bacteria that form the basis of biological preparation contributes to the timely formation of a typical product organ, the cloves are characterised by a

standard size, the plant is more resistant to bacterial diseases.

The use of biologics during the growing season of the potato plant ensures optimal plant development, especially in its early stages; increases its immunity, growing process, and the overall yield (Fig. 1). The activity of bacteria that form the basis of Mycofrend preparation ensures the development of mycorrhiza on the surface of tubers and the root system, and the development of a larger number of commercial tubers. When studying the complex effect of biological preparations in the conditions of the Odesa Oblast (Ukraine), an increase in the potato yield was noted (Table 2).



**Figure 1.** Development of potato tubers depending on the use of biological preparations

**Note:** a – control, b – experimental

**Source:** compiled by the authors

**Table 2.** Yield of Tiras potatoes using a comprehensive system of biologics in the Odesa Oblast (Ukraine), t/ha

Control			Experimental			Increment, t/ha
Area, ha	Gross harvest, t	Yield, t/ha	Area, ha	Gross harvest, t	Yield, t/ha	
0.5	10.85	21.7	0.5	12.7	25.4	3.7

**Source:** compiled by the authors

The general use of biologics of bacterial origin in open ground conditions contributed to the total potato yield of 25.4 t/ha, or 17.1%. Plants develop tubers weighing 50-80 g. The content of tubers in the total crop weighing 80 g is 18.7%, and tubers weighing from 50-80 g – 81.3%, and are characterised by a more stable immunity to

diseases, the marketability of products increases by 5%. According to biometric measurements, the average weight of the Brussels sprouts head was higher in hybrids grown using organic technology and provided an increase in the indicator of relatively intensive technology by 0.1-0.6 g, depending on the hybrids under study (Table 3).

**Table 3.** Biometric indicators of Brussels sprouts

Variant	Average head weight, g	Number of heads per plant, units	Plant height, cm
Organic cultivation technology			
Franklin F <sub>1</sub> (control)	9.8	90	82
Diamant F <sub>1</sub>	9.2	87	80
Bokser F <sub>1</sub> (control)	8.9	86	75
Dolores F <sub>1</sub>	8.4	85	73
Intensive cultivation technology			
Franklin F <sub>1</sub> (control)	9.2	88	80
Diamant F <sub>1</sub>	8.7	86	76
Bokser F <sub>1</sub> (control)	8.5	86	72
Dolores F <sub>1</sub>	8.3	83	70

**Source:** compiled by the authors

The complex use of biological preparations contributed to the development of a much larger number of heads on the plant. In particular, the largest number of heads was obtained using organic technology from plants of the Franklin F<sub>1</sub> hybrid – 90 units, while with intensive technology, this hybrid on average developed 88 heads per plant. The use of biological preparations during the cultivation of Brussels sprouts ensures rapid survival of the plant in the open ground, stimulates growth processes. Fungicidal and

insecticidal preparations help to increase the plant's resistance to damage. Biological preparations, especially stimulating ones, and organo-mineral fertiliser HelpRost increase plant resistance to stress factors and improve plant nutrition. Plants of Franklin F<sub>1</sub> hybrid (control) had the highest height under organic cultivation technology, where the increment relative to intensive technology was 2 cm (Table 4). A strong correlation was found between plant height and the number of heads per plant ( $r = 0.91$ ).

**Table 4.** Yield of Brussels sprouts under various technologies in the conditions of Vinnytsia National Agrarian University

No.	Hybrids (A)	Yield, t/ha	± to control		Average for factor A	Average by factor B
			t/ha	%		
Intensive cultivation technology (B)						
1	Franklin F <sub>1</sub> (c)	8.1	-	-	-	7.4
2	Diamant F <sub>1</sub>	7.5	0.6	-7.4	7.8	
3	Boxer F <sub>1</sub> (c)	7.3	-	-	-	
4	Dolores F <sub>1</sub>	6.9	-0.4	-5.4	7.1	
Organic cultivation technology (B)						
1	Franklin F <sub>1</sub> (c)	8.8	-	-	-	7.8
2	Diamant F <sub>1</sub>	8.0	0.8	-9.0	8.4	
3	Boxer F <sub>1</sub> (c)	7.6	-	-	-	
4	Dolores F <sub>1</sub>	7.1	-0.5	-6.5	7.3	
	LSD <sub>05</sub> (A)	0.3	-			
	LSD <sub>05</sub> (B)	0.4				
	LSD <sub>05</sub> (AB)	0.7				

**Source:** compiled by the authors

The action of biological preparations contributes to the development of marketable cabbage heads. In order to obtain a high-quality

product of Brussels sprouts, there is a combination of using organo-mineral fertiliser HelpRost Vegetables with Organic Balance biological

preparation three times in the phase of development and growth of the product organ, where the yield increase is 0.4 t/ha.

The use of biologics during the growing season of Chinese cabbage plants has a positive effect on growth, development, and yield.

Biological products, especially those with a stimulating effect, and organo-mineral fertiliser HelpRost ensure plant resistance to stress factors, namely biotic, anthropogenic, climatic, and edaphic, improve product quality, and provide balanced plant nutrition (Table 5).

**Table 5.** Chinese cabbage yield, t/ha

Experiment variant	Yield, t/ha				Marketability, %
	Harvest on 15.06	± to control	Total	± to control	
Control	1.7	-	18.1	-	78
Organic Balance 0.5 l/ha, Bitoxibacillin BTU 8.0 l/ha, Lepidocide 7.0 l/ha, Lyposam 0.3 l/ha	2.7	+1.0	20.1	+2.0	87
HelpRost Vegetables 2.0 l/ha, Bitoxibacillin BTU 8.0 l/ha, Lepidocide 7.0 l/ha, Lyposam 0.3 l/ha	2.2	+0.5	19.2	+1.1	85
HelpRost Vegetables 2.0 l/ha, Organic Balance 0.5 l/ha, Bitoxibacillin BTU 8.0 l/ha, Lepidocide 7.0 l/ha, Lyposam 0.3 l/ha	3.3	+1.6	21.6	+3.5	90

Source: compiled by the authors

Organic products are becoming increasingly popular in Ukraine, and there are a number of farms that grow them. Among these farms is Organic-D enterprise. Growing carrots

with the introduction of a complex of biological preparations, a yield increase of 3.7 t/ha was obtained, and the gross yield increased by 1.9 t (Table 6).

**Table 6.** Yield of table carrots of the Olympus F<sub>1</sub> hybrid for the use of a comprehensive system of biological preparations at the Organic D farm, t/ha

Control			Experimental			Increment, t/ha
Area, ha	Gross harvest, t	Yield, t/ha	Area, ha	Gross harvest, t	Yield, t/ha	
0.5	25.4	50.9	0.5	27.3	54.6	3.7

Source: compiled by the authors

By increasing the production of organic goods, the farm in the following years also received an increase in the carrot yield due to the

introduction of biological preparations in combination with the use of high-quality high-yielding hybrids of foreign selection (Table 7).

**Table 7.** Yield of carrot hybrids using a complex system of biological preparations at the Organic D farm, t/ha

Carrot hybrids (A)	Introduction of biological preparations (B)	Yield, t/ha	± to control	
			t/ha	%
Bolivar F <sub>1</sub> (control)	without introduction of biological preparations (control)	61.4	-	-
Abaco F <sub>1</sub>	introduction of biological preparations (experiment)	60.5	-0.9	-1.5
Miroflores F <sub>1</sub>	introduction of biological preparations (experiment)	63.7	+2.3	+4
LAS <sub>05</sub> (AB)		0.9	-	

Source: compiled by the authors

Among the studied hybrids, the highest yield was provided by the Miroflores F<sub>1</sub> – 63.7 t/ha, which is 2.3 t/ha more than the control, which is 4% more. The significance of this difference is confirmed by the results of the variance analysis. Considering the biological and genetic characteristics of the Abaco F<sub>1</sub> hybrid and the use of biologics in this variant, the yield was at the level of 60.5 t/ha, which is 0.9 t/ha less

compared to the Bolivar F<sub>1</sub> hybrid. It is important when growing agricultural products, including vegetables, to obtain their high quality indicators, and the nitrate content should not exceed the permissible norm. The high content of nitrates primarily causes the use of high doses of mineral fertilisers. That is why the use of biological preparations ensures the production of products with a lower content of nitrates (Fig. 2).



**Figure 2.** Nitrate content in carrot vegetables (2021)

**Note:** a – experiment: introduction of biological preparations; b – control: without introduction of biological preparations

**Source:** photo by authors

The use of biologics during tomato cultivation ensures good survival of the plant in the open ground, increasing the total and marketable yield. Preparations of fungicidal and insecticidal action contribute to increasing the plant's

resistance to damage, and biological preparations of stimulating action and organo-mineral fertiliser HelpRost improve plant resistance, improve plant nutrition, and stimulate the development of more fruits (Table 8).

**Table 8.** Efficiency of tomato cultivation technology (Institute of Vegetable and Melon Growing of the National Academy of Agrarian Sciences of Ukraine, 2019)

Variants	Total yield t/ha	Yield of marketable products, t/ha	Marketability, %	Biochemical parameters of fruits			
				Dry soluble substance, %	Total sugar, %	Ascorbic acid, mg/100 g	Acidity, %
Reference (control)	55.8	41.3	74.0	4.05	3.42	20.55	0.55
BTU-centre system	66.8	56.7	84.9	4.32	3.85	20.68	0.55
LSD <sub>0.95</sub>	5.3	4.4		0.37	0.36	1.55	0.05

**Source:** compiled by the authors

The effect of these biologics contributes to the formation of a total 66.8 t/ha and a marketable yield of 56.7 t/ha. To obtain high-quality tomatoes, the use of organo-mineral fertiliser HelpRost Boron at a dose of 2 l/ha with

Organic Balance biological product with a dose of 0.5 l/ha and Azotofit with a dose of 0.3 l/ha during the flowering and fruiting phase of the plant improves the quality of products (Table 9).

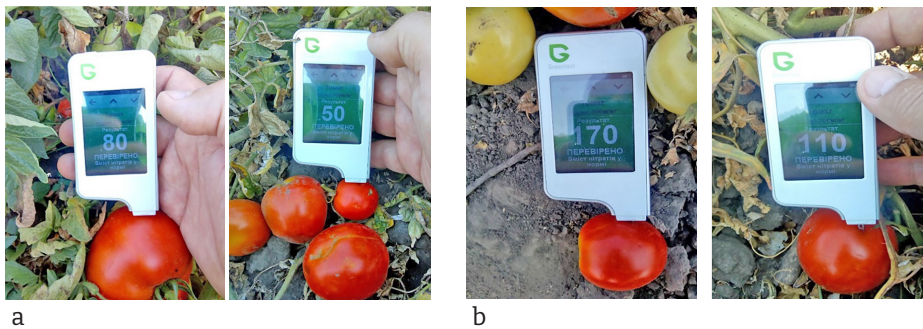
**Table 9.** Yield of tomatoes of the Asvon variety for the use of a comprehensive system of biological preparations in the conditions of Ukraine in 2020, t/ha

Control			Experimental			Increment, t/ha
Area, ha	Gross harvest, t	Yield, t/ha	Area, ha	Gross harvest, t	Yield, t/ha	
0.25	6.82	27.3	0.25	7.37	29.5	2.2

Source: compiled by the authors

The use of biological products contributes to better plant survival in the soil, provides nutrients to the plant during the growing season, increases immunity to diseases, reduces the total number of pathogens, and increases overall yields. The activity of bacteria that form the basis of biologics contributes to the development

of a typical and marketable product organ. In open ground conditions, the use of biologics increases the total yield of tomatoes by 8%, which is 29.5 t/ha. Plants are characterised by more resistant immunity to diseases, and plant productivity increases by 9%, significantly reducing the nitrate content in the fruit (Fig. 3).



**Figure 3.** Actual value of nitrate content in tomato fruits

Note: a – experimental tomato variety Asvon; b – control tomato variety Asvon Permissible rate – 300 mg/kg

Source: photo by authors

Research on biological products was also carried out at the Mykolaiv National Agrarian University (NAU), where tomatoes were grown in open ground. Biological preparations were used in the cultivation of tomatoes.

Biochemical analysis showed that the use of biological preparations contributed to an increase in the dry matter in tomato fruits by 1.03% – for the Rio Fuego variety and 1.39% – for the Missouri variety (Table 10).

**Table 10.** Dry matter content in tomato fruits depending on the use of biological preparations for organic cultivation in the conditions of the Mykolaiv NAU, %

No.	Variant	Repeatability			Average	± to control, %
		1	2	3		
Rio Fuego variety						
1	Treatment with water (control)	3.59	3.54	3.62	3.58	-
2	Introduction of biological preparations	4.52	4.71	4.61	4.61	+1.03

Table 10, Continued

No.	Variant	Repeatability			Average	± to control, %
		1	2	3		
Missouri variety						
1	Treatment with water (control)	3.04	2.83	2.97	2.95	-
2	Introduction of biological preparations	4.42	4.32	4.28	4.34	+1.39

Source: compiled by the authors

Harvest accounting showed that the applied biological products contributed to an increase in yield (Table 11). Thus, for the Rio Fuego variety, the increase was 17.7 t/ha, that is, 33.3% more than the control, and for the Missouri variety, the increase was 14.2 t/ha, which is 36.8% more compared to the variant where biologics were not introduced. In order to determine the effect on the growth, development, and yield of asparagus beans, seed material was treated with an inoculant. According to Table 12, it was found that the

biological preparation Anderiz has a positive effect on the assimilation surface, plant height, number and weight of beans, and the overall yield. The increase in leaf surface area in Laura and Purpurova asparagus bean varieties was 0.8 and 1.0 m<sup>2</sup>/ha, respectively. The height of plants increased by 1.2 cm when using the inoculant. The number and weight of beans on the plant also increased by 0.6 units/plant and 1 g/plant – in the Laura variety, as well as 0.8 units/plant and 1.4 g/plant – in the Purpurova variety.

**Table 11.** Commercial yield of tomato fruits depending on the use of biological preparations for organic cultivation in the conditions of the Mykolaiv NAU, t/ha

No.	Variant	Repeatability			Average	± to control, t/ha	± to control, %
		1	2	3			
Rio Fuego variety							
1.	Treatment with water (control)	31.4	41.3	33.4	35.4	-	-
2.	Introduction of biological preparations	55.7	58.8	46.8	53.1	+17.7	+33.3
Missouri variety							
1.	Treatment with water (control)	23.9	25.1	23.8	24.3	-	-
2.	Introduction of biological preparations	41.8	37.4	36.4	38.5	+14.2	+36.8

Source: compiled by the authors

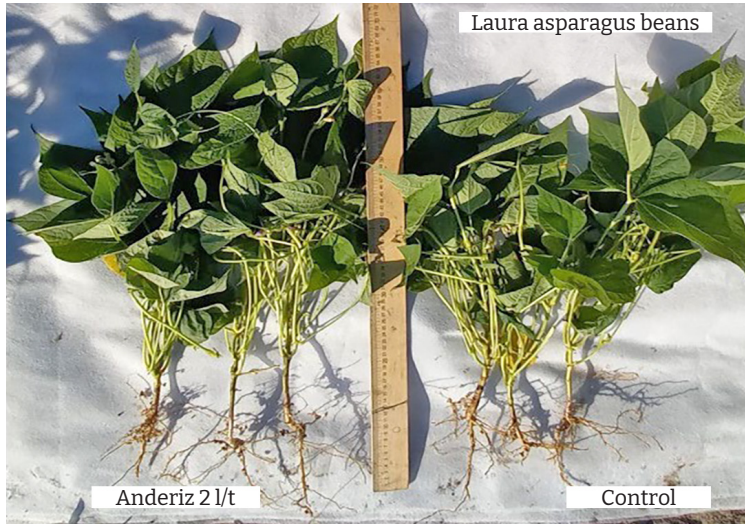
**Table 12.** Productivity of asparagus beans based on seed inoculation, 2021

Variant	Leaf area of crops, m <sup>2</sup> /ha	Plant height, cm	Number of beans per plant, units/plant	Weight of beans, g/plant	Yield of green beans, t/ha
Asparagus beans, Laura variety					
Control	25.0	38.5	16.0	40.0	8.9
Anderiz 2 l/t	25.8	39.7	16.6	41.0	9.4
Asparagus beans, Purpurova Koroleva variety					
Control	22.0	36.3	15.0	38.0	8.4
Anderiz 2 l/t	23.0	37.5	15.8	39.4	9.0

Source: compiled by the authors

The use of a nitrogen fixer significantly increases the activity of nodule bacteria, which contributes to the development of

more nodules in the main root zone, which increases the effectiveness of their action (Fig. 4).



**Figure 4.** Development of nodules on the root system of asparagus beans (2021)

**Source:** photo by authors

Seed inoculation contributed to an increase in the yield of green asparagus beans. The yield increase in the Laura and Purpurova varieties was 0.5 and 0.6 t/ha compared to the variants where seed inoculation was not carried out. A strong direct correlation was found between the number of beans per plant and yield ( $r = 0.98$ ), and a strong direct correlation between the weight of beans per plant and yield ( $r = 0.96$ ).

The introduction of advanced technologies into production does not always allow producing high-quality vegetable products. As noted by I. Koblianska *et al.* (2022), every year more and more farmers are switching to organic production, which is possible in Ukraine. According to the findings of R.V. Logosha *et al.* (2019), L. Zarina *et al.* (2021), various methods and approaches to growing vegetable plants are used in agriculture. One way to increase yields is to use better precursors, which increase the nitrogen content due to the activity of nitrogen-fixing bacteria.

According to X. Feng *et al.* (2020), the use of microorganisms in the growing process can significantly improve the yield, quality, and antioxidant enzymatic activity of tomatoes. The use of straw mulching of soil significantly increases the growth, chlorophyll content, transpiration rate, and soluble sugar content in tomatoes, and at the same time improves soil properties. In

addition, according to this study, it was found that the general condition of plants, the quality and resistance of tomatoes to diseases improves.

According to V.H. Serhienko *et al.* (2023), fusarium wilt, alternariasis, vascular and mucosal bacteriosis prevailed on various varieties of white cabbage plants. The use of biological preparations significantly reduced the development of these diseases of white cabbage, including fungal and bacterial diseases. Researchers have found that biological preparations increase resistance to diseases by 62%, and protection against bacterial diseases by 65-79%. The positive effect of biological preparations on crop indicators was revealed, which increased it by 14.5-92%. The use of biological preparations significantly improves the biometric parameters of the plant and the overall yield.

Orgamika F biological product not only reduced the damage to cabbage vegetable crops by fusarium, but also helped to improve the quality indicators of seedlings. A. Allayarov *et al.* (2021) found that soaking seeds in a biological suspension showed the best efficiency. Biological efficiency of Orgamika F for growing white cabbage with titrated suspension  $1 \times 10^4$  CFU/ml was 69.9%, and at a titer of  $1 \times 10^8$  CFU/ml was 74.7%, cauliflower – 72.2% and 75.1%, respectively, Chinese cabbage – 72.5% and 76.2%, red cabbage –

70.4% and 76.8%, and savoy cabbage – 72.4% and 77.8%, respectively.

Market research shows that the number of organic products increases every year, but their price is also increasing. In order to produce high-quality environmentally friendly vegetable products, research is being conducted on further improvement in specialised farms (Koblianska et al., 2022). I. Bender et al. (2020) showed that organic products are much better than those grown using traditional technology. Such products have smaller pesticide residues or do not accumulate them at all compared to vegetables grown using traditional technology. In addition to obtaining high-quality products, a clean environment is preserved and maintained (Mazur et al., 2020; Dydiv et al., 2023). However, the accumulation of heavy metals in vegetable products may depend on the time of sowing. Therefore, it is important to optimise the growing conditions, in combination with the biological preparations used, it can ensure maximum effectiveness. Substances of organic origin have a positive effect on increasing and maintaining soil conditions at the appropriate level, namely, the physical, chemical, and biological characteristics of the soil (Lepse et al., 2021).

Previous research by S.A. Vdovenko et al. (2018) established the influence of new strains of nodule bacteria on the development of the symbiotic apparatus of common beans (*Phaseolus vulgaris* L.). It was proved that the use of biological preparations provides an increase in interphase periods. The effect of inoculation with a complex of bacterial preparations Azotofit-L, Biomag, Biocomplex-BTU-L was investigated. The use of the bacterial preparation Biocomplex-BTU-L helped to increase the number and weight of nodules on the root system of the Zironka variety. The use of the bacterial preparation Biocomplex-BTU-L contributed to the production of 18.4 t/ha or 9.4 t/ha.

The effect of pre-sowing seed treatment with an inoculant and its combination with a plant growth stimulator on the development of symbiotic plant productivity and the accumulation of biological nitrogen in the soil was studied by I.M. Didur et al. (2019). Based on the results obtained, it was found that the use of pre-sowing treatment of alfalfa seeds with rhizobiphyte

in combination with Emistim S against the background of liming of the soil and the introduction of a full lime norm under hydrolytic acidity ensures the accumulation of the greatest amount of biologically fixed nitrogen. This average reached 236.1 hwt/ha over the years of research.

According to S.A. Vdovenko & P.A. Shvydky (2022) found that by growing sweet peppers in open field conditions under organic farming, it is possible to obtain a significant increase in plant biometric parameters. It is important to apply the recommended rates of the biological product, as an increase in these rates does not give the desired result. Adhering to optimal standards, the number of fruits on the plant and the overall yield increase. Bacterial preparations contribute to an increase in fruit weight of up to 14.5 g.

Thus, the use of bacterial-derived preparations is an impetus for economic growth and the provision of quality products to the population. Given the constant increase in demand for organic products, it becomes possible to provide the population with high-quality vegetables and preserve the environment as a whole.

## CONCLUSIONS

To provide the population with high-quality vegetable products, it is necessary to use organic technologies that can be implemented by using preparations of bacterial origin. As a result of the use of bacterial preparations, the yield of vegetable plants grown in open ground conditions significantly increased. The use of biologics ensured the total yield of potatoes at the level of 25.4 t/ha, and the marketability of potato tubers for the use of biological preparations increases by 5%; the complex use of biological preparations on Brussels sprouts formed the largest number of heads – 90 units; during the cultivation of Chinese cabbage, Organic Balance biological preparation provided an increase in yield to 3.5 t/ha and marketability of products of 90%; the use of biological preparations provided an increase in the yield of the Asvon tomato variety by 2.2 t/ha, and during the cultivation Laura and Purpurova asparagus beans, it increased by 0.5 and 0.6 t/ha. The use of biological preparations during the cultivation of winter garlic increased gross output by 5%.

Complex application of biological preparations had a positive effect on the biometric parameters of the plant, they contributed to the growth of the assimilation surface area in asparagus bean plants of Laura and Purpurova varieties by 0.8 and 1.0 m<sup>2</sup>/ha, respectively, increase the height of the plant to 37.5-39.7 cm, and the weight of beans to 39.4-41.0 g. A positive effect of biological preparations on the biochemical parameters of products was revealed, namely: they increased the dry matter in tomato fruits by 1.03% – in the Rio Fuego variety and by 1.39% – in the Missouri Variety; the nitrate content in Asvon variety decreased to 50-80 mg/kg.

The prospect of further research is to expand the understanding of the effect of biological preparations on organic cultivation of vegetable plants to optimise their use. Possible areas of research include further analysis of the effects of various biological preparations on different types of vegetables, investigation of their

impact on the quality and safety of products, and optimisation of methods and recommendations for farmers in the field of organic cultivation. The research will be aimed at the mechanisms of interaction between biological products and plants, which will help improve their effectiveness and adaptation to different growing conditions. Consideration of the environmental and economic aspects of the introduction of biological preparations is also an important aspect of further research for the development of sustainable and effective organic agricultural production practices. In the future, it is planned to investigate the effect of biological preparations on the yield and quality of vegetable plant products under greenhouse conditions.

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### CONFLICT OF INTEREST

None.

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## **Вплив біологічних препаратів на органічне вирощування овочевих рослин**

**Анотація.** Впровадження органічної технології для вирощування овочевих рослин дасть можливість зменшити екологічне навантаження пестицидами, отримати безпечну овочеву продукцію з високими показниками врожаю. Метою дослідження було вивчення впливу біологічних препаратів на органічне вирощування овочевих рослин. Для вивчення ефективної дії препаратів було використано польовий, вимірювально-ваговий, математичний та статистичний методи. Дослідження проводилося в 2018-2021 рр в різних областях України. Встановлено, що системне застосування біопрепаратів в процесі вегетації овочевих рослин забезпечує швидкий ріст і розвиток, сприяє підвищенню імунітету до захворювань, знижує діяльність патогенних мікроорганізмів у ґрунті, забезпечується збільшення загальної врожайності. Загальне застосування біопрепаратів в умовах відкритого ґрунту сприяє в отриманні загальної врожайності картоплі на рівні 25,4 т/га, а комплексне застосування біологічних препаратів на капусті брюсельській формує більшу кількість головок – 90 шт. Біопрепарат Органік баланс під час вирощування капусти пекінської забезпечує приріст урожаю до 3,5 т/га і товарність продукції 90 %. Хімічний аналіз визначив, що застосування біопрепаратів збільшує суху речовину в плодах помідора на 1,03 % – у сорту Ріо-Фуего та 1,39 % – у сорту Міссурі. Приріст, урожаю у досліджуваних сортів квасолі спаржевої Лаура та Пурпурова складає 0,5 та 0,6 т/га

порівняно з варіантами де інокуляція насіння не проводилась. Використання біологічних препаратів забезпечує отримання більшої врожайності у рослин помідора сорту Асвон на 2,2 т/га, значно знижується вміст нітратів у плодах до 50-80 мг/кг, тоді як на контролі – 110-170 мг/кг, зростає вміст сухої речовини на 1,03 та 1,39 % залежно від сорту. Валовий збір продукції часнику озимого стрілкового за використання біопрепаратів зростає на 5 %, товарність бульб картоплі зростає на 5 %. Органічні технології дозволять фермерам зменшити використання пестицидів, отримати екологічно чисту продукцію та підвищити врожайність

**Ключові слова:** біопрепарати; органічна технологія; овочеві рослини; продуктивність; якість; врожайність

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## **Effect of filter cake and bagasse ash application on selected chemical properties of acidic Nitisol**

**Abstract.** The rising cost of lime, traditionally used to address soil acidity and its detrimental effects on soil fertility, has prompted the exploration of organic by-products as more affordable alternatives for mitigating soil acidity, particularly for low-income farmers. Therefore, the objective of this study was to investigate effects of filter cake (FC) and bagasse ash (BA) application on soil acidity under greenhouse condition. The experiment was laid out in a completely randomised design with four replications. The FC and BA were investigated separately each with six levels (0, 20, 40, 60, 80, and 100) t/ha<sup>-1</sup>. The acidic soil was collected from Imbibir area at a depth of 0-20 cm, air dried, ground and passed through 4 mm sieve. Each pot was received 4 kg of soil with respective treatment material after they were well homogenised. The laboratory analysis revealed that the soil had an initial pH of 5.1, while filter cake and bagasse ash had pH values of 8.0 and 10.2, respectively. Application of FC increased soil pH from 5.1 to 7.3, along with improvements in organic matter, nitrogen, phosphorus, sulphur, potassium, calcium, magnesium, and cation exchange capacity. Similarly, BA application raised pH from 5.1 to 7.4 and enhanced organic matter, nitrogen, phosphorus, sulphur, potassium, calcium, magnesium, and cation exchange capacity. The maximum effects for both FC and BA occurred at the highest application rate (100 t/ha<sup>-1</sup>), while iron and manganese content increased with BA application but decreased as rates increased, and copper and zinc levels were positively affected by both FC and BA applications. Overall, both FC and BA applications significantly improved soil pH and nutrient content. The findings of this study can provide practical and cost-effective solutions for improving soil fertility and crop production

**Keywords:** Imbibir; leaching; fixation; basic cations; acid forming cations; exchangeable acidity

### **INTRODUCTION**

Soil acidity is a significant factor limiting agricultural productivity in highland regions of Ethiopia. Excessively acidic soil hinders the availability of essential macro and micronutrients

such as nitrogen, phosphorus, potassium, and iron, leading to reduced crop yields and lower quality agricultural produce. Farmers often have limited resources and may not afford expensive

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lime to address this issue. Therefore, the search for more affordable and environmentally friendly methods of soil acidity correction, including the use of organic materials, becomes an urgent task to support sustainable agricultural development in Ethiopia's highland regions.

M.T. Ejersa (2021) noted that in Ethiopia, 43% of arable lands have been affected by soil acidity. The western, southern, northwestern and central highlands of the country are the areas where soil acidity becoming a serious threat to crop production. Imdibir, the site from where the experimental soil was collected, is located in central highlands that affected with soil acidity. The leaching of basic cations (Ca, Mg, and K) and replacing by acid forming cations ( $\text{Al}^{3+}$  and  $\text{H}^+$ ) due to heavy rainfall, excessive application of  $\text{H}^+$  releasing inorganic fertilisers and removal of basic cations during harvesting of the crops are the main causes of soil acidity in the study area. R. Hume *et al.* (2022) noted that the excessive application of urea ( $\text{NH}_2\text{-CO-NH}_2$ ) and ammonium ( $\text{NH}_4^+$ ) containing fertilisers contributes protons ( $\text{H}^+$  ions) supply during the nitrification of  $\text{NH}_4^+$  to nitrate ( $\text{NO}_3^-$ ). The release of  $\text{H}^+$  into the soil solution reduces the pH of the soil. P.M. Kopittke *et al.* (2019) concluded that a small decrease in soil pH decreases the availability of soil nutrients (P, K, Ca, and Mg), affects the soil structure, functioning of microbial communities, nitrogen fixation by soil microbes, and sustainability of crop production. The level of available phosphorus in acidic soils is also low. The reason for low availability of phosphorus in acidic soil is owing to fixation of dissolved phosphorus by aluminium and iron. This condition can be minimised by organic amendments (Mutammimah *et al.*, 2020). In Ethiopia, liming has been practicing improving soil pH and nutrient availability in acid affected soil. However, the high price of agricultural lime has been challenging the low income (poor) farmers. For that reason, the researchers and farmers are shifting their idea to organic amendment of acidic soils. According to D. Alabi *et al.* (2022), N. Xu *et al.* (2022), organic fertiliser is cheap, affordable and reduces the cost of using inorganic fertiliser. Furthermore, the addition of agricultural by-products to mineral soils has the potential to improve crop production. That is why this study

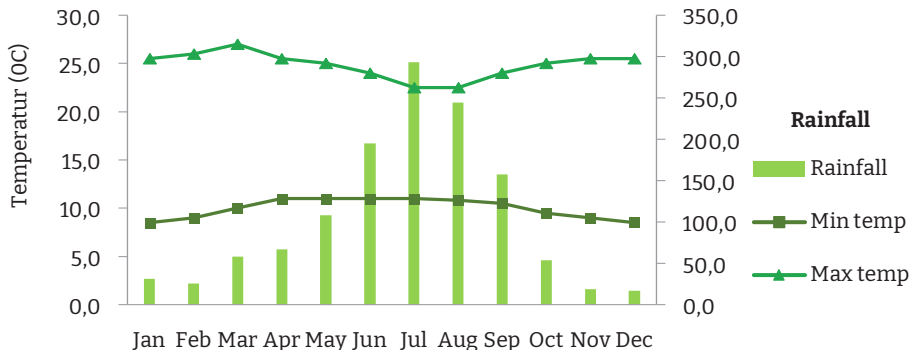
was focused on filter cake (FC) and bagasse ash (BA) application for soil acidity amendment. A. Soltangheisi *et al.* (2019) determined that both FC and BA are sugar industry by-products. FC is a waste by-product from the process of sugar clarification, composed of a mixture of ground sediment and crushed sludge. FC increases soil fertility by providing nitrogen and phosphorous for crops or soil cover. Due to its chemical nature, FC can increase the organic matter content of the soil. Bagasse ash (BA) is also a sugar industry by-product obtained from combustion of bagasse that is used for steam/energy generation. These industrial by-products improve soil properties and crop yields. Replacing chemical fertilisation with these organic by-products not only minimises the surplus usage of chemical fertilisers, Replacing chemical fertilisation with these organic by-products not only minimises the surplus usage of chemical fertilisers, but also a cost-effective and an eco-friendly approach (Raza *et al.*, 2021). These sugar industry by-products (FC and BA) contain micronutrients and macronutrients (Ca, Mg, P, and K) (Hale *et al.*, 2020). Soil application of FC can provide nutrients and enhance physical quality. FC provides nutrients suitable for plant development, and the levels of available P. A. Gonfa *et al.* (2018) and F. Silva *et al.* (2019) noted that FC keeps available P at agronomically adequate levels by improving soil pH. BA application is also recognised as a potential fertiliser as it contains P and K. Nevertheless, it is often disposed of as waste in landfills. However, many reports have been presented by different researchers as both FC and BA have capacity of amending soil chemical properties. However, there was no exhaustive investigation report of FC and BA on acidic Nitisol. Therefore, the purpose of this study was to investigate the effect of FC and BA application on chemical properties amendment of acidic Nitisol.

## MATERIALS AND METHODS

*Description of the study site.* The pot experiment was conducted in 2021 at Debre Zeit Agricultural Research Centre (DZARC) under controlled environment condition. The experimental soil was acidic Nitisol and collected from Imdibir area. Imdibir is located in Cheha District, Gura Zone, which is 188 km from the capital

city, Addis Ababa. Imdibir is geographically located to south of the capital city, between 8°7'-8.117°N and 37°56'-37.933°E. The altitude of Imdibir ranges between 2,130-2,164 m.a.s.l. The average annual rainfall in the Imdibiru area is

1,268 mm, based on the ten years monthly data (2001-2010) of the area. The average maximum and minimum temperature for the last ten years (2001-2010) were 24.64°C and 10.29°C, respectively (Fig. 1).



**Figure 1.** Average ten years monthly precipitation and temperatures of Imdibir area (2001-2010)  
**Source:** District Agricultural Office (n.d.)

*Collection of experimental soil.* The representative experimental soil was collected for pot experiment from 20 farms. Acid affected soil was selected purposely from the study area to investigate effects of filter cake (FC) and bagasse ash (BA) application in amending soil acidity. The soil was taken at the depth 0-20 cm from each field using sampling system. Ten (10) kg of soil was taken per field. To prepare for pot experiment, all soils that collected separately were composited, well mixed, air dried, ground with mortar and pestle and passed through 4 mm size. One kg of soil sample was taken from homogenised experimental soil, reground, passed through 0.5 and 2 mm sieve and used for laboratory analysis.

*Treatment materials.* Filter cake (FC) and bagasse ash (BA) were collected from government sugar estate factory. The FC and BA were selected for two reasons: 1) they were locally available in many sugar factories; 2) they were expected to have a high nutrient content and the potential to change soil acidity.

*Experimental design and treatment set-up.* The pot experiment was conducted at Debre Zeit Agricultural Research Centre (DZARC) under greenhouse condition. The experimental design was completely randomised design (CRD). Filter cake (FC) was air dried, grounded, and weighed according to the treatment levels. The

bagasse ash (BA) was also weighed according to the treatment levels. The levels (rates) of filter cake and bagasse ash were 0, 20, 40, 60, 80, and 100 t/ha<sup>-1</sup>. Each treatment was replicated quartile (four times). The rates of FC were based on that of E.M. Ossom *et al.* (2010) and of BA on that of T. Ferreira *et al.* (2012). Each pot was labelled (tagged) with treatment rate and material that it received. Four (4) kg of experimental soil and known amount of treatment material were well homogenised and transferred to the pot that had been tagged. Each pot was received equal amount of water before sowing and left without receiving seed for one day. In the next day, each pot was received 10 seeds of durum wheat. Each pot was receiving 100 ml of water within three days interval. The seedlings were thinned to seven after they reached 7 cm to minimise the competition for nutrients. Ultimately, the wheat that received BA application has matured earlier than that received FC application. The time variation in maturity may be conditioned by time to taken for FC to be mineralised and being available to the plant.

*Analysis of chemical properties of selected soil and treatment materials.* The chemical properties of the soil and treatment materials were analysed using standard analytical laboratory procedures. The pH of the soil and treatment

materials was analysed potentiometrically with 1:2.5 soil to water ratio. Electrical conductivity (EC) was measured using digital conductometer and the supernatant used for pH reading. Exchangeable acidity ( $H^+ + A^{3+}$ ) was determined by percolating the soil with 1M KCl solution. The acidity brought into soil solution from various sources was measured by titration in the presence of standardised 0.02M HCl and 0.02M NaOH using phenolphthalein indicator.

Organic carbon (OC) was determined by Walkley-Black wet oxidation method and the obtained results were converted to organic matter (OM) using the conversion factor 1.724. Total nitrogen (TN) was determined by Kjeldahl macro digestion method using sulphuric acid and mixed catalysts to convert organic nitrogenous to ammonium sulphate. Soil phosphorus (P) was analysed spectrophotometrically using Bray-II method for soil before planting and Olsen method for soil that affected with treatment materials based on their pH. Sulphur (S) was determined turbidimetrically using barium chloride to precipitate  $SO_4^{2-}$ -S in the form of barium sulphate ( $BaSO_4$ ). The turbidity was measured using spectrophotometer. Exchangeable bases were determined by ammonium acetate method which

adjusted to pH 7.0. The reading was performed using atomic absorption spectrophotometer (AAS), AA series model. Cation exchangeable capacity (CEC) was determined, using 10% sodium chloride as extractant solution after the residue of ammonium salt have been washed with 97% ethanol alcohol. The distillation was conducted using Kjeldahl distillation unit and the quantification was made by titration method. Soil micronutrients were determined using diethylenetriaminepentaacetic acid (DTPA) as extracting solution and reading was conducted using atomic absorption spectroscopy (AAS), AA series model. Correlations among the treatment rates and different variables were computed using Pearson's correlation analysis.

*Statistical analysis and data interpretation.* All data generated from the soil affected by FC and BA application were subjected to statistical analysis using (SAS version 9.0). Significant difference among treatments means was assessed using the least significant difference (LSD) test at 0.05 probability level.

*Analytical results of soil and treatment materials before planting.* The experimental soil and treatment materials were analysed before sowing and the results are presented below (Table 1).

**Table 1.** Chemical properties of soil, filter cake and bagasse ash

Chemical parameter	Soil before sowing	Filter cake (FC)	Bagasse ash (BA)
pH-H <sub>2</sub> O	5.1	8.0	10.2
EC (dS/m)	0.01	1.70	3.90
OM (%)	3.38	36.20	3.60
N (%)	0.16	1.77	0.17
Avail P (%)	0.0010	1.62	0.85
Avail S (%)	0.0035	1.67	1.29
Exch Na (cmol(+)/kg)	0.25	4.02	1.82
Exch K (cmol(+)/kg)	1.89	4.04	1.41
Exch Ca (cmol(+)/kg)	5.04	65.00	13.18
Exch Mg (cmol(+)/kg)	2.80	26.00	5.84
Exch.Al+H (Meq/100gsoil)	0.54	-	-
Fe (mg/kg)	44.0	3.00	3.00
Mn (mg/kg)	154	39.00	19.00
Cu (mg/kg)	0.56	1.24	0.40
Zn (mg/kg)	2.40	31.00	10.50

**Source:** developed by the author

The EC of the soil before sowing was low. The reason for low EC may be due to leaching of cations and anions by heavy rain of the

study area. The organic matter (OM) content of the soil before sowing was moderate according to G. Getachew & T. Mamo (2019). However, the

nitrogen content of the soil before sowing was found being low (Landon, 1991). The reason may be due to leaching of nitrogen that changed into inorganic N form. The available P content of the soil was determined using Bray-II method as the soil was strongly acidic before sowing and the results was found being medium and the value was found being 0.001% (10 mg/kg<sup>-1</sup>).

The available sulphur was determined by turbidimetry and the result was found being 0.0035% (35.2 mg/kg<sup>-1</sup>) for soil before sowing. The exchangeable Na, K, Ca, and Mg content of the soil before sowing were found low, very high, very high, and medium, respectively (FAO, 2006) (Table 1). The exchangeable acidity was found being 0.54 meq/100 g soil. The micronutrients were also analysed for experimental soil before planting (Table 1). According to B. Jones (2003), the soil Fe, Mn, Cu, and Zn content are rated as high, very high, low, and high, respectively. The high micronutrients content of this soil shows that the soil was strongly acidic. This may be due to high leaching of basic cations with heavy rainfall.

The experimental materials (filter cake (FC) and bagasse ash (BA)) were analysed to determine their nutrient content. The data revealed that the pH of FC and BA were 8.0 and 10.2, respectively. The FC contained 36.2% OM, 1.77%

N, 1.62% P, and 1.67% sulphur. The BA contained 0.85 % P and 1.29% SO<sub>4</sub><sup>-2</sup>-S before sowing.

The content of Na, K, Ca, and Mg in FC were 4.02, 4.04, 65, and 26 cmol(+) kg<sup>-1</sup>, respectively (Table 1). Soil CEC, sum of bases (S) and base saturation ratio (V) were significantly improved with increasing rates of filter cake. This coincided with the finding of the Fe, Mn, Cu, and Zn content of the FC of 3, 39, 1.24, and 31 cmol(+)kg<sup>-1</sup>, respectively. BA contained 3.6% OM, 0.17% N, 0.85% P, and 1.29% sulphur. The exchangeable base of BA were 1.84, 1.41, 13.81, and 5.84 cmol(+) kg<sup>-1</sup> for Na, K, Ca, and Mg, respectively while the Fe, Mn, Cu, and Zn contents were 3, 19, 0.40, and 10.5 mg/kg, respectively. The results show that FC contained relatively more nutrients compared to BA.

## RESULTS AND DISCUSSION

### *Chemical properties of soil as affected by filter cake (FC) and bagasse ash (BA) application*

The soil was also analysed after affected with FC and BA rates application to assess the impact of FC and BA on soil chemical properties. The ANOVA showed that the pH of the soil was significantly affected (P<0.0001) by FC and BA rates application. The pH was increased with increasing rates of FC and BA application (Table 2, 3).

**Table 2.** Analytical results of the soil as affected by FC application

FC (kg ha <sup>-1</sup> )	pH-H <sub>2</sub> O (1.:2.5)	EC (dS/m)	OM (%)	N (%)	Ava.P (mg/kg)	Ava.S (mg/kg)
0	5.1 <sup>e</sup>	0.01 <sup>e</sup>	3.5 <sup>f</sup>	0.14 <sup>e</sup>	10.0 <sup>f</sup>	35.2 <sup>f</sup>
20	6.2 <sup>d</sup>	0.25 <sup>d</sup>	3.8 <sup>e</sup>	0.18 <sup>d</sup>	42.0 <sup>e</sup>	76.5 <sup>e</sup>
40	6.5 <sup>c</sup>	0.30 <sup>c</sup>	4.2 <sup>d</sup>	0.20 <sup>c</sup>	97.5 <sup>d</sup>	119.4 <sup>d</sup>
60	6.9 <sup>b</sup>	0.54 <sup>b</sup>	4.8 <sup>c</sup>	0.21 <sup>b</sup>	139.8 <sup>c</sup>	156.5 <sup>c</sup>
80	7.0 <sup>b</sup>	0.54 <sup>b</sup>	5.1 <sup>b</sup>	0.22 <sup>b</sup>	185.8 <sup>b</sup>	266.5 <sup>b</sup>
100	7.3 <sup>a</sup>	0.63 <sup>a</sup>	5.4 <sup>a</sup>	0.26 <sup>a</sup>	224.5 <sup>a</sup>	389.4 <sup>a</sup>
LSD (5%)	0.20	0.03	0.11	0.01	5.71	0.156
CV (%)	2.14	4.13	1.64	3.75	3.28	0.059

**Note:** values with the same letters within a column are not significantly different at  $\alpha = 0.05$

**Source:** developed by the author

**Table 3.** Analytical results of soil as affected by BA application

Ba (kg ha <sup>-1</sup> )	pH-H <sub>2</sub> O (1.:2.5)	EC (dS/m)	OM (%)	N (%)	Ava.P (mg/kg)	Ava.S (mg/kg)
0	5.1 <sup>d</sup>	0.01 <sup>e</sup>	3.5 <sup>c</sup>	0.14 <sup>c</sup>	10.0 <sup>f</sup>	35.2 <sup>e</sup>
20	6.8 <sup>c</sup>	0.21 <sup>e</sup>	3.6 <sup>b</sup>	0.15 <sup>b</sup>	14.4 <sup>e</sup>	55.8 <sup>d</sup>
40	6.9 <sup>cb</sup>	0.24 <sup>d</sup>	3.8 <sup>a</sup>	0.16 <sup>b</sup>	19.9 <sup>d</sup>	65.3 <sup>c</sup>
60	7.0 <sup>b</sup>	0.30 <sup>c</sup>	3.8 <sup>a</sup>	0.17 <sup>b</sup>	40.2 <sup>c</sup>	76.6 <sup>b</sup>
80	7.1 <sup>b</sup>	0.34 <sup>b</sup>	3.8 <sup>a</sup>	0.17 <sup>b</sup>	55.0 <sup>b</sup>	77.3 <sup>b</sup>

Table 3, Continued

Ba (kg ha <sup>-1</sup> )	pH-H <sub>2</sub> O (1.:2.5)	EC (dS/m)	OM (%)	N (%)	Ava.P (mg/kg)	Ava.S (mg/kg)
100	7.4 <sup>a</sup>	0.38 <sup>a</sup>	3.8 <sup>a</sup>	0.18 <sup>a</sup>	57.7 <sup>a</sup>	104.9 <sup>a</sup>
LSD (5%)	0.19	0.02	0.06	0.01	1.61	3.40
CV (%)	1.81	3.21	2.46	4.56	3.96	3.42

**Note:** values with the same letters within a column are not significantly different at  $\alpha=0.05$

**Source:** developed by the author

In general, except for control, the soil pH fell in the range of slightly acidic to slightly alkaline for FC application and neutral to slightly alkaline for BA application (Table 2, 3). The reason for soil pH increment may be due to the presence of basic cations (Ca and Mg) in the form of carbonates within the FC and BA. The finding was in line with that reported by T. Matsi & V.Z. Keramidas (1999) that changes in pH values strongly dependent on ash application rates. The finding also corroborates with A. Demeyer *et al.* (2001) that the increase of pH in acidic soil is conditioned by high alkalinity of BA. Application of FC and BA also highly significantly affected ( $P<0.001$ ) soil EC, OM, N, Ava.P and Ava.S (Table 2, 3). The maximum and the minimum value were recorded at 100 t/ha<sup>-1</sup> and control treatment both for FC and BA application (Table 2, 3). The EC of the soil was low before FC and BA application. However, the EC of the soil found being increased after the soil affected with FC and BA application. The reason may be due to the availability of free cations and anions in the treatment materials. The soil treated with FC showed the dominance over the same soil treated with BA application in EC. The reason might be due to high Ca and Mg content in the FC. S. Ghulam *et al.* (2010) also reported that FC has capacity to increase the EC of the soil. In general, both FC and BA applications significantly increased the EC of the experimental soil over the control treatment.

The OM content of the soil was highly significantly ( $P<0.0001$ ) increased over control with increasing rates of FC and BA applications (Table 2, 3) and the lowest and the highest values were recorded at control and 100 t/ha<sup>-1</sup> for both treatment variants. However, FC application increased the soil OM content more than BA applications. Naturally, FC is rich in organic matter content when compared with BA. This may be due to removal of OM from BA during ashing process. Similarly, the N content of the soil was highly significantly ( $P<0.0001$ ) affected with FC

and BA application (Table 2, 3). The maximum and minimum values were recorded at 100 t/ha<sup>-1</sup> and control treatment for both materials. The same to OM, the maximum soil N content, was recorded by the soil that affected with FC application when compared with soil that affected with BA application. This may be due to high N content in FC when compared with that of BA. According to J.R. Landon (1991) the maximum value of N content for soil that affected with FC application was in the range of moderate and in the range of low for soil affected with BA application. The reason is that during burning and/or ashing of bagasse, N escapes in the form of gas. However, both treatment materials increased the soil N content progressively. When comparing the two by-products, the FC application increased soil N content over BA application with respective to their rates. S. Ghulam *et al.* (2010) also reported that application of FC increased the soil N content progressively as the rates of application increased.

The soil available P and S content were highly significantly affected ( $P<0.0001$ ) with FC and BA application. The increment was gone progressively and /or according to their rates for both nutrients. Accordingly, the maximum and minimum results were recorded at 100 t/ha<sup>-1</sup> and at control for both treatment materials (Table 2, 3). According to B. Jones (2003) the maximum values of P that recorded with soil that affected with FC and BA application are categorised in the rate/range of very high and the minimum value that recorded at control in the range of low. J.M. Khan (2011) reported that both treatment materials (FC and BA) application increased the P content of the soil. The findings also coincide with that of E. Ferreira *et al.* (2012) that application of BA increased soil P content. The reason for soil available P increment may be due to incorporation of P through FC and BA application, and due to soil pH increment. The improvement of soil pH

improves the release of P from fixed form to available form. Application of FC and BA was also improved the sulphur content of the experimental soil (Table 2, 3). However, according to D.A. Horneck *et al.* (2011), the experimental soil was high in available S content before it was receiving the treatment materials.

The basic cations of the soil were also subjected to laboratory analysis using neutral ammonium acetate (PH=7.0) as extracting solution.

The ANOVA showed that both FC and BA application highly significantly affected ( $P<0.0001$ ) the basic cations, CEC and BS of the experimental soil (Table 4, 5).

**Table 4.** Analytical results of soil exchangeable basic cations as affected by FC application

FC (t/ha <sup>-1</sup> )	Na cmol <sup>(+)</sup> /kg	K cmol <sup>(+)</sup> /kg	Ca cmol <sup>(+)</sup> /kg	Mg cmol <sup>(+)</sup> /kg	CEC cmol <sup>(+)</sup> /kg	BS (%)
0	0.22 <sup>e</sup>	1.40 <sup>d</sup>	4.9 <sup>f</sup>	3.5 <sup>f</sup>	22.8 <sup>f</sup>	43.8 <sup>e</sup>
20	0.46 <sup>d</sup>	2.28 <sup>c</sup>	14.1 <sup>e</sup>	4.8 <sup>e</sup>	30.8 <sup>e</sup>	71.0 <sup>d</sup>
40	0.46 <sup>d</sup>	2.28 <sup>c</sup>	16.6 <sup>d</sup>	5.9 <sup>d</sup>	31.8 <sup>d</sup>	79.6 <sup>c</sup>
60	0.67 <sup>c</sup>	2.88 <sup>b</sup>	18.4 <sup>c</sup>	6.3 <sup>c</sup>	32.8 <sup>c</sup>	86.0 <sup>b</sup>
80	0.93 <sup>b</sup>	2.93 <sup>a</sup>	21.9 <sup>b</sup>	7.8 <sup>b</sup>	34.8 <sup>b</sup>	96.6 <sup>a</sup>
100	1.11 <sup>a</sup>	2.93 <sup>a</sup>	22.9 <sup>a</sup>	8.9 <sup>a</sup>	36.5 <sup>a</sup>	98.0 <sup>a</sup>
Mean	0.64	2.45	16.45	6.03	31.54	79.12
LSD (5%)	0.07	0.14	0.54	0.05	0.74	8.77
CV (%)	7.15	1.14	2.19	0.59	1.56	7.59

**Note:** values with the same letters within a column are not significantly different at  $\alpha=5\%$

**Source:** developed by the author

**Table 5.** Analytical results of soil as affected by BA application

BA(t/ha)	Na cmol <sup>(+)</sup> /kg	K cmol <sup>(+)</sup> /kg	Ca cmol <sup>(+)</sup> /kg	Mg cmol <sup>(+)</sup> /kg	CEC cmol <sup>(+)</sup> /kg	BS (%)
0	0.22 <sup>e</sup>	1.4 <sup>f</sup>	4.9 <sup>f</sup>	3.5 <sup>f</sup>	22.8 <sup>e</sup>	43.8 <sup>f</sup>
20	1.1 <sup>d</sup>	2.2 <sup>e</sup>	8.4 <sup>e</sup>	5.6 <sup>e</sup>	28.1 <sup>d</sup>	61.4 <sup>e</sup>
40	1.2 <sup>d</sup>	2.6 <sup>d</sup>	9.6 <sup>d</sup>	6.5 <sup>d</sup>	28.1 <sup>d</sup>	70.9 <sup>d</sup>
60	1.5 <sup>c</sup>	3.5 <sup>c</sup>	9.8 <sup>c</sup>	8.8 <sup>c</sup>	29.1 <sup>c</sup>	78.9 <sup>c</sup>
80	2.1 <sup>b</sup>	3.9 <sup>b</sup>	12.2 <sup>b</sup>	9.1 <sup>b</sup>	31.1 <sup>b</sup>	87.8 <sup>b</sup>
100	2.3 <sup>a</sup>	4.2 <sup>a</sup>	13.1 <sup>a</sup>	9.5 <sup>a</sup>	32.0 <sup>a</sup>	91.4 <sup>a</sup>
Mean	1.52	3.30	9.51	7.54	28.92	72.50
LSD (5%)	0.05	0.13	1.13	0.15	0.62	2.55
CV (%)	2.20	2.57	0.88	1.33	1.41	2.33

**Note:** values with the same letters are not significantly different at  $\alpha=5\%$

**Source:** developed by the author

The highest values were recorded at maximum rates of FC and BA application and the minimum at control for all basic cations, CEC and base saturation (Table 4, 5). The maximum K results were recorded at maximum rate of FC and BA application with values of 2.93 and 4.20 cmol(+)/kg, respectively. The application of both treatment materials progressively increased the K content in experimental soil. S. Ghulam *et al.* (2010) also reported that filter cake application progressively increased the soil K content. The minimum soil K content was recorded at control with value 1.40 cmol (+)/kg. According to FAO (2006) both maximum and

minimum value of K are categorised under very high rate. The same to K the highest Ca content was recorded at the highest rate of FC and BA application with values 22.9 and 13.5 cmol(+)/kg, respectively. Accordingly, the maximum Ca value obtained from the soil that received the maximum application of FC is in the range of very high values, and the maximum value obtained from the soil that received the maximum application of BA is in the range of high values. The maximum Mg content of the soil that affected with FC and BA application was recorded at maximum rate of FC and BA application with values 8.9 and 9.5 cmol(+)/kg, respectively

(Table 4, 5). These values are rated as high and very high for FC and BA application, respectively. The results revealed that BA application was more affected the soil Mg content when compared to FC application. In general, application of FC was increased soil Ca content over the soil that received BA application and BA increased K and Mg content over the soil that received FC rates application. The reason for high Ca content in the soil that affected with FC application may be due to the existence of substantial amounts of  $\text{CaCO}_3$  in the FC.  $\text{CaCO}_3$  used to increase soil pH and soil calcium content. However, both treatment materials had increased exchangeable basic cations of the experimental soil. J.M. Khan (2011) and E. Ferreira *et al.* (2012) also reported that both FC and BA application rates increased the basic cations content of the soil. The reason may be conditioned by incorporation of cations through FC and BA application and increment of soil pH which has contribution for nutrient release and availability. This indicates that nutrients are released and available at their optimum pH ranges. S.E. Hale *et al.* (2020) also reported that application of ash at the rates 3 to 5 t/ha<sup>-1</sup> decreased soil acidity, increased base saturation and the total amount of nutrients.

The CEC of the experimental soil was highly significantly ( $P < 0.0001$ ) affected with FC and BA application. The CEC of the soil was increased progressively with increasing rates of FC and BA application (Table 4, 5). The minimum CEC was recorded at control and the maximum at maximum rate (100 t/ha<sup>-1</sup>) of FC and BA application, and the values were 22.8, 36.5, and 32.0 cmol(+)/kg<sup>-1</sup>, respectively (Table 4, 5). In general, all treatments that received FC and BA application had recorded the CEC values that fell in the range of high rate. The CEC value that recorded at control treatment was found fell

in the range of medium. The reason for increment of soil CEC by FC over that of BA was due to high OM and Ca content of FC. M.S. Mokolobate & R.J. Haynes (2002) reported that application of FC has improved the CEC of the soil. BA also increased the CEC of the soil because of its high cations contents and pH.

Base saturation (BS (%)) of the experimental soil was significantly ( $P < 0.0001$ ) affected with FC and BA application. The lowest value was recorded at control and the highest at the maximum rates (100 t/ha<sup>-1</sup>) of FC and BA application (Table 4, 5) and the results were 43.8, 98.0, and 91.4 cmol(+)/kg. According to P. Hazelton & B. Murphy (2007) the maximum values recorded at 100 t/ha<sup>-1</sup> of FC and BA application are rated as very high and the minimum as moderate. The finding corresponds to that of S. Ghulam *et al.* (2010) that FC application rates improved the chemical properties of the experimental acidic Nitisol. The finding are also in agreement with that of E. Ferreira *et al.* (2012) that BA applications improved soil base saturation as it contained good amount of basic cations. Hence, FC and BA application can be potentially improve soil fertility by increasing basic cations, of the soil. As a whole, the organic inputs had shown their potential of neutralising acidic Nitisol, improved basic cations and base saturation. This is a great advantage for farmers who cannot afford the inorganic compounds used as lime material.

Exchangeable acidity and micronutrients are other soil chemical parameters that were subjected to laboratory analysis during this study. The results are presented in the (Table 6, 7). The ANOVA showed that soil exchangeable acidity ( $\text{H}^+ + \text{Al}^{3+}$ ) highly significantly ( $P < 0.0001$ ) affected with FC and BA application. The maximum value was recorded at control and the minimum at 100 t/ha<sup>-1</sup> FC and BA application (Table 6, 7).

**Table 6.** Analytical results of soil acidity and micronutrients as affected by FC application

FC rates (t/ha <sup>-1</sup> )	Ex. Acidity meq/100 g soil	Fe mg/kg	Mn mg/kg	Cu mg/kg	Zn mg/kg
0	0.54 <sup>a</sup>	16.1 <sup>f</sup>	66.1 <sup>f</sup>	0.54 <sup>e</sup>	7.8 <sup>f</sup>
20	0.42 <sup>b</sup>	22.3 <sup>e</sup>	89.0 <sup>e</sup>	1.9 <sup>d</sup>	11.9 <sup>e</sup>
40	0.30 <sup>c</sup>	24.6 <sup>d</sup>	102.8 <sup>d</sup>	2.1 <sup>c</sup>	16.5 <sup>d</sup>
60	0.19 <sup>d</sup>	26.5 <sup>c</sup>	116.0 <sup>c</sup>	2.2 <sup>b</sup>	18.1 <sup>c</sup>
80	0.14 <sup>e</sup>	29.1 <sup>b</sup>	140.8 <sup>b</sup>	2.5 <sup>a</sup>	22.0 <sup>b</sup>

Table 6, Continued

FC rates (t/ha <sup>-1</sup> )	Ex. Acidity meq/100g soil	Fe mg/kg	Mn mg/kg	Cu mg/kg	Zn mg/kg
100	0.06 <sup>f</sup>	31.3 <sup>a</sup>	149.6 <sup>a</sup>	2.5 <sup>a</sup>	24.4 <sup>a</sup>
Mean	0.27	24.9	115.11	2.14	16.80
LSD (5%)	0.01	0.80	2.37	0.06	0.39
CV(%)	2.60	2.29	1.35	1.96	1.52

**Note:** values with the same letters within a column are not significantly different

**Source:** developed by the author

**Table 7.** Analytical results of soil sample as affected by BA application

BA rates (t/ha <sup>-1</sup> )	Ex. Acidity meq/100g soil	Fe mg/kg	Mn mg/kg	Cu mg/kg	Zn mg/kg
0	0.54 <sup>a</sup>	16.1 <sup>d</sup>	66.1 <sup>d</sup>	0.54 <sup>f</sup>	7.8 <sup>d</sup>
20	0.42 <sup>b</sup>	25.2 <sup>a</sup>	75.2 <sup>a</sup>	1.60 <sup>a</sup>	16.2 <sup>c</sup>
40	0.28 <sup>c</sup>	20.4 <sup>b</sup>	72.0 <sup>b</sup>	1.50 <sup>b</sup>	16.5 <sup>c</sup>
60	0.20 <sup>d</sup>	16.7 <sup>c</sup>	60.5 <sup>d</sup>	1.40 <sup>c</sup>	17.5 <sup>b</sup>
80	0.12 <sup>e</sup>	10.4 <sup>e</sup>	54.0 <sup>e</sup>	1.30 <sup>d</sup>	18.1 <sup>a</sup>
100	0.04 <sup>f</sup>	4.4 <sup>f</sup>	43.8 <sup>f</sup>	1.20 <sup>e</sup>	18.5 <sup>a</sup>
Mean	0.27	15.52	62.67	1.41	15.77
LSD (5%)	0.01	0.61	0.80	0.01	0.49
CV (%)	2.72	2.60	0.87	0.55	2.06

**Note:** values with the same letters within a column are not significantly different

**Source:** developed by the author

The results were 0.54, 0.06, and 0.04 cmol(+)/kg<sup>-1</sup> for control, and 100 t/ha<sup>-1</sup> of FC and BA application, respectively (Table 6, 7). B.M. Dee *et al.* (2002) reported that both FC and BA application significantly reduced the concentration of exchangeable acidity of the soil. The reason may be due to soil pH and basic cations improvement with FC and BA application. The presence of Ca in the FC and BA can precipitate Al in the form of Al(OH)<sub>3</sub> and decrease its availability and/or solubility in the soil solution.

Filter cake (FC) and BA application affected the soil micronutrients differently and partly differently. Application of FC affected soil micronutrients highly significantly ( $P < 0.0001$ ) and positively (Table 6). The results gradually increased based on the increasing rates of FC applications. The lowest values of micronutrients were recorded at control and the highest – at maximum rate (100 t/ha<sup>-1</sup>) of FC application. The values for were 16.1, 66.1, 0.54, and 7.8 mg/kg<sup>-1</sup> for minimum results and 31.1, 149.6, 2.6, and 24.4 mg/kg<sup>-1</sup> for maximum Fe, Mn, Cu and Zn content, respectively. According to B. Jones (2003), Fe and Zn fell in the range of high and Mn in the range of high to very high categories for FC applications. On

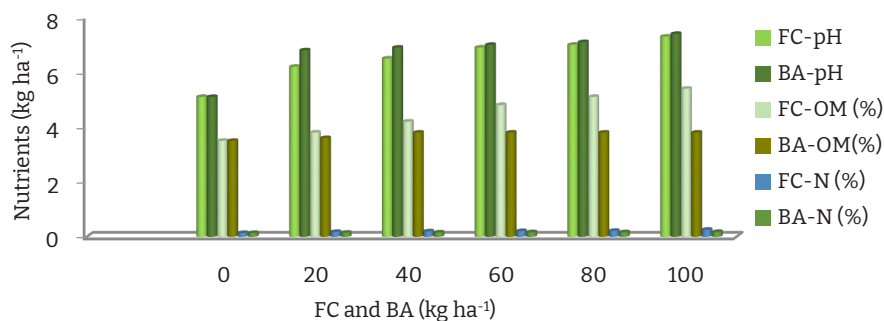
the other hand, all results of Cu fell in the range of low for soil affected with FC applications even if the results were going increasing based on the rates of FC applications (Table 6). K. Kaur *et al.* (2004), S. Ghulam *et al.* (2010) also reported that FC application increased the micronutrients content of the soil.

The BA application affected soil micronutrients partly negatively and partly positively. Fe and Mn were affected negatively and Cu and Zn positively with FC applications. Both Fe and Mn were increased at 20 t/ha<sup>-1</sup> BA applications and then declined. The reason may be that the solubility Fe and Mn decrease as soil pH increase. The lowest and the highest results were recorded at 100 and 20 t/ha<sup>-1</sup> BA application, and the values were (4.4, 43.8 and, 25.2 75.2 mg/kg<sup>-1</sup>) for Fe and Mn, respectively (Table 7). The highest Fe value (25.2 mg kg<sup>-1</sup>) for soil affected with BA application was found in the range of high and the lowest (4.4 mg/kg<sup>-1</sup>) in the range of medium. For Mn, the lowest value (43.8 mg kg<sup>-1</sup>) was in the range of high, and the highest (75.2 mg/kg<sup>-1</sup>) in the range of very high. Both the lowest (0.54 mg/kg<sup>-1</sup>) and the highest (1.20 mg/kg<sup>-1</sup>) content of Cu were found in the range of low Cu categories. The Zn

content of the soil increased progressively with increasing rates of BA applications. The lowest value ( $7.8 \text{ mg/kg}^{-1}$ ) was recorded at control treatment and the highest ( $18.5 \text{ mg/kg}^{-1}$ ) – at  $100 \text{ t/ha}^{-1}$  of BA applications (Table 7). The lowest and the highest values of Zn were found in the range of high and very high, respectively (Table 7). In general, BA application reduced Fe and Mn content of the soil. E. Ferreira *et al.* (2012) also reported that BA application reduced the soil micronutrients. The reason may be due to increase in soil pH as BA rate application increase. As soil pH increase the availability (solubility) of micronutrients decrease. However, Cu availability increase at optimum (neutral) soil pH.

*Comparison of soil chemical properties that affected with FC and BA application.* The analytical results of FC and BA indicated that the nutrients content of FC was somewhat higher than that of BA. The analysis was also conducted on soil affected with FC and BA application

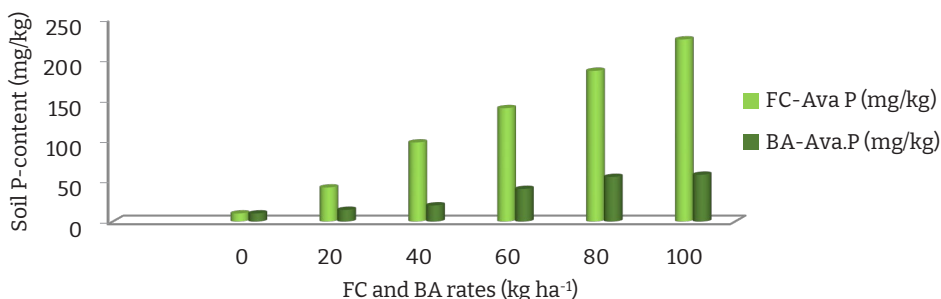
to observe the nutrients contribution of FC and BA for the soil. As observed from (Fig. 2) above, BA applications more affected soil pH compared with the soil affected with FC applications. On the other hand, FC applications more affected soil OM (%), and N (%) compared with BA rates application. The responses were directly related with properties of treatment materials with BA was high in pH when compared with FC, and FC was high in OM and N content. The reason for high OM and N content in FC may be due to its existence in natural status (without losing OM and N). However, BA was an organic material that subjected to fire (ashing) for the purpose of steam generation. In general, ashing could affects OM, N, and S content of organic substances. FC applications also dominated over BA applications in improving soil phosphorus (P) content (Fig. 3). The reason was that FC was rich in P content compared with BA.



**Figure 2.** Graph of soil chemical parameters as affected with FC and BA application

**Note:** FC-pH - FC-affected soil pH

**Source:** developed by the author

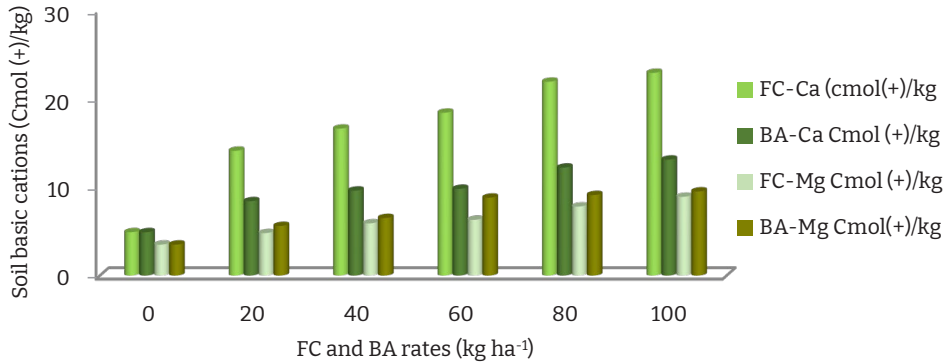


**Figure 3.** Graph of soil P as affected with FC and BA application

**Source:** developed by the author

The Figure 4 showed that FC application rates progressively increased the Ca content of the soil by dominating over soil Ca content that affected by BA rate applications. The soil response was correct that FC was high in Ca con-

tent compared to BA. However, BA improved soil Mg content more than FC even if FC was high in Mg content (Fig. 4). The lower contribution of Mg in FC compared to BA may be conditioned by nutrient imbalance, as FC had an excess of Ca.

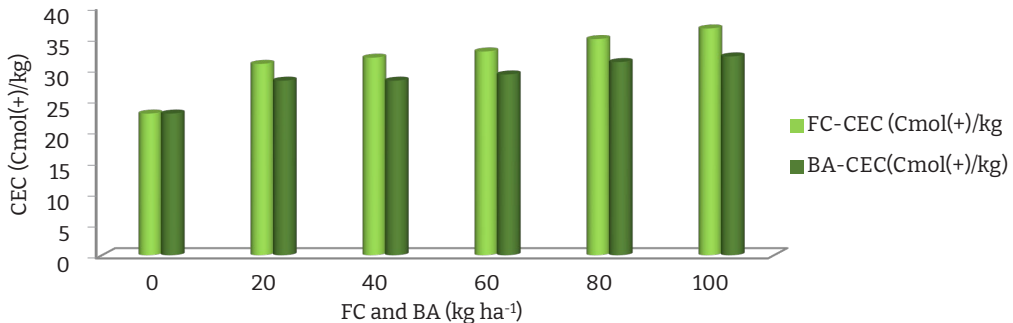


**Figure 4.** Soil basic cations as affected with FC and BA rates application

Source: developed by the author

The FC application dominated over BA application in improving soil cations exchangeable capacity (CEC) (Fig. 5). The reason was that FC was rich in CEC source substances (OM and CaCO<sub>3</sub>). However, both treatment

materials (FC and BA) increased the soil CEC progressively. In general, FC and BA applications were found to affect the soil nutrients content according to the quantity of the nutrients they contained.



**Figure 5.** Soil CEC as affected by FC and BA application rates

Source: developed by the author

*Correlation analysis.* The correlation analysis was conducted among the nutrients and rates of FC and BA, and among different nutrients values obtained from soil affected with FC and BA application. The correlation analysis showed that all nutrients positively and highly significantly ( $P < 0.0001$ ) correlated with FC application rates. The OM, Ava.P, Ca, and MG

positively correlated with pH with correlation coefficient ( $r$ ) = 0.86, 0.76, 0.80, and 0.88, respectively (Table 8). OM correlated with Ava.P, Ca, and Mg with  $r = 0.69, 0.76, \text{ and } 0.77$ , respectively. In the same way, Ava.P of the soil positively and highly significantly correlated with Ca and Mg with correlation coefficient  $r = 0.98 \text{ and } 0.96$  for FC application. Mg correlated with Ca with  $r = 0.96$ .

**Table 8.** Correlation of soil nutrients as affected with FC application

Var.	Rates	pH	OM(%)	Ava.P	Ca	Mg
Rates	1					
pH	0.81****	1				
OM(%)	0.74****	0.86****	1			
Ava.P	0.98****	0.76****	0.69****	1		
Ca	0.98****	0.80****	0.76****	0.98****	1	
Mg	0.98****	0.88****	0.77****	0.96****	0.96****	1

Source: developed by the author

**Table 9.** Correlation of soil nutrients as affected with BA application

Var.	Rates	pH	%OM	Ava.P	Ca	Mg
Rates	1					
pH	0.95****	1				
OM (%)	0.99****	0.96****	1			
Ava.P	0.99****	0.95****	0.99****	1		
Ca	0.94****	0.96****	0.93****	0.90****	1	
Mg	0.98****	0.95****	0.90****	0.98****	0.97****	1

Source: developed by the author

The same as FC, the nutrients positively and significantly correlated ( $P < 0.0001$ ) with the rates of BA application. OM, Ava.P, Ca, and Mg highly significantly correlated with pH of the soil obtained from the soil affected with BA application and the correlation coefficients ( $r$ ) were = 0.96, 0.95, 0.96, and 0.95, respectively (Table 9). This indicates that BA application increased soil pH and the availability of P, Ca, and Mg. Available P (Ava.P), Ca, and Mg were correlated with OM with  $r = 0.99$ , 0.93, and 0.90, respectively. The Ava.P content of the soil affected with BA positively correlated with Ca and Mg with correlation coefficient ( $r$ ) = 0.98 and 0.96, respectively. Magnesium (Mg) positively correlated with calcium (Ca) with  $r = 0.97$ .

## CONCLUSIONS

Soil acidity is becoming a critical problem in Ethiopian high rainfall areas. To solve this problem, researchers and farmers practice liming even on a large scale. However, the cost of lime is rising, and farmers are unable to afford the cost. Hence, organic amendments were considered as an option to manage soil acidity. The application of organic fertilisers increases soil pH, available P, available Ca, organic

matter, CEC, and total N. Organic amendments improve soil phosphorus availability by forming Al-complex ( $\text{Al}(\text{OH})_3$ ) with organic anions. The complex of Al with organic anions improves soil P availability by making P freely available in the soil. Hence, to amend chemical properties of acidic Nitisol, FC and BA were considered as organic amendment materials. FC and BA had pH of 8.2 and 10.2, respectively and they affected the pH of the soil accordingly. Both sugar industry by-products are also rich in basic cations, CEC, and base saturation. FC was richer in Ca, OM, P, and N content compared to BA. The results showed that the pH of acidic Nitisol was improved with FC and BA application. Both, FC and BA application improved the soil fertility parameters (OM, N, Ava.P, CEC), basic cations (K, Ca, Mg), base saturation, micronutrients, and decreased soil exchangeable acidity ( $\text{Al}^+ + \text{H}^+$ ). FC has increased soil OM, N, and Ca content of the soil when compared to BA application. The reason is that FC is more organic in nature when compared to BA. The reason is that, bagasse ash is a by-product obtained after bagasse subjected to the boilers of sugar factory for steam for steam/energy generation. Therefore, its OM, N, and S content are

negatively affected during combustion. As a result, BA relatively less affected soil OM, N, and S compared to FC application. Nevertheless, BA has well affected acidic Nitisol when compared to the control. BA application also increased soil pH and Mg content over FC application. The reason is that BA was comparatively high in pH compared to FC. In general, the results showed that FC and BA application are promising in amending soil acidity. However, a far-reaching field experiment is required to make a better recommendation.

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## CONFLICT OF INTEREST

None.

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## Вплив застосування фільтраційного кеку та золи жому на окремі хімічні властивості кислого нітїзолу

**Анотація.** Зростання вартості вапна, яке традиційно використовується для боротьби з кислотністю ґрунту та її негативним впливом на родючість ґрунту, спонукало до вивчення органічних побічних продуктів як більш доступної альтернативи для зменшення кислотності ґрунту, особливо для фермерів з низькими доходами. Тому метою цього дослідження було вивчити вплив застосування фільтраційного кеку (ФК) та золи жому (ЗЖ) на кислотність ґрунту в тепличних умовах. Експеримент був закладений у повністю рандомізованому досліді з чотирма повтореннями. Окремо досліджували ФК та ЗЖ з шістьма рівнями (0, 20, 40, 60, 80 та 100) т/га<sup>-1</sup>. Кислий ґрунт був відібраний з Імдїбїрського району з глибини 0-20 см, висушений на повітрі, подрїбнений і пропущений через сито з розміром отворів 4 мм. У кожен горщик було внесено по 4 кг ґрунту з відповідним оброблювальним матеріалом після того, як вони були добре гомогенізовані. Лабораторний аналіз показав, що початковий рН ґрунту становив 5,1, тоді як фільтраційний осад та зола жому мали значення рН 8,0 та 10,2, відповідно. Застосування ФК підвищило рН ґрунту з 5,1 до 7,3, а також покращило вміст органічної речовини, азоту, фосфору, сірки, калїю, кальцію, магнію та ємність катїонного обміну. Аналогічно, застосування ЗЖ підвищило рН з 5,1 до 7,4 і збільшило вміст органічної речовини, азоту, фосфору, сірки, калїю, кальцію, магнію та ємність катїонного обміну. Максимальний ефект як для ФК, так і для ЗЖ спостерїгався при найвищій нормі внесення (100 т/га<sup>-1</sup>), тоді як вміст залїза і марганцю збільшувався при внесенні ЗЖ, але зменшувався зі збільшенням норми, а вміст мїдї і цинку позитивно впливав як при застосуванні ФК, так і ЗЖ. Загалом, застосування як ФК, так і ЗЖ значно покращило рН ґрунту та вміст поживних речовин. Результати цього дослідження можуть забезпечити практичні та економічно ефективні рішення для покращення родючості ґрунту та виробництва сільськогосподарських культур

**Ключові слова:** Імдїбїр; вилуговування; фіксація; основні катїони; кислотоутворюючі катїони; обмінна кислотність

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## **Assessment of the development of *Lactuca sativa* Batavia Aficion in hydroponic and aquaponic systems**

**Abstract.** The need to improve the methods of growing plants in hydroponic systems to ensure optimal conditions for their growth and achieve high yields is urgent. The purpose of this study was to compare the hydroponic production of *Lactuca sativa* Batavia Aficion using a conventional Knop nutrient solution compared to aquaponics using nutrient-rich fish water. Laboratory, potentiometric, and photometric methods were used for this purpose. The yield, biometric, and qualitative indicators of lettuce leaves were investigated. Despite the lower nutrient concentration in the aquaponic solution, the nutritional status of *Lactuca sativa* Batavia Aficion was within the optimal range. The nitrate content of lettuce grown in the aquaponics system was higher than in hydroponics, but there were no significant differences in the content of total N (3.24% and 2.97%), Mg (1,973 mg/kg and 1,943 mg/kg), Fe (93.91 mg/kg and 93.83 mg/kg), K (73.7 mg/kg and 73.6 mg/kg), and Ca (19.5 mg/kg and 20.1 mg/kg). The yield of *Lactuca sativa* Batavia Aficion on aquaponics was 2.8 kg/m<sup>2</sup> and 3.2 kg m<sup>2</sup> – on hydroponics, with a density of 36 plants per square metre. Water monitoring in the aquaponic system showed low concentrations of nitrates, phosphorus (P), potassium (K), and magnesium (Mg), but the proportion of mineral nutrients and pH were stable throughout the lettuce growing period. Lettuce leaves in the aquaponics system reached a fresh

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weight of 80 g in 34 days, which is on average 13% less than lettuce leaves in the hydroponics system. The EC (electrical conductivity) values recorded in this study in a hydroponic system were between 1.2 and 1.5 cm/m. In the aquaponic system, EC has higher values due to the low rate of water replacement, contributing to greater growth and accumulation of solution ions. However, due to continuous recirculation in the water, the conditions become satisfactory for growing plants. The results obtained can contribute to the creation of more efficient and sustainable agricultural systems, reducing resource consumption and improving the resistance of cultivated crops to various stressful conditions

**Keywords:** electrical conductivity; yield; lettuce; nutrition; macro- and microelements

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## INTRODUCTION

Climate change on planet Earth, the devastation of fertile land in Ukraine caused by insufficient rainfall, and the use of pesticides, herbicides, and insecticides make it difficult to grow crops for food. Population growth and urban expansion create demand for products with less water and energy use. In urban areas, where there is a lack of available soil due to development, soil-free farming systems should be introduced.

During the period of military operations, most of the land is not suitable for agricultural use, which increases the demand for alternative types of crop cultivation. According to J. Lobo (2019), hydroponic cultivation improves crop growing technologies through minimal environmental impact, improved pest control, and high yields. As for aquaponics, compared to traditional agriculture, it produces 8 times more protein and vegetable crops. In addition, another advantage is the independence of production from environmental conditions, the possibility of an automated, controlled regime of growing conditions for almost any type of hydrobionts and agricultural plants (Singh, 2019).

One of the industries that produces food the fastest in the world is aquaculture. Between 2010 and 2018, global aquaculture production increased by 5.3% annually. Production increased from 57.7 million tonnes in 2010 to 82.1 million tonnes in 2018. It is expected that 186 million tonnes of fish will be consumed worldwide in 2030, and aquaculture will provide up to 50.2% of this demand (Summary report..., 2018).

The prospects of using both technologies in Ukraine and the positive environmental and economic conditions were discussed by Y.-T. Chu *et al.* (2023). They noted that there are

various methods of hydroponics, such as drip irrigation techniques, film systems and root immersion systems, which help to precisely control the nutrition of plants and create optimal conditions for their growth. Hydroponics can be classified according to the typology of systems, such as soil-free irrigation, aeroponics or aquaponics, opening up wide opportunities for improving agricultural products and creating sustainable and efficient plant cultivation systems.

Aquaponics, according to S.O. Lavrenko *et al.* (2019), helps to reduce the use of chemical fertilisers and water treatment chemicals, making this system environmentally friendly. It contributes to the conservation of water resources, as the water in the system circulates and is processed, providing optimal conditions for plant growth and fish health. In addition, aquaponics can be implemented even in limited spatial conditions, making it an excellent option for urban farming and sustainable development. This reasonable combination of fish and crop production contributes to the development of a balanced ecosystem approach to food production, where the interaction between components contributes to high productivity and reduces the negative impact on the environment.

Aquaponic nutrient solutions are not as easy to maintain as hydroponic solutions. Aquaponics is influenced by many factors, such as fish feeding rate, hydraulic loading rate, and pH. The study by B. Matysiak *et al.* (2023) showed that despite the low mineral content of aquaponic solution, the mineral content of medium-type lettuce leaves was within the optimal range. Z.M. Nadia *et al.* (2023) found that tilapia fish is

commonly used in aquaponics to study yield.

T. Yang & H.J. Kim (2019) investigated the effect of hydraulic load velocity on spatial and temporal characteristics of water quality and crop growth and yield in aquaponics systems, which is an urgent problem in modern agroecology. The results have helped to improve plant cultivation technologies and aquatic bioresources, contributing to the efficient use of resources and environmental conservation. Understanding this impact helped to optimise the management processes of aquaponic systems to achieve more sustainable and efficient agricultural products. S. Wongkiew *et al.* (2017) proved that the use of aquaponic systems for sustainable resource recovery is a hot topic in modern science. Combining nitrogen transformation processes with microbial communities in such systems opens up opportunities for a deeper understanding of ecosystem processes and optimising their functioning. This ensures sustainable food cultivation and efficient use of resources, and reduces the negative impact on the environment. These technologies have potential and will play a significant role in food production in the future.

The goal was to compare the cultivation of *Lactuca sativa* Batavia Aficion on hydroponic and aquaponic systems. To achieve this goal, it was necessary to conduct an experiment to determine the possibility of obtaining a proper harvest and high quality of lettuce leaves.

## MATERIALS AND METHODS

The study was conducted in June-July 2023 in the educational and scientific laboratory of cyclic aquatic agroecosystems of the National University of Water and Environmental Engineering. One variety of lettuce was used – Batavia Aficion. Lettuce seedlings were grown in a coconut substrate for two weeks and placed on aquaponics and hydroponics on June 2, 2023, on specially designed floating expanded polystyrene boards (0.9 m×0.6 m) with holes (12 pcs. on a raft with a planting density of 36 seedlings per square metre. To meet the nutrient concentration targets, high-purity mineral salts were added to the hydroponics system according to the Knop recipe (Kotsyuba, 2006), which contained N – 200 mg/l, P – 62 mg/l, K – 150 mg/l, Ca –

210 mg/l, Mg – 50 mg/l, S – 70 mg/l, Fe – 2.5 mg/l, Mn – 0.62 mg/l, Mo – 0.03 mg/l, Zn – 0.09 mg/l, Cu – 0.5 mg/l, B – 0.44 mg/l, which was filled with settled water with a volume of 350 litres. The water used in both systems had the following levels: pH – 6.3; EC (electrical conductivity) ranged from 1.2 to 1.5 mmS/cm, remaining within the limits necessary for good salad development; hardness – 6.5 mmol/dm<sup>3</sup>; nitrites – 0.18 mg/dm<sup>3</sup>; sulphates – 11.6 mg/dm<sup>3</sup>; chlorides – 7 mg/dm<sup>3</sup>; phosphates – 1.04 mg/dm<sup>3</sup>; nitrates – 9 mg/dm<sup>3</sup>. HCl and Na<sub>2</sub>CO<sub>3</sub> were added to regulate the pH. The temperature was at 25°C, the humidity was 75%, and the photoperiod was 17 hours. Dissolved oxygen was maintained at more than 6 mg/l to support nitrification and fish growth in the aquaponic system (Tyson *et al.*, 2004). *Clarias gariepinus* (African sharptooth catfish) was used in aquaculture because of its high productivity indicators, fastidiousness to the conditions of maintenance and easy adaptation to their changes, good consumption of any feed, and resistance to various diseases (Ola-Oladimeji *et al.*, 2016). With an average planting density of 90.6 kg/m<sup>3</sup> with a total volume for growing of 5.1 m<sup>3</sup>, this resulted in a total fish biomass of 462.1 kg. Nitrates in fresh plant material were determined by the potentiometric method. The content of other components was determined from dried plant raw materials. The content of P, K, Ca, Mg, Fe, Mn, Cu, Zn, and B was determined photometrically. The nitrogen content was analysed using the Kjeldahl method (Latimer, 2012).

The macronutrient content in water was analysed using Lasa Agro 1900 spectrophotometer (Germany). The following methods were also used to study water quality: measuring the concentration of nitrate ions by photocolourimetric method (Measurement Methodology No. 081/12-0651-09, 2010), measurement of the mass concentration of ammonium ions by photocolourimetric method with Nesler reagent (Measurement Methodology No. 081/12-0106-03, 2010), measurement of the mass concentration of chlorides by titrimetric (Measurement Methodology No. 081/12-0653-09, 2010), and measurement of the mass concentration of calcium and magnesium by titrimetric method (Measurement Methodology No. 081/12-0644-09, 2010). During the first experimental week,

only half the amount of salts was added to limit EC and allow the seedlings to adapt to the nutrient solution and avoid osmotic shock. Hydrogen pH and ppm mineralisation, electrical conductivity, and temperature were monitored regularly (every 4 days).

When harvesting lettuce from the systems, the weight of shoots and roots was analysed using one-way variance analysis (Anova). The plant growth index NDVI (normalised differential vegetation index) was also calculated. *Lactuca sativa* Batavia Aficion was collected when it reached commercial maturity, i.e., 34 days after transplanting, after which the air-dry and absolutely dry weight of the plant, the number of leaves, the height and width of the plant, the volume of the root system, and the biomass of the plant were determined. During the study, the Convention on Biological Diversity (1992) and Convention on the Trade in Endangered Species of Wild Fauna and Flora (1973) standards were observed.

## RESULTS AND DISCUSSION

The assessment of development in hydroponic and aquaponic systems included a comprehensive investigation of various aspects of these innovative agricultural production methods. First, the key aspect is plant productivity, which is important to evaluate in terms of parameters such as height, number of leaves, root system weight, and yield. In hydroponic systems, it is important to consider optimal nutrient levels and control their concentration. In addition, in the case of aquaponics, where the interaction of fish and plants plays an important role, the influence of fish on plant development and the quality of the grown product should be evaluated. Water parameters such as pH, electrical conductivity, and nutrient concentration determine the effectiveness of these systems and their environmental safety. In addition, the assessment of development in hydroponic and aquaponic systems involves monitoring the biological environment, including the state of microorganisms in the root environment of plants. Understanding the diversity and activity of microorganisms helps to ensure optimal conditions for biological filtration and ecosystem maintenance, ensuring the sustainability and effectiveness of these innovative agricultural practices.

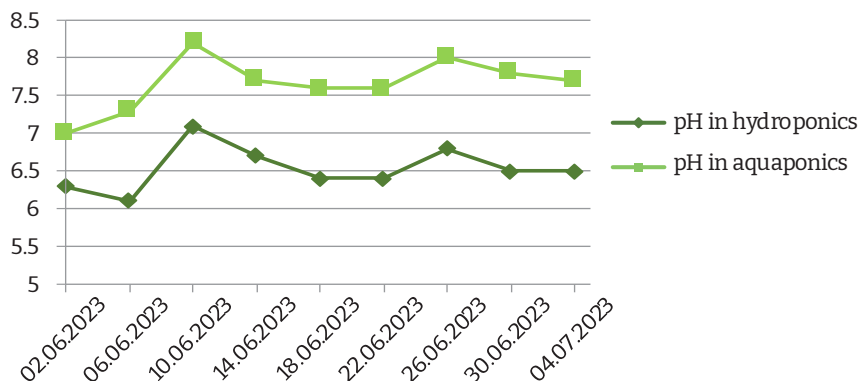
In addition, it is important to evaluate the economic performance of hydroponic and aquaponic systems. Analysing inputs and outputs, determining the costs of maintaining the systems and the profitability of growing plants and fish, allows assessing the effectiveness of these methods in terms of financial decision-making. A significant part of the assessment should focus on sustainable development and environmental safety. Determining the impact of these systems on the environment, in particular water resources and biodiversity, helps to determine their suitability for sustainable use in practice. This assessment should also consider technological aspects, such as automation and monitoring of systems that can affect production efficiency and reduce risks in hydroponics and aquaponics systems. A comprehensive assessment of these aspects helps not only to understand the current state of hydroponic and aquaponic systems, but also to develop strategies to further improve their productivity, environmental safety, and economic sustainability.

Analysis of water in a hydroponic system showed a good balance of mineral nutrients, since the content of  $\text{N-NH}_4^+$  (at the beginning of the experiment – 0.29 mg/dm<sup>3</sup> and at the end – 0.14 mg/dm<sup>3</sup>), P (respectively 0.34 mg/dm<sup>3</sup> and 0.16 mg/dm<sup>3</sup>), K (3.5 mg/dm<sup>3</sup> and 3.1 mg/dm<sup>3</sup>), Ca (142 mg/dm<sup>3</sup> and 143 mg/dm<sup>3</sup>) and Mg (27.6 mg/dm<sup>3</sup> and 26.8 mg/dm<sup>3</sup>) remained at the same level throughout the entire growing period of *Lactuca Batavia Aficion*. Relative to the aquaponic system, the average macronutrient content is  $\text{NO}_3^-$  – 4 mg/l, P – 3 mg/l, K – 20 mg/l, Ca – 143 mg/l, Mg – 29 mg/l. Copper as a component of enzymes is involved in photosynthesis and the synthesis of carbohydrates and protein. The copper content of water in the hydroponic system was five times higher than in aquaponics. PH affects the solubility and toxicity of chemicals and heavy metals, and the ability of plants to absorb them, so it is necessary to adjust and control the ideal pH range.

At the beginning of the experiment, there was a normal pH, but there was a slight decrease (6.1) due to the addition of new water with a low pH. Then it rose again until it reached pH 7.1, which leads to precipitation of nutrients and other chemical compounds.

For an aquaponic system, the pH values range from (7.0-8.0). As can be seen from Figure 1, the pH starts at 7.0, which is normal and ideal for this system, after a while the PH

increased sharply (8.2), which is associated with the accumulation of waste and chemicals in the water that are produced by fish and other microorganisms.

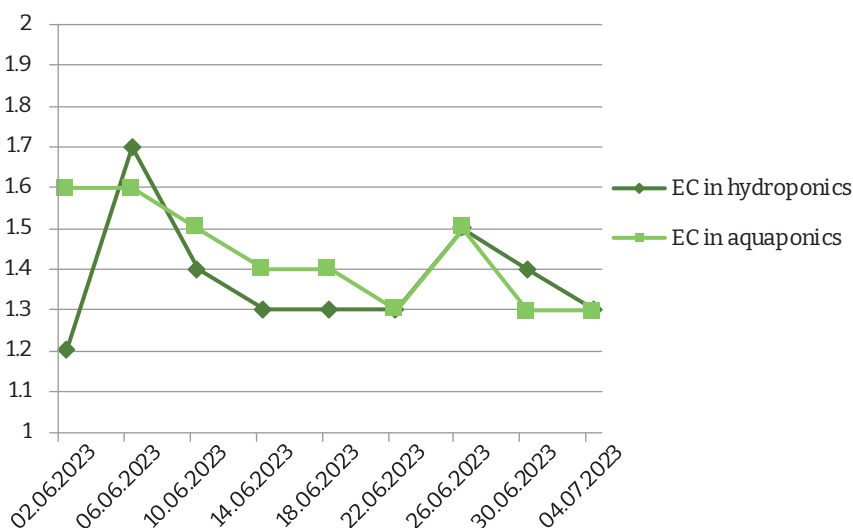


**Figure 1.** pH value of aquaponic and hydroponic systems

Source: compiled by the authors

From the hydroponic system, it ranged from (1.2-1.5 S/m). These values are in the ideal range, especially for growing lettuce. In fact, the EC was slightly high at the beginning (1.7), and to avoid any further increase, the solution was replaced and diluted. After about 12 days and with increased plant growth, the EC values decreased

and remained stable. This can be explained by the absorption of chemicals and nutrients from the water, as plant growth has increased dramatically at this stage, which requires a large amount of nutrients and ultimately leads to low EC. In the aquaponic system, EC values ranged from (1.2-1.8 S/m).



**Figure 2.** Electrical conductivity (S/m) in hydroponic and aquaponic systems

Source: compiled by the authors

The studied morphological characteristics of lettuce showed that the yield of leafy lettuce grown on hydroponics is better than on aquaponics. *Lactuca sativa* Batavia Aficion reached fresh weights of 93 g and 80 g in hydroponics and aquaponics and developed 20 and 17 leaves, respectively. The height of the largest (leaf length was taken into account together with the length of the root system) plant in hydroponics was 60 cm, aquaponics – 48 cm. The maximum volume of the lettuce root system in hydroponics was 55 ml, in aquaponics – 45 ml. The results of air-dry plant biomass with a maximum weight of 55 g in hydroponics and 44 g in aquaponics were also obtained, including absolutely dry plant biomass with a maximum weight (samples were dried in a drying oven at 65°C for 4 hours for two days) in hydroponics – 54 g, in aquaponics – 42 g. Based on the calculation of the plant growth index, the average daily growth rate was established (the difference between measuring the plant size at the end of the experiment and at the beginning, divided by the number of days between measurements), in hydroponics lettuce grew – 2.2 cm, aquaponics – 1.9 cm daily.

The accumulation of nutrients by plants did not differ significantly between the systems. By nitrate content (2,742 mg/kg – hydroponics, 2,263 mg/kg – aquaponics), total N (3.24% and 2.97%), Fe (93.91 mg/kg and 93.83 mg/kg), K (73.7 mg/kg and 73.6 mg/kg), and Ca (19.5 mg/kg and 20.1 mg/kg) content. Magnesium is part of chlorophyll, the main pigment of green plants that provides photosynthesis, a process that is key to life on Earth. Magnesium is the leading atom in the structure of chlorophyll and plays a critical role in converting solar energy into chemical energy necessary for plant growth and development. In addition, magnesium is one of the most important mineral elements for many biochemical processes in living organisms, including the activation of enzymes and the regulation of cell function. Regarding its content, higher values were recorded in the hydroponic system – 1,973 mg/kg, compared to the aquaponic system – 1,943 mg/kg. The sulphur content in the leaves was almost twice as high in the aquaponic system (18.3 mg/kg) as in the hydroponic system (8.6 mg/kg). This is due to the fact that sulphur deficiency is rarely

observed in aquaponic systems, and it is mainly present as a soluble sulphate anion ( $\text{SO}_4^{2-}$ ). Sulphate is absorbed directly by the plant and plays an important role in the synthesis of numerous amino acids, proteins, and oils.

To ensure optimal access of lettuce roots to nutrients in the hydroponic system, it is recommended to keep the pH range in the range of 6.0–6.5, since even a slight increase in the pH level to 7.0 can lead to a decrease in the fresh and dry weight of plants. In aquatic aquaculture systems, the ideal pH is in the range of 7.0–8.0, and for nitrifying bacteria, the optimal pH is about 7.5 for efficient conversion of ammonia to nitrates (Suhl *et al.*, 2016). In aquaponics, the key step is nitrification, which converts toxic ammonia ( $\text{NH}_3$ ) to nitrates ( $\text{NO}_3^-$ ) for absorption by plants. When the pH level increases above 7.0, most phosphorus forms insoluble compounds, and from 30% to 65% of this element remains in fish sediments, which cannot be used by plants. In addition, if the pH values are higher than 6.5, plants will face a complicated process of absorbing trace elements such as iron, copper, zinc, boron, and manganese.

According to T. Asao (2012), the use of hydroponics as a standard methodology for research in plant biology is widespread. Hydroponics involves growing plants without soil, providing the necessary nutrients directly through the solution. This controlled and soil-free environment allows researchers to precisely regulate various factors, which contributes to the standardisation of methodologies in plant biology research.

T.S. Anderson *et al.* (2017) studied the growth response and elemental composition of Batavia lettuce fibres (*Lactuca sativa*, Flandria variety) under hydroponic conditions, in particular, by investigating changes in pH and alkalinity levels. By experimenting with different pH and alkalinity levels in a hydroponic environment, the researchers aim to understand how these environmental factors affect the overall growth and elemental composition of plant tissues. The experiment examines the effect of different levels of acidity (pH) and alkalinity on parameters such as plant height, leaf development, and the concentration of essential elements in lettuce fibres. This analysis is important for optimising hydroponic cultivation practices, as it provides conclusions about ideal

conditions for maximising the growth and nutritional quality of Batavia lettuce.

The aquaponics system is considered to be one of the most productive in agricultural production, but its efficiency and yields are still insufficiently studied compared to hydroponics, which is one of its alternatives. Researchers, including B. Delaide *et al.* (2016), conducted a comparative study that analysed the yield of shoots and roots, and the nutrient content of lettuce grown in conventional hydroponic solutions and under aquaponic conditions. They concluded that aquaponics systems can outperform hydroponics in terms of growth and productivity. This study compared aquaponics with hydroponics to test this, because a number of studies have shown that a nutrient solution in hydrocultural media is better and more successful in growing lettuce and plants are mostly stress-free because water and nutrients are always available.

This study found that the water in the aquaponics system was deficient in nitrogen, phosphorus, and potassium, but at the same time had adequate levels of calcium and magnesium, which came from tap water used to fill aquariums. According to A. Graber & R. Junge (2009), aquaponics solution contains three times less nitrogen, 10 times less phosphorus, and 45 times less potassium compared to hydroponics solution. G. Rafiee & C.R. Saad (2005) and Z. Schmautz *et al.* (2015) confirm that the main source of phosphorus in aquaponics is fish feed, although only 15% of the phosphorus from the feed is consumed by fish, and plants can absorb phosphorus from aquaculture.

J.E. Rakocy (2012) and H.R. Roost (2014) argue that fish feeds also contain certain trace elements, but the amount of potassium (K), iron (Fe), magnesium (Mg), manganese (Mn), and copper (Cu) in them is limited. Despite this, it was possible to achieve a satisfactory yield of lettuce – 2.8 kg/m<sup>2</sup> in the aquaponics system and 3.2 kg/m<sup>2</sup> in the hydroponic system, with a density of 36 plants per square metre. This demonstrates the effectiveness of both systems in growing plants and highlights the potential of aquaponics to provide a sustainable crop with a limited content of certain nutrients in the water.

E. Pantanella *et al.* (2012), E. Alcarraz *et al.* (2018) previously reported higher yields in

aquaponics compared to hydroponics, even at lower concentrations of mineral nutrients. However, the current study found that the growth and yield of lettuce grown in aquaponics was lower than in hydroponics. Factors that can affect the yield of aquaponic lettuce include the level of electrical conductivity (EC), pH, concentration and ratio of nutrients in the water for fish, water quality, water temperature, and the composition of the nutritious diet for fish. T. Yang & H.J. Kim (2020) investigated the effect of different levels of hydraulic loading on the spatial and temporal characteristics of water quality, and on plant growth and yield in aquaponics systems. By changing the hydraulic load, researchers aim to study its effect on the distribution of water quality parameters in the system in space and time. In addition, the paper examines how these changes affect the overall growth and productivity of plants in aquaponics. E.A. van Os *et al.* (2002) described that the method of hydroponic cultivation of vegetables and ornamental plants can effectively control the growth environment of plants, providing them with the necessary nutrients in optimal concentrations.

W.A. Lennard & B.V. Leonard (2004) compared two methods of fluid circulation: mutual movement and constant flow in an integrated aquaponics system with a gravel bed. These two methods were evaluated for their effectiveness and impact on the growth and health of plants and fish. As a result of the study, it was found that the system with mutual fluid movement showed better indicators of plant growth and fish development compared to the constant flow system. The analysis showed that the mutual movement of fluid contributes to better circulation of nutrients and oxygen, which contributes to an overall increase in system performance. These results highlight the importance of optimising fluid circulation to improve the efficiency of aquaponic gravel bed systems.

S. Wongkiew *et al.* (2017; 2018) focused on aquaponic systems as a means of sustainable resource recovery, in particular, investigating the relationship between nitrogen transformations and microbial communities to uncover the complex relationships between nitrogen transformations, which are key to nutrient cycling in aquaponic ecosystems, and diverse microbial

communities. Nitrogen plays an important role in aquaponics, being converted from fish waste (ammonium) to forms that can be absorbed by plants (nitrate), which contributes to the overall stability and efficiency of the system.

Leafy vegetables such as lettuce contain significant amounts of natural nitrates, which can pose a risk to human health. The study by M. Iammarino *et al.* (2014) includes systematic monitoring of nitrite and nitrate levels in leafy vegetables, particularly spinach and lettuce, to contribute to the risk assessment associated with their consumption. Nitrites and nitrates are essential components for plant nutrition, but their accumulation in the edible parts of vegetables can pose a potential health risk to consumers. By regularly evaluating and quantifying the levels of nitrites and nitrates in spinach and lettuce, researchers aim to understand changes over time and identify possible factors that affect their concentrations. This monitoring process is important for assessing the safety of consuming these leafy greens, as increased levels of nitrites and nitrates are associated with negative health effects, especially in certain cancers.

Comparing both systems, this study showed that aquaponics produces lower yields. In the future, special attention should be paid to the microbiota present in both water and the rhizosphere; it can be assumed that they contain effective rhizobacteria and/or fungi that promote growth and supplement the aquaponic solution with minerals for greater yield. In addition, it can be concluded that the effectiveness of aquaponics without additional minerals depends on plant genotype.

## CONCLUSIONS

Under optimal conditions in the laboratory, including light and temperature, a satisfactory yield and quality of *Lactuca sativa* Batavia Aficion was obtained in the aquaponics system with a deep culture module after 34 days of aquaponics cultivation – 2.8 kg/m<sup>2</sup> and in hydroponics – 3.2 kg/m<sup>2</sup>. Production of *Lactuca sativa* Batavia Aficion using a hydroponic system with a nutrient solution according to Knop's recipe yielded a 40% higher yield. This is conditioned by free access to nutrients and easy root growth in a hydroponic solution. The development of

*Lactuca sativa* Batavia Aficion in the aquaponic system requires a slightly longer period due to the fact that it mainly depends on the amount, quality, and rate of transformation of fish waste by the microbiome, which are organic materials and usually take time to decompose by microorganisms. The aquaponic solution had a low mineral content, but despite this, the mineral content of lettuce leaves was within the optimal range (the nitrate content of lettuce grown in the aquaponic system was higher than in hydroponics, but there was no significant difference in the content of total N (3.24% and 2.97%), Mg (1,973 mg/kg and 1,943 mg/kg) and Fe (93.91 mg/kg and 93.83 mg/kg), K (73.7 mg/kg and 73.6 mg/kg) and Ca (19.5 mg/kg and 20.1 mg/kg), and the nutritional value was similar to lettuce, which was traditionally grown in a greenhouse).

Further study may include expanding the research area to other plant varieties or species to determine whether the approaches and results obtained remain effective across crops. It is also worth investigating the effect of other nutrient solutions or aquaponic systems on the cultivation of *Lactuca sativa* Batavia Aficion and studying the optimal conditions for better growth and yield. In addition, a detailed analysis of the interaction between plants and fish in the aquaponic system can be performed to improve relationships and optimise processes. Such further research will help to expand the understanding of the optimal conditions for hydroponic and aquaponic cultivation of *Lactuca sativa* Batavia Aficion and may be important for practical applications in agriculture.

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## CONFLICT OF INTEREST

None.

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## Оцінка розвитку *Lactuca sativa* Batavia Aficion в гідропонній та аквапонній системах

**Анотація.** Потреба удосконалення методів вирощування рослин у гідропонних системах забезпечення оптимальних умов для їхнього росту та досягнення високих врожаїв є актуальною. Мета цього дослідження полягала в тому, щоб порівняти гідропонне виробництво *Lactuca sativa* Batavia Aficion з використанням звичайного поживного розчину Кнопа в порівнянні з аквапонією з використанням багаті поживними речовинами рибної води. Для цього були використані лабораторний, потенціометричний та фотометричний методи. Досліджено врожайність, біометричні та якісні показники листя салату. Незважаючи на нижчу концентрацію поживних речовин в аквапонічному розчині, поживний статус *Lactuca sativa* Batavia Aficion був у межах оптимального діапазону. Вміст нітратів в листі салату, вирощеного у системі аквапоніки був вищим ніж у гідропоніці, проте не було виявлено істотної різниці за вмістом загального N (3,24 % та 2,97 %), Mg (1973 мг/кг та 1943 мг/кг) та Fe (93,91 мг/кг та 93,83 мг/кг), вміст K (73,7 мг/кг та 73,6 мг/кг) і Ca (19,5 мг/кг та 20,1 мг/кг). Врожайність *Lactuca sativa* Batavia Aficion становила на аквапоніці – 2,8 кг/м<sup>2</sup> та 3,2 кг/м<sup>2</sup> – на гідропоніці, при щільності 36 рослин на метр квадратний. Моніторинг води в аквапонічній системі показав низьку концентрацію нітратів, фосфору (P), калію (K) і магнію (Mg), але частка мінеральних поживних речовин, а також рН були стабільними протягом усього періоду вирощування салату. Листя салату в системі аквапоніки за 34 дні досягли свіжої ваги 80 г, що в середньому на 13% менше, ніж листя салату в системі гідропоніки. Значення ЕП (електропровідність) зареєстровані в цьому дослідженні у гідропонній системі були між 1,2 і 1,5 См/м. В аквапоній системі, ЕП має вищі значення через низьку швидкість заміни води, сприяючи більший ріст і накопичення іонів розчину. Однак за рахунок безперервної рециркуляції в воді, умови стають задовільними для вирощування рослин. Отримані результати можуть сприяти створенню більш ефективних та стійких агрокультурних систем, зменшуючи споживання ресурсів і покращуючи стійкість вирощуваних культур до різних стресових умов

**Ключові слова:** електропровідність; врожайність; салат листовий; живлення; макро- та мікроелементи

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## **Formation of productivity of maize hybrids of different ripening groups in the Forest-Steppe region**

**Abstract.** The relevance of the study is determined by the necessity of scientifically substantiating the rational ratio of maize hybrids of different ripening groups to ensure the realisation of the genetic potential in forming pre-harvest grain moisture at the level of 18-22%. Therefore, the purpose of the study is to identify the most adapted and plastic ripening groups considering biological features and to identify stable hybrids based on economic efficiency through the calculation of the hybrid's productivity efficiency index. The method of plot division was used to conduct field research in accordance with the requirements of the research methodology. The results revealed that maize hybrids of different ripening groups react differently to temperature conditions, especially during the interphase period – 3-5 leaves. Maize hybrids with FAO (ripening group of the hybrid) 180-250, having a flint grain subtype, are characterised by faster linear plant growth due to higher cold resistance, making them suitable for early sowing when the soil temperature is 6-8°C. Hybrids with FAO 300 and above, with a dent grain subtype, exhibit slower initial plant growth and are more thermophilic. Therefore, it is advisable to plant them after the soil has been thoroughly warmed to 8-10°C. Studies have established that the highest grain yield was obtained from mid-late maturity maize hybrids (FAO 401-500) – 10.04-10.17 t/ha, with a maximum level of 14.89 t/ha in 2017. However, considering the dynamics of productivity levels over the years, the most plastic hybrids, i.e., those with the smallest difference in yield between years, are phenotypes with FAO 201-300. It was determined that early and mid-early ripening group hybrids had lower pre-harvest grain moisture – 0.6-23.9% compared to 28.7-27% in mid-ripening and mid-late ripening groups.

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This resulted in a higher productivity efficiency index for these hybrids. The materials of the study contain results for further research on optimising the use of maize hybrids with different FAO numbers and are of practical significance for farms of various ownership forms

**Keywords:** growth and development phases; yield; mineral fertilisers; pre-harvest moisture; organogenesis

## INTRODUCTION

The stability of maize production and the optimisation of sequential harvesting with subsequent moisture control are ensured through the selection and optimal balance of hybrids from different ripening groups. Research on maize hybrids of various ripening groups in the Forest-Steppe region is essential for optimising crop cultivation and ensuring a stable food supply in the region. The focus is on selecting the most productive and resilient hybrids (Bakhmat & Kyrlyuk, 2016). Considering the increasing costs of post-harvest grain processing, it is practical to increase the proportion of intermediate hybrids with dent kernels to 45-50%, characterised by higher moisture content (Ovcharuk *et al.*, 2021). Obtaining existing and developing new elements of regional maize cultivation technology requires significant attention to optimizing production costs and studying grain market dynamics (Maslak, 2017).

S.O. Serna-Saldivar (2019) analysed the lengthening of the vegetation period for intermediate hybrids of maize in the context of applying standard mineral fertilizer rates to achieve programmed yields of 12-14 t/ha. This extension results in reduced grain moisture levels, necessitating additional production costs and, consequently, an increase in production costs. Long-term studies have shown that harvesting maize with high pre-harvest grain moisture, besides increasing production costs for post-harvest processing by 25%, also deteriorates its quality indicators (Heiniger, 2018; Shynkaruk & Lykhochvor, 2021a).

Based on the study by R.W. Gesch *et al.* (2021), it can be concluded that in regions with limited heat resources, desiccation is a suitable agrotechnical measure for reducing pre-harvest grain moisture and limiting the development of disease agents, particularly *Fusarium*. Desiccation significantly reduces grain moisture,

enabling optimal harvest timing and, consequently, reduces post-harvest processing costs.

By multi-year research conducted by R. Khanam *et al.* (2022), it has been established that 50% of corn productivity is determined by adaptive properties to specific soil-climatic conditions, 30% by the level of material-resource provision of the cultivation technology, and 20% by weather conditions. S.M. Kalenska & V.A. Taran (2018) asserted that corn hybrids from different breeders manifest differently in specific zonal cultivation conditions since the realisation of potential individual productivity occurs under certain characteristics. Hence, the correct choice of hybrid, especially considering the maturity groups according to FAO, its resistance to abiotic factors, and immunity to harmful organisms, determines the features of grain yield formation and its production cost.

According to O. Hayduk (2022), the rates of moisture removal are crucial in regions with limited thermal resources, as of November 2022, the cost of drying 1 tonne of corn amounted to 150 UAH. Considering unfavourable ripening weather conditions, the cost of grain post-harvest processing for a yield of 8 tons/ha and pre-harvest moisture content of 28% was 16,800 UAH, constituting almost 75% of the expenses for the cultivation technology. Therefore, optimising the ratio of maturity groups of corn hybrids, considering climate changes, the structure of production costs, and post-harvest grain processing, acquires significant scientific and practical importance.

The purpose of the study is to substantiate the features of growth and development of corn hybrids of different maturity groups, investigate the influence of the size of FAO (Food and Agricultural Organization) on the formation of grain yield level and moisture content. Calculations of the efficiency index of hybrid productivity were planned to justify economic efficiency.

## MATERIALS AND METHODS

The experimental study was conducted in the educational, scientific, and production laboratory of the Department of Plant Science, a separate

unit of the "Agronomic Research Station" at the National University of Life and Environmental Sciences of Ukraine during the years 2017-2022 according to the developed scheme (Table 1).

**Table 1.** Experiment scheme

Factor A – corn hybrid maturity group by FAO			Factor B – corn hybrids
Option designation	FAO	Option designation	Hybrid
A1	180-200	B1	DKC 3050( Bayer), DKC 3151( Bayer), EU Sirius (Lidea), MAS 10.A (MAS Seeds)
A2	201-300	B2	B2 Ayaks (RAGT), SI Phenomenon (Syngenta), Lipekks (RAGT), DKC3796 (Bayer)
A3	301-400	B3	B3 DKC3939 (Bayer), Dublikks (RAGT), Gekksgon (RAGT), Harmonium (Lidea)
A4	401-500	B4	B4 Lexstur (RAGT), DKC5075 (Bayer), DKC4717 (Bayer), DKC5141 (Bayer)

**Source:** compiled by the authors

The field study was established using the split-plot method according to the requirements of the research methodology. The efficiency index of hybrid productivity was calculated following the method of Y.M. Pashchenko *et al.* (2008). The soil was typical chernozem with low humus content, loamy in texture. The humus content in the arable layer (according to Tyurin) was 3.4% (DSTU 7855:2015...). The soil was moderately provided with easily hydrolysed nitrogen, above-average in mobile phosphorus and exchangeable potassium. The study was conducted following the requirements of the International Convention on Biological Diversity (1992).

The technology of growing hybrids of corn of different maturity groups was as follows: predecessor – winter wheat; soil cultivation – plowing to a depth of 25-27 cm; pre-sowing soil treatment included closing moisture and pre-sowing cultivation to a depth of seed placement (4-5 cm); fertilisation –  $N_{90}P_{60}K_{60}$ , particularly phosphorus and potassium fertilisers were applied under the main soil treatment; nitrogen fertilisers – finely,  $N_{60}$  was applied during pre-sowing cultivation and  $N_{10}$  – as top dressing

in the phase of 5-7 leaves; during sowing, a complex mineral fertiliser was applied at the rate of  $N_{10}P_{10}K_{10}$  per row; sowing time – the soil temperature at the depth of seed placement was 8-10°C; the seed sowing rate was determined by the maturity group, specifically for hybrids FAO 180-200, it was 80,000 seeds/ha, FAO 201-300 – 70,000 seeds/ha, FAO 301-400 – 60,000 seeds/ha, and FAO 401-500 – 55,000 seeds/ha; crop care included applying a Titus herbicide (Corteva, USA) at the rate of 50 g/ha) with the addition of Trend 90 as insurance; the crops were treated with Coragen insecticide (Food Machinery and Chemical Corporation, USA) at the rate of 120 mg/ha with a working solution volume of 250 l/ha at the beginning of high ear flowering using a high-clearance sprayer; harvesting was done at the stage of full grain ripeness.

## RESULTS AND DISCUSSION

The entire range of corn hybrids based on FAO values is divided into 5 maturity groups: early maturing – FAO up to 200, intermediate-early – FAO 201-300, intermediate – FAO 301-400, intermediate-late – FAO 401-500, and late maturing – FAO above 501 (Table 2).

**Table 2.** Distribution of corn hybrids by maturity groups

Hybrid requirements	Maturity group				
	early-ripe	mid-early	intermediate-ripe	mid-late	late-ripe
Active temperature sum, °C	2200	2400	2600	2800	3000
Effective temperature sum, °C:	900-1000	1100	1150	1200	1300
n specifically, from emergence to tassel emergence	400	450	500	550	600
n from tassel emergence to wax ripeness	400	450	500	550	600
Vegetation period, days	90-105	106-115	116-120	121-130	More than 131
Number of leaves, pcs.	12-14	14-16	16-18	18-20	More than 20
FAO value	100-200	201-300	301-400	401-500	More than 501

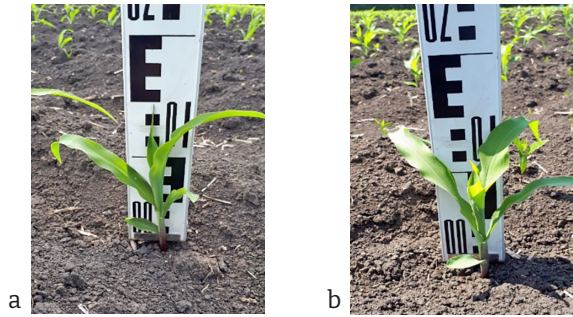
**Source:** developed based on research by V.M. Kabanets *et al.* (2022)

FAO (conditional index of rapidity) is a comprehensive indicator that considers the hybrid's relation to the sum of active and effective temperatures, mineral nutrition level, moisture supply, etc. A difference of 10 points in FAO indicates that the hybrid will have an extended vegetative period by 1-2 days, or it will form 1-2% more dry matter at the beginning (Kalenska & Taran, 2018). One of the criteria for determining the FAO value is the number of leaves. However, this property is determined not only by genetic characteristics but also depends on the growing conditions. Thus, based on long-term studies of corn morphogenesis by D.F. Tomashevsky (1970), it is stated that the first and second stages of organogenesis occur at the stage of vernalisation. The longer this interphase period, the more nodes and leaves are formed at the second stage of organogenesis. This explains that when moving hybrids that are regionally adapted for southern regions to northern latitudes, they form more leaves because these hybrids undergo the stage of vernalisation slowly due to low spring temperatures.

To ensure sustainable corn production in the Forest-Steppe region, a well-founded ratio of corn maturity groups should be followed (Lavrynenko *et al.*, 2016). According to V.S. Tsykov (2003), the recommended ratio of maturity groups in the Forest-Steppe is as follows: early

maturing hybrids – 35%, intermediate-early – 55%, intermediate – 10%. However, climate change in recent years has influenced the distribution of hybrids by FAO, and according to scientific and production recommendations, the share of early maturing hybrids is 20%, intermediate-early – 40%, intermediate – 30%, and intermediate-late – 10% (Mokrienko *et al.*, 2017; Khanam *et al.*, 2022; Kabanets *et al.*, 2022).

Hybrids of different maturity groups differ in both biological characteristics and economic traits. Specifically, early and intermediate-early corn hybrids with a flint grain subtype are more cold-resistant and characterized by faster initial growth, indicating their suitability for early sowing when the soil temperature at a depth of 10 cm is 6-8°C. The middle-ripening and late-ripening hybrids with dent grain are more thermophilic plants and require soil warming up to 10-12°C. Accordingly, hybrids with flint grain during ripening will be characterized by slower rates of moisture loss – 0.2-0.4% per day, whereas dent hybrids have the ability to reduce moisture content from 0.5 to 0.8% (Pashchenko *et al.*, 2008). Field studies have shown that hybrids of maize of different maturity groups reacted differently to changes in temperature regime at the initial stages of organogenesis, particularly until the formation of 5-7 leaves (Fig. 1).



**Figure 1.** Initial growth rates of maize hybrids of different maturity groups, 2022

**Note:** a – mid-early hybrids with FAO 201-300; b – intermediate ripening hybrids with FAO 301-400

**Source:** photographed by the authors

Hybrids with FAO 301-400 and FAO 401-500 were found to be more sensitive to temperature fluctuations, exhibiting lower cold resistance. Genotype and grain subspecies influenced cold resistance, especially early and mid-early maturity group hybrids, thanks to the flint grain subspecies, proved to be more resistant to rapid fluctuations in daily and nighttime temperatures. Particularly note-

worthy are the years 2017 and 2021 when, after a sharp increase in active temperatures in the second and third decades of April, a significant drop in air temperature was observed at the beginning of May. As a result, partial damage to the growth point was noted, leading to a 10% decrease in yield. This phenomenon in agronomy is called “temperature paralysis” (Fig. 2).



**Figure 2.** Determination of maize plant viability of hybrids with FAO 301-400 after 24 hours, 2017

**Source:** photographed by the authors

Maize cold resistance is also associated with the plant’s need for a sum of effective temperatures required at the initial stages of growth and development. Hybrids with FAO 201-300 have greater tolerance to fluctuations in daily and nighttime temperatures (Mokrienko *et al.*, 2017). Starting from the 11-13 leaf stage (tassel emergence), changes in the intensity of linear growth occur – more intensive plant growth is observed in mid-ripening hybrids. These differences in growth and development throughout the vegetative period are due to both genetic

and morphobiological characteristics. Analysing the initial growth rates of maize plants, it was noted that early and mid-early hybrids are less responsive to deviations from the optimal temperature regime, being more cold-resistant. Therefore, it is advisable to sow them in optimal-early sowing dates.

Observations of the growth and development of maize plants of different maturity groups confirmed that the duration of the interphase period between emergence and tasseling has a significant impact on pollination

efficiency. It was established that a duration of more than 60 days negatively affects pollination efficiency, increasing the likelihood of “poor kernel filling”. This is because plants are exposed to critically high temperatures (pollination burn) during the formation of generative organs, resulting in a delay in tassel flowering and initiation. Studies have shown that in maize hybrids with FAO 301-400 and FAO 401-500, the delay in tassel flowering and initiation averaged 7 and 9 days, respectively.

In early and mid-early hybrids, tassel emergence occurs on the 55th day after emergence, resulting in nearly simultaneous flowering, differing by 2-3 days, ensuring full pollination (Mokrienko, 2014).

The ultimate indicator of maize production efficiency is grain yield. Studies have shown that the realisation of genetic potential and natural resources is determined by the complex influence of all cultivation factors, especially temperature and water regimes (Table 3).

**Table 3.** Grain yield of maize hybrids from different maturity groups, t/ha 2017-2022

FAO	Hybrid	Year						Average for 2017-2022
		2017	2018	2019	2020	2021	2022	
180-200	DKC 3050	8.25	7.71	5.67	5.17	8.74	8.22	7.29
	MAC 10.A	7.64	6.54	5.01	5.00	8.04	7.88	6.69
	ES Sirius,	8.01	7.94	4.18	4.35	8.24	8.06	6.80
	DKC 3151	8.76	8.13	6.08	5.75	9.02	8.71	7.74
	Average	8.17	7.58	5.24	5.07	8.51	8.22	7.13
201-300	Ayax	10.15	9.23	7.02	7.54	10.78	11.25	9.33
	SI Phenomenon	10.78	9.15	6.42	6.12	11.02	11.86	9.23
	Lipekks	11.6	9.61	7	6.97	11.78	12.12	9.85
	DKC3796	11.4	9.46	6.52	6.14	11.97	11.97	9.58
	Average	10.98	9.36	6.74	6.69	11.39	11.80	9.49
301-400	DKC3939	10.45	9.22	6.04	5.74	10.97	8.98	8.57
	Dublikks	11.22	9.47	5.01	4.32	11.74	9.03	8.47
	Hexagon	12.87	12.21	4.78	4.12	13.12	10.78	9.65
	Harmonium	13.23	12.45	4.62	4.47	13.45	11.12	9.89
	Average	11.94	10.84	5.11	4.66	12.32	9.98	9.14
401-500	Lekstur	12.54	10.42	4.06	4.00	11.23	9.25	8.58
	DKC5075	13.74	11.03	3.98	3.74	12.57	10.06	9.19
	DKC4717	14.51	13.97	4.15	3.78	13.02	10.78	10.04
	DKC5141	14.89	14.02	3.75	3.56	13.74	11.03	10.17
	Average	13.92	12.36	3.98	3.77	12.64	10.28	9.49

**Source:** compiled by the authors

Studies have shown that in dry years, especially in 2019 and 2020, when Growing Degree Days (GDD) for June-July were 0.64 and 0.52, respectively, mid-early and mid-late hybrids, being exposed to heat stress, yield lower compared to mid-early and early maturity groups. For instance, in 2019, the average grain yield of mid-late hybrids was 3.98 t/ha, while in early maturity groups, it was 5.74 t/ha. This is also associated with the higher drought resistance of hybrids belonging to the flint grain subspecies.

For example, the test weight of flint hybrids was 620 g/l, whereas dent hybrids had only 497 g/l.

In wetter years, a reverse pattern was observed, where hybrids with higher FAO numbers produced higher grain yields. For example, in 2017, the grain yield of mid-late hybrids was 13.92 t/ha, while for early maturity groups, it was 8.17 t/ha. On average over the years of the study, hybrids with FAO 201-300 and FAO 401-500 were the most stable maturity groups. However, it is noteworthy that in critical years regarding

moisture supply, mid-late hybrids show a more significant reduction in productivity compared to mid-early hybrids.

Research aimed at determining the optimal maturity group was also conducted by V. Cherchel *et al.* (2021). They noted that in favourable conditions, the difference in grain yield of maize hybrids from different maturity groups was 0.42 t/ha between early and mid-early forms, 0.17 t/ha between mid-early and mid-late forms, and 0.07 t/ha between mid-late and late forms. In stressful conditions, the differences were 0.33 t/ha, 0.25 t/ha, and 0.21 t/ha, respectively. It should be noted that the largest difference in grain yield was observed between early and mid-early maturity groups. In these studies, the biggest difference in grain yield was recorded between hybrids with FAO 180-200 and 401-500, amounting to 2.36 t/ha.

High grain yield does not always correspond to a corresponding level of maize production profitability. When choosing maize hybrids, it is also important to consider the rate of moisture loss (Mokrienko, 2014). Table 4 shows the calculations of the productivity efficiency index, which takes a comprehensive approach to selecting the maturity group into account. The higher the index, the higher the level of profitability. Research has shown that the lowest pre-harvest moisture content was recorded in early and mid-early maize hybrids, respectively 20.6% and 23.9%, while in mid-early and mid-late hybrids, it was 28.7% and 32.7%. The efficiency index was calculated by dividing grain yield by pre-harvest moisture content. The highest efficiency index was observed in mid-early maturity group hybrids – 0.49, whereas in mid-late group, it was only 0.31.

**Table 4.** Productivity efficiency index of hybrids in 2022

FAO	Hybrid	2022	Pre-harvest moisture, %	Productivity efficiency index of hybrid
180-200	DKC 3050	8.22	22,0	0.37
	MAC 10.A	7.88	21.6	0.36
	ES Sirius	8.06	20.2	0.40
	DKC 3151	8.71	18.7	0.47
	Average	8.22	20.6	0.40
201-300	Ayax	11.25	25.4	0.44
	SI Phenomenon	11.86	24.1	0.49
	Lipekks	12.12	23.1	0.52
	DKC3796	11.97	23.2	0.52
	Average	11.80	23.9	0.49
301-400	DKC3939	8.98	26.8	0.34
	Dublikks	9.03	27.9	0.32
	Hexagon	10.78	30.5	0.35
	Harmonium	11.12	29.8	0.37
	Average	9.98	28.7	0.35
401-500	Lekstur	9.25	32.8	0.28
	DKC5075	10.06	31.5	0.32
	DKC4717	10.78	32.6	0.33
	DKC5141	11.03	34.1	0.32
	Average	10.28	32.7	0.31

**Source:** compiled by the authors

In Table 5, calculations of grain drying costs and economic efficiency associated with drying it to the base moisture level of 14% are provided.

The calculations consider the cost of 1 tonne of maize grain, which is 4500 UAH, and drying cost of 1 tonne percent is 150 UAH.

**Table 5.** Calculation of grain drying costs and economic efficiency of maize production in 2022

FAO	Moisture difference to base, %	Drying costs, UAH/ha	Harvest value, UAH/ha	Harvest value with drying, UAH/ha
180-200	6.6	8137.8	36978.8	28841.0
201-300	9.9	17523	53100.0	35577.0
301-400	14.7	22005.9	44898.8	22892.9
401-500	18.7	28835.4	46260.0	17424.6

**Source:** compiled by the authors

The highest harvest value was obtained when growing mid-early and mid-late maturity group hybrids, amounting to 44898.8 UAH/ha and 46260 UAH/ha, respectively. However, due to the high pre-harvest moisture content of the grain, additional costs for drying the grain to the base level significantly increase, resulting in a harvest value of 22892.9 UAH/ha and 17424.6 UAH/ha for these maturity groups, respectively. The highest figures were recorded when growing mid-early hybrids, amounting to 35577 UAH/ha.

The calculation of the harvest value, considering the drying costs, confirmed the reliability of the productivity efficiency index. Therefore, when choosing a hybrid, it is necessary to consider not only the potential yield but also the moisture loss characteristics, which depend on the maturity group, grain subspecies, number of envelope leaves, and peculiarities of tassel formation. Long-term research has established that optimising maize hybrid maturity groups will enhance their productivity by realising their genetic potential and effectively utilising resources, especially heat and moisture. The hybrids of the mid-early maturity group are the most stable in forming high yields due to the reduced risk of plant exposure to high temperatures during flowering and grain formation, thus avoiding firing and “tip-back”.

The conducted study has established that to achieve high grain yield, the duration of the interphase period from emergence to tassel flowering should also be considered. The importance of the duration of this vegetative growth period is highlighted by the findings of M.F. Danilevich *et al.* (2021). An increase in this period raises the risk of flowering occurring under higher, suboptimal temperature conditions of 23-25°C, adversely affecting silk pollination. The current study revealed that in early and mid-early maturity group

hybrids, this period was 54-58 days, whereas in mid-early and mid-late hybrids, it extended to 62-66 days. This negatively affected silk pollination and consequently reduced grain yield, especially in years with high-temperature regimes, resulting in a decrease ranging from 10% to 17%.

The highest grain yields from 2017 to 2021 were achieved by mid-early and mid-late maturity group maize hybrids, indicating their high ecological plasticity. However, the study by L. Shynkaruk & V. Lykhochvor (2021b) showed that hybrids with a long vegetative period, having FAO 400 and above, are characterised by increased pre-harvest grain moisture content. Consequently, their efficiency index was 0.31 compared to 0.49 in mid-early hybrids, indicating increased production costs. Economic efficiency calculations for maize production demonstrated that drying costs for mid-early maturity group hybrids amounted to 17.5 thousand UAH/ha, mid-early and mid-late hybrids incurred 22.0 thousand UAH/ha and 28.8 thousand UAH/ha, respectively.

Similar studies by R.W. Gesch *et al.* (2021) and R.L. Nielsen (2020) noted that the use of mid-early and mid-late maturity group maize hybrids, especially under restricted temperature conditions, requires desiccation to achieve grain with optimal pre-harvest moisture content. This, in turn, increases the cost of grain. Pashchenko conducted similar studies determining the productivity efficiency index of hybrids in the Steppe zone, and their production verification confirmed the effectiveness of calculating this indicator, leading to an 8-10% increase in maize grain yield due to the correct choice of maturity group (Pashchenko, 2008).

This study established that the rate of moisture loss is influenced by morphological characteristics of plants, including the number of husk leaves, the diameter of the tassel, grain

subspecies – dent subspecies capable of losing 0.5-0.7% moisture, whereas flint subspecies lose 0.2-0.3%, corresponding to the quality composition of the grain. The shape of the tassel also significantly influences the rate of moisture loss – barrel-shaped maize tassels exhibit uniform moisture loss along the tassel. Similar results regarding moisture loss dynamics in maize hybrids were obtained by M.V. Kapustian *et al.* (2021). L. Shynkaruk & V. Lykhochvor (2021a) also note that the formation of the number of tassels on the plant significantly influences the pre-harvest moisture content of maize grain. Thus, the formation of the second (lower) tassel leads to an increase in the pre-harvest moisture content of the grain by 2-4%. In the conditions of the Forest-Steppe, studies on determining the stability of maize hybrids of different maturity groups with high and medium yield values and high agronomic stability have also confirmed the effectiveness of maize hybrids with FAO 240-270. Accordingly, their share should constitute 55-60% (Grabovsky *et al.*, 2014).

Therefore, the correct selection of maize hybrids based on the intensity of cultivation technology and optimising their ratio, with a preference for mid-early hybrids up to 60%, will stabilise grain production, especially in extreme years.

## CONCLUSIONS

Hybrids of maize with different vegetative periods differ in their growth and development rates at the initial stages of organogenesis, have varying resistance to temperature regimes, and therefore respond differently to sowing dates. Early and mid-early maize hybrids, belonging to the flint grain subspecies, exhibit higher cold resistance and are advisable to be sown at a soil temperature of 6-8°C. These hybrids also demonstrate higher drought tolerance, leading to the formation of superior grain yield as a key element of crop structure.

Under extreme weather conditions, when there is a deficit of soil moisture during the vegetative period and the negative impact of aerial dryness on plants, early and mid-early maturity group maize hybrids are more adapted and flexible. For instance, in the dry years of 2019 and 2020, the grain yield of early maturity group hybrids was 5.24 and 5.07 t/ha, respectively, while for mid-late maturity group, it was 3.98 and 3.77 t/ha, respectively. In years with sufficient soil moisture, hybrids with FAO 301-401 and FAO 401-500 are more productive, yielding 12.32 and 12.64 t/ha, respectively, compared to 8.51 t/ha in early maturity group. However, it should be noted that maize hybrids with FAO 301-400 have a lower pre-harvest grain moisture content of 28.7% compared to 32.7% in hybrids with FAO 401-500, resulting in lower costs for drying.

Utilising the productivity efficiency index of a hybrid as a comprehensive parameter allows optimising hybrid selection across maturity groups. Based on years of research, hybrids with FAO 201-300 are the most stable maturity group considering economic efficiency. The research findings will be promising for further studies aiming to optimise the hybrid composition for specific soil-climatic conditions, enhancing maize production efficiency. In the future, research on the productivity formation of maize hybrids of different maturity groups can explore more aspects, such as molecular mechanisms of maturity, interaction with different soil types, and the impact of climate change on maize cultivation. This can help develop new hybrids that are more productive, stress-resistant, and contribute to increased maize yield, which is crucial for ensuring food security.

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## CONFLICT OF INTEREST

None.

## INTRODUCTION

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## **Формування продуктивності гібридів кукурудзи різних груп стиглості в Лісостепу**

**Анотація.** Актуальність досліджень зумовлена необхідністю наукового обґрунтування раціонального співвідношення гібридів кукурудзи різних груп стиглості, що забезпечить реалізацію генетичного потенціалу з формуванням передзбиральної вологості зерна на рівні 18-22 %. Тому метою досліджень передбачалося виявити найбільш адаптовані та пластичні групи стиглості з урахуванням біологічних особливостей, а також виявити стабільні гібриди з урахуванням економічної ефективності через розрахунок індексу ефективності продуктивності гібриду. Метод розщеплення ділянок був використаний для проведення польового досліді згідно з вимогами методик дослідної справи. Результатами досліджень встановлено, що гібриди кукурудзи різних груп стиглості неоднаково реагують на температурний режим, особливо, у міжфазний період сходи – 3-5 листок. Гібриди кукурудзи з ФАО (група стиглості гібриду) 180-250, які мають кремезніший підвид зерна, характеризуються більш швидким лінійним ростом, що обумовлено вищою холодостійкістю рослин, а відповідно, і придатні для ранніх строків сівби, коли температура ґрунту становить 6-80°C. Гібриди з ФАО 300 і вище, з зубовидним підвидом зерна, мають повільніше темпи початкового росту рослин і є більш теплолюбними, а тому їх доцільно висівати за стійкого прогрівання ґрунту 8-100°C. Дослідженнями встановлено, що найвищу врожайність зерна формували середньопізні гібриди кукурудзи (ФАО 401-500) – 10,04-10,17 т/га, з максимальним рівнем 14,89 т/га у 2017 році. Проте, якщо врахувати динаміку рівня продуктивності по рокам, то найбільш пластичними гібридами, тобто ті, які мають найменшу різницю по врожайності по рокам, є фенотипи з ФАО 201-300. З'ясовано, що гібриди ранньостиглої і середньоранньої груп стиглості характеризувалися нижчою передзбиральною вологістю зерна – в 0,6-23,9 % проти 28,7-2,7 % відповідно у середньостиглих і середньопізніх, що і обумовило вищий індекс ефективності продуктивності гібридів. Матеріали статті містять результати для подальших досліджень з оптимізації використання гібридів кукурудзи з різним ФАО, а також мають практичне значення для господарств різних форм власності

**Ключові слова:** фази росту й розвитку; урожайність; мінеральні добрива; передзбиральна вологість; органогенез

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## **Assessment of the influence of mineral fertilisers on the phosphate regime of meadow chernozem carbonate soil and yield of sunflower and winter wheat**

**Abstract.** The relevance of the study lies in the need to maintain optimal levels of mobile phosphorus in carbonate soils to support healthy plant growth and development, as it can be converted into less mobile forms in such soils. The purpose of the study was to assess the impact of various long-term fertilisation strategies on the content of various forms of phosphorus in the soil to improve

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this availability. The research was conducted in 2019-2022 as a stationary experiment in a separate division of the National University of Life and Environmental Sciences of Ukraine "Agronomic Experimental Station" in Kyiv Oblast on meadow chernozem carbonate low-humus coarse-sawn light loamy soil in a five-field crop rotation, where the influence of different levels of fertiliser saturation (no fertiliser, minimum, average, and optimal) on soil phosphate status and yield of Etana winter wheat variety and Sumiko sunflower hybrid was investigated. Soil samples were taken from the 0-20 and 20-40 cm layers, and the group and fractional composition of phosphates was determined using the Chang-Jackson method and the content of mobile phosphates using the Chirikov and Machigin methods. According to the analysis of the group and fractional composition of soil phosphates, it was found that in meadow chernozem carbonate low-humus coarse-sawn light loamy soil, the content of iron phosphates prevails among all fractions during long-term fertilisation. The results showed an increase in the content of aluminium phosphates in the 0-20 cm surface layer of the soil of two variants with long-term fertilisation, and an increase in the content of the second fraction of soluble calcium phosphates ( $\text{Ca-P}_{11}$ ), with the minimum saturation ( $\text{N}_{27}\text{P}_{18}\text{K}_{20}$ ) with the highest available phosphate fraction for plants ( $\text{Ca-P}_1$ ) is observed. The content of mobile phosphates was maximal at optimal fertiliser saturation ( $\text{N}_{81}\text{P}_{54}\text{K}_{62}$ ) and was 4.8 and 8.5 mg/100 g of soil, the aftereffect of organic fertilisers positively affected the accumulation of mobile phosphates in the soil. The highest yield of winter wheat (7.55 t/ha) and sunflower (4.28 t/ha) was obtained with optimal fertiliser saturation, the lowest – without the use of fertilisers, where it was 4.45 t/ha for winter wheat and 2.23 t/ha for sunflower. The results of the study can be used to develop more sustainable and effective strategies for using phosphorus in soils, which can help preserve soil resources and prevent possible contamination of water sources due to excessive phosphorus intake

**Keywords:** group and fractional composition; mobile phosphates; soil medium reaction; phosphate mobilisation; available phosphorus

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## INTRODUCTION

Soils by genetic types are characterised by a different composition of mineral forms of phosphates. Thus, di- and octacalcium phosphates predominate in carbonate soils, and calcium phosphates and fluorooxides (hydroxyl-, fluorapatite, variscite, etc.) predominate in slightly acidic soils, and aluminium and iron phosphates (variscite, strangite, barrandite, etc.) predominate in acidic soils. The stability of mineral compounds depends on different soil conditions. First of all, it depends on the size of the reaction of the soil environment, the activity of various cations (especially Ca, Mg, Al, Fe), and on fertilisers applied, liming, plastering, irrigation. Thus, A.O. Khristenko (2020) found that the systematic use of organo-mineral fertilisers creates conditions for increasing the mobility of phosphates even in conditions when the phosphorus balance was negative. Thus, they suggest that the use of even small fertiliser rates will create conditions for simple restoration of soil fertility. According to O. Litvinova *et al.* (2019; 2020), plants

can use all those phosphorus fractions that are converted to phosphate ions in the soil. Phosphorus is the macronutrient of plant nutrition, without which their growth and development are impossible, which is why organic and mineral fertilisers are used to cover the removal of this element, and preserve and increase it in soils. S.L. Bauke *et al.* (2018) state that phosphorus levels in deep soil vary significantly depending on the specific feeding strategy used in long-term agricultural experiments. Long-term agricultural experiments show that the fertilisation methods used can significantly affect the availability of phosphorus in deep soil layers.

W.W. Zhang *et al.* (2019) proved that water-soluble fractions of P, the content of which in soils is only 0.8-8.0 mg kg<sup>-1</sup>, are closely related to crop yields. In addition, plants absorb mobile, namely metabolically sorbed phosphorus compounds, which easily and quickly enter the soil solution. The content of mobile phosphates in non-fertilised soils varies significantly

(10-100 mg kg<sup>-1</sup>). F.J. van der Bom *et al.* (2019) found that fertiliser application methods and their forms are an important factor affecting P fractions in the soil. They described that the practice of long-term application of phosphorous fertilisers has a significant impact on the soil's ability to supply and retain phosphorus, changing its chemical characteristics over time. Understanding the impact of long-term application of phosphorous fertilisers is important for optimising soil management and ensuring sustainable phosphorus resources for growing crops. The study by Y.P. Wang *et al.* (2022) aims to create a global model for understanding the dynamics of inorganic phosphorus in soil, in particular, to investigate the relationship between the kinetics of metabolism and the bioavailability of phosphorus in soil, which affects various physical and chemical properties of soil. The paper examines how various soil characteristics, such as pH, texture, organic matter content, and mineral composition, affect the kinetics of inorganic phosphorus metabolism. This exchange process plays an important role in determining the availability of phosphorus for plants and its potential for release into the environment.

C.M. Nobile *et al.* (2020) investigated the sorption and availability of phosphorus in andosol after a decade of applying organic or mineral fertilisers, highlighting the importance of changes in soil pH and organic carbon compared to phosphorus accumulation. The study highlights how changes in soil pH and the presence of organic carbon that affect different fertilisation practices can affect the sorption and availability of phosphorus, affecting its availability for plant uptake. Understanding the inter-

action between soil pH, organic carbon content, and phosphorus accumulation is essential for optimising fertiliser nutrition strategies and managing phosphorus availability in agriculture and environmental systems, with important implications for sustainable nutrient management and environmental protection practices.

The results of the investigation of Ukrainian and foreign studies indicate that the processes of phosphate conversion in soil are complex and are associated with a number of phenomena: dissolution and precipitation, adsorption and desorption, mineralisation and biological absorption, and other processes of phosphorus conversion occurring in different soil, and climatic conditions with different intensity. Fertiliser application affects the available phosphorus concentrations in the soil in the long run. Therefore, the purpose of the study is to investigate the impact of various long-term fertilisation strategies on the availability of phosphorus in the soil to improve this availability.

## MATERIALS AND METHODS

The research was conducted on the territory of a Separate Division of the National University of Life and Environmental Sciences of Ukraine (SD NUBiP of Ukraine) "Agronomic experimental station" (coordinates of the research site latitude: 50° 4'25.30"N, longitude: 30°13'18.14"E) in a stationary experiment in a five-field crop rotation with the following alternation of crops: clover – sunflower – winter wheat – grain corn – barley + clover in 2019-2022 PP. Table 1 shows various crop rotations and fertiliser compositions for growing sunflower and winter wheat in experimental plots used for research.

**Table 1.** Saturation of crop rotation with fertilisers in experimental plots

Crop rotation	Fertilisers for sunflower (NPK)	Fertilisers for winter wheat (NPK)
1. No fertilisers (control)	-	-
2. Minimal	N <sub>27</sub> P <sub>18</sub> K <sub>20</sub>	N <sub>25</sub> P <sub>25</sub> K <sub>35</sub>
3. Aftereffect of organic fertilisers	N <sub>55</sub> P <sub>36</sub> K <sub>41</sub>	N <sub>55</sub> P <sub>55</sub> K <sub>80</sub>
4. Average	N <sub>55</sub> P <sub>36</sub> K <sub>41</sub>	N <sub>90</sub> P <sub>45</sub> K <sub>45</sub>
5. Optimal	N <sub>81</sub> P <sub>54</sub> K <sub>62</sub>	N <sub>140</sub> P <sub>70</sub> K <sub>70</sub>

**Source:** compiled by the authors

The soil of the experimental site is meadow chernozem carbonate low-humus coarse-sawn

light loamy, which has a slightly alkaline reaction of the soil solution in a layer of 0-20 cm

(pH was 7.8) and a high absorption capacity of 31.2 meq/100 g of soil. Studies on the determination of the group and fractional composition of soil mineral phosphates by the Chang-Jackson method in the Ginzburg-Lebedeva modification in 0-20 and 20-40 cm layers (DSTU 7854:2015, 2015). This method is based on sequential tillage with various solvents, each of which extracts certain fractions of soil phosphates: the phosphorus fraction Ca-P<sub>I</sub>, Ca-P<sub>II</sub>, Ca-P<sub>III</sub>, Al-P, and Fe-P. First, the fraction of the most soluble forms of phosphates of alkaline and alkaline earth elements (Ca-P<sub>I</sub> fraction) was isolated using an ammonium-molybdate extract (pH 4.8): alkali metal and ammonium phosphates, acidic and freshly deposited Ca and Mg phosphates, and partially F<sup>2+</sup> (like vivianite) phosphates pass into the extract. The second fraction of less soluble forms of phosphates (Ca-P<sub>II</sub>) was determined in an acetate-molybdate extract (pH 4.3), where di-base and Mg phosphates (mainly secondary-formed di-, tri-, octacalcium phosphates) and a significant amount of F<sup>2+</sup> (like vivianite) phosphates pass. The third fraction of phosphates (Al-P) was determined in a fluoramonic extract (pH 8.5), into which aluminium phosphates (such as variscite, wavelite, etc.) and part of organic phosphorus pass. The fourth fraction of iron-bound phosphates (Fe-P) was determined in the alkaline extract of the washed soil residue after preliminary extraction. Determination of the last fraction in the sequential isolation of mineral forms of phosphorus (Ca-P<sub>III</sub>) was carried out in an acid extract (0.5 rate H<sub>2</sub>SO<sub>4</sub>), where highly

basic calcium phosphates such as apatite (natural and secondary formed) pass. The content of mobile phosphates in non-carbonate soil samples was determined by Chirikov methods (DSTU 4115-2002, 2002), and in carbonate samples – by Machigin method (DSTU 4114-2002, 2002). Soil samples at the experimental sites were taken in 0-20 and 20-40 cm layers. The content of mobile phosphates was determined by Chirikov (DSTU 4115-2002, 2002) and Machigin (DSTU 4114-2002, 2002) methods. The study complied with the provisions of the Convention on the Trade in Endangered Species of Wild Fauna and Flora (1973) and Convention on Biological Diversity (1992).

## RESULTS AND DISCUSSION

Phosphorus, unlike nitrogen and potassium, does not disappear from the soil due to its inertness and accumulates in large quantities. This leads to a change in the phosphate regime of the soil: the ratio between different groups of phosphorous compounds, the degree of their mobility, and the redistribution of phosphorus forms along the soil profile.

It is important to note that most of the reserves of available phosphorus compounds are located in the arable soil layer and naturally in deeper soil layers they decrease. According to the analysis of forms of mineral phosphorus compounds in meadow chernozem carbonate low-humus coarse-sawn light loamy soil with the annual application of various fertiliser options, the predominant fraction in all variants of the experiment is iron phosphates (Table 2).

**Table 2.** Group and fractional composition of soil mineral phosphates according to the Chang-Jackson method in the Ginzburg-Lebedeva modification (2019-2022)

Fertiliser saturation	Mineral phosphate fractions, mg/100 g of soil				
	Ca-P <sub>I</sub>	Ca-P <sub>II</sub>	Ca-P <sub>III</sub>	Al-P	Fe-P
Without fertilisers (control)	4.42	6.63	13.9	7.70	31.8
Minimum (N <sub>27</sub> P <sub>18</sub> K <sub>20</sub> )	13.8	12.5	16.2	14.6	35.4
Aftereffect of organic fertilisers + N <sub>55</sub> P <sub>36</sub> K <sub>41</sub>	8.71	9.65	13.5	9.90	45.5
Average (N <sub>55</sub> P <sub>36</sub> K <sub>41</sub> )	4.42	7.24	12.3	7.42	33.0
Optimal (N <sub>81</sub> P <sub>54</sub> K <sub>62</sub> )	9.12	13.1	19.7	15.1	51.2

Source: compiled by the authors

A high amount of iron phosphates is also observed in the variant without fertilisation (control) – 31.80 mg/100 g of soil. The greatest changes in this phosphate fraction occurred at the optimal saturation of fertilisers with the application of mineral fertilisers at the rate  $N_{81}P_{54}K_{62}$  and amounted to 51.2 mg/100 g of soil, which is 19.4 mg higher than the amount of Fe-P in the control variant. In addition, a fairly significant increase in iron phosphates compared to the control was observed in the variant with the aftereffect of organic fertilisers +  $N_{55}P_{36}K_{41}$  – 45.5 mg/100 g of soil, or 13.7 mg more than the control variant. Changes in the content of iron phosphates in variants with the introduction of lower rates of mineral fertilisers ( $N_{27}P_{18}K_{20}$ ) and  $N_{55}P_{36}K_{41}$  without the aftereffect of organic fertilisers were not so significant and exceeded the amount of Fe-P in the control variant by 3.63 and 1.21 mg/100 g of soil, respectively.

Soils contain from amorphous to crystalline forms of Fe oxides, such as goethite, whose effect on the retention of inositol phosphates is well known. Contribution of other common crystalline Fe oxides, such as hematite, magnetite, and maghemite. These oxides exhibit different ability to retain and release phosphorus due to their specific surface properties and resistance to protons, organic acids, and complexing agents. Thus, the four crystalline iron oxides showed different ability to retain organic phosphorus in the form of myoinositol hexaphosphate depending on the surface properties and stability of complexes, affecting the degree of release, accumulation, and turnover in soils.

With long-term application of mineral fertilisers, the content of aluminium phosphates in the surface layer of the soil of 0-20 cm of two variants increased especially. Option with the application of  $N_{27}P_{18}K_{20}$  was distinguished by an increase in the Al-P fraction by 6.87 mg/100 g of soil compared to the control variant. In the variant with the introduction of mineral fertilisers at the rate  $N_{81}P_{54}K_{62}$ , the changes in aluminium phosphate content were even greater – 15.1 mg/100 g of soil versus 7.70 mg/100 g of soil in the control. Minor changes in the content of aluminium phosphates occurred in the variant with the aftereffect of organic fertilisers and the introduction of  $N_{55}P_{36}K_{41}$  – 9.90 mg/100 g of soil,

that is, only 2.2 mg/100 g of soil is higher relative to the Al-P content in the non-fertilised option.

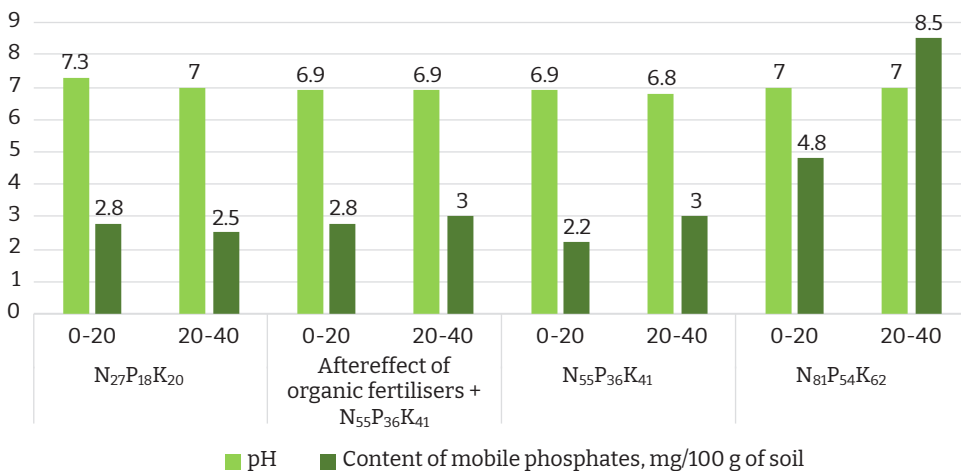
In the variant with the introduction of only mineral fertilisers ( $N_{55}P_{36}K_{41}$ ) conditions were created that contributed to minor changes in the amount of aluminium phosphates (7.42 mg/100 g of soil versus 7.70 mg/100 g of soil in the control). Under the influence of mineral fertilisers, the soil was enriched with active phosphorus mineral compounds. The amount of the second fraction of soluble calcium phosphates (Ca-P<sub>II</sub>) increased most significantly in comparison with the control in variants with the rates of mineral fertilisers  $N_{27}P_{18}K_{20}$  and  $N_{81}P_{54}K_{62}$ . Thus, the content of active phosphorus compounds in the control variant was at the level of 6.63 mg/100 g, while in the above-mentioned variants, this indicator increased, respectively, to 12.45 and 13.08 mg/100 g of soil. In the soil on variants with an aftereffect of organics +  $N_{55}P_{36}K_{41}$  and by applying only mineral fertilisers ( $N_{55}P_{36}K_{41}$ ), the increase in active mineral phosphorus compounds compared to the control was significantly less – by 3.02 and 0.61 mg/100 g of soil, respectively.

Content of the most accessible phosphorus fraction for plants (Ca-P<sub>I</sub>) is observed in the variant with the introduction of  $N_{27}P_{18}K_{20}$  – 13.8 mg/100 g of soil, and the least (4.42 mg/100 g of soil) – in the control variant and in the option with the application of mineral fertilisers at the rate  $N_{55}P_{36}K_{41}$ . By the content of strongly bound calcium phosphates (Ca-P<sub>III</sub> fraction) compared to the control variant, the options with the introduction of mineral fertilisers at the rate  $N_{27}P_{18}K_{41}$  and  $N_{81}P_{54}K_{62}$  are very different. In the 0-20 cm soil layer of the control variant, the amount of strongly bound phosphates was 13.92 mg/100 g of soil. In the variant with the addition of  $N_{27}P_{18}K_{41}$ , the content of this fraction increased to 16.19 mg/100 g of soil, which is 2.27 mg/100 g more than in the control. The use of a higher rate of mineral fertilisers contributed to an increase in the Ca-P<sub>III</sub> fraction to 19.72 mg/100 g of soil, which is 5.80 mg/100 g more than in the control version. Application of only mineral fertilisers at the rate  $N_{55}P_{36}K_{41}$  and their application against the background of the aftereffect of organic fertilisers did not contribute to such a significant increase in the content

of strongly bound calcium phosphates relative to the control variant. On the contrary, the content of the Ca-P<sub>III</sub> fraction in the soil, these variants were lower compared to the control and amounted to 13.50 mg/100 g of soil in the variant with an aftereffect of organic fertilisers and 12.16 mg/100 g of soil in the version with the introduction of only mineral fertilisers.

One of the conditions for obtaining high stable crop yields and preventing phosphorus losses from soils is rational management of phosphorus nutrition. The study by Q. Wang *et al.* (2022), which covered a period of more than 29 years, found that the application of mineral fertiliser in the amount of 36 t/ha on chernozem provided higher yields of agricultural crops, and the level of phosphorus compounds compared to non-fertilised variants. However, there was practically no difference in crop yields when using nitrogen-potash and nitrogen-phosphorus-potash fertilisers. A possible reason for this is that adding nitrogen and potassium can increase plant phosphorus uptake and root

biomass. L.P. Yuan *et al.* (2020) suggest that another reason for the lack of changes in crop yields is the rather high phosphorus content in soils. Most crops, especially grain crops, use only mobile forms of phosphorus. It is such crops as rye, wheat, barley and corn that have a very low degree of assimilation of hard-to-dissolve soil phosphorus compounds. This is the reason for a good response to the application of available forms of phosphorous fertilisers. Under these conditions, phosphorus is absorbed more vigorously and calcium is absorbed significantly less. If an excessive amount of calcium cations is formed, they bind phosphorus and transfer it to hard-to-reach forms. It is precisely because of the low availability of phosphorus available to plants in the soil that the payback of phosphorous fertilisers is quite high. The availability of phosphorus compounds in the soil is closely related to the reaction of the soil environment. The studies, conducted on meadow chernozem soil, found that the response of the soil environment varied depending on fertiliser (Fig. 1).



**Figure 1.** Reaction of the soil medium and the content of mobile phosphates according to the Machigin method in meadow chernozem carbonate soil (2019-2022)

Source: compiled by the authors

The control showed the lowest pH values – 6.5 in the 0-20 cm layer of soil and 6.6 in the 20-40 cm layer. Therefore, in these samples, the content of mobile phosphates was determined according to the Chirikov method and it was 15.9 and 17.6 mg/100 g of soil, respectively, according

to the soil layers, which corresponds to a high content (15.1-20.0 mg/100 g of soil). Other soil samples contained carbonates, so the content of mobile phosphates was determined according to the Machigin method. Fertilisation options differed in pH values, which was 6.9-7.3 pH units

in a 0-20 cm layer and 6.8-7.0 in a 20-40 cm layer of meadow chernozem soil. The highest pH value, which corresponds to a slightly alkaline reaction of the soil medium, was 7.3 in the variant with  $N_{27}P_{18}K_{20}$ .

The content of mobile phosphates on fertilised variants was 2.2-4.8 mg/100 g of soil in the upper 0-20 cm layer and 2.5-8.5 mg/100 g of soil in a 20-40 cm layer. Naturally, the highest content of mobile phosphates in the arable and sub-arable layers was on the variant with the highest rate of mineral fertilisers  $N_{81}P_{54}K_{62}$  and rated as high in 0-20 cm layer and very high in 20-40 cm layer. On the variant with an aftereffect of organic fertilisers +  $N_{55}P_{36}K_{41}$ , the content of mobile phosphates according to Machigin was 2.8-3.0 mg/100 g of soil, respectively. Such values indicate an average degree of soil availability.

Based on the research, the effectiveness of organic fertilisers on the phosphorus regime of the soil was proved, as the content of mobile phosphates was slightly lower in the variant with  $N_{55}P_{36}K_{41}$  and amounted to 2.2-3.0 mg/100 g of soil.

G.N. Hospodarenko et al. (2015) based on mathematical analysis of spring barley yield data, show that with low fertilisation rates ( $N_{45}P_{45}K_{45}$ ), it is not possible to maintain it at a constant level, although it was higher compared to areas without fertilisers. In the variants of the experiment with high doses of fertilisers, a decrease in the average annual yield increase was noted over time. The researchers conclude that the nutrient regime of the soil is no longer a limiting factor in the development of the spring barley crop, and its increase is possible due to such factor as the variety (Table 3).

**Table 3.** Influence of fertiliser application on the yield of the Ethana winter wheat variety and the Sumiko sunflower hybrid on meadow chernozem carbonate soil

Fertiliser saturation	Grain yield, t/ha <sup>-1</sup>	
	winter wheat	sunflower
Without fertilisers (control)	4.45 e	2.23 e
Minimum ( $N_{27}P_{18}K_{20}$ )	5.30 d	2.83 d
Aftereffect of organic fertilisers + $N_{55}P_{36}K_{41}$	6.15 c	3.42 b
Average ( $N_{55}P_{36}K_{41}$ )	6.67 b	3.17 c
Optimal ( $N_{81}P_{54}K_{62}$ )	7.55 a	4.28 a

**Note:** means in columns with the different letter are highly significantly different according to the Fisher's test ( $P \leq 0.05$ )

**Source:** compiled by the authors

Analysing the data in Table 3, it should be noted that the use of fertilisers on meadow chernozem carbonate soil had a significant effect on the yield of both winter wheat and sunflower. The yield increase was 0.85-3.1 (winter wheat); 0.60-2.05 t/ha<sup>-1</sup> (sunflower). The highest yield of winter wheat is obtained with optimal fertiliser saturation – 7.55 t/ha<sup>-1</sup>, and the smallest – without fertiliser application – 4.45 t/ha<sup>-1</sup>. The difference between the minimum and average saturation was significant and the increase in yield for the latter was 1.37 t/ha<sup>-1</sup>. When growing sunflower seeds, the average fertiliser saturation also had a greater impact on the yield compared to the minimum, the difference was +0.34 t/ha<sup>-1</sup>. The highest yield of sunflower is obtained with optimal fertiliser saturation –

4.28 t/ha<sup>-1</sup>, and the smallest – without fertiliser application – 2.23 t/ha<sup>-1</sup>.

Other researchers have also conducted similar studies. For example, M. Chen & T.E. Graedel (2016) found that the introduction of superphosphate for 65 years caused a significant increase in the proportion of all mineral phosphate fractions in the soil, except for the calcium-bound fraction. However, no significant effect of superphosphate on the content of organic phosphorus compounds was observed. In the experiment, where manure was used as a fertiliser containing phosphorus in an equivalent amount to superphosphate, the proportion of easily accessible phosphorus mineral compounds in the soil increased compared to the use of mineral fertilisers.

Some long-term studies by J. Ahlgren *et al.* (2013) showed that the combination of mineral fertilisers with organic fertilisers primarily affected the concentration of P in the soil. Phosphorous fertilisers can directly affect the concentration of phosphorus in the soil by ingesting both orthophosphates and organic phosphorus compounds (Abdala *et al.*, 2015; Barrow *et al.*, 2015).

According to the conclusions of the research team, the application of organic fertilisers increased the concentration of organic matter in the soil. This led to an increase in the desorption of mineral phosphorus compounds due to changes in the soil reaction, which led to an increase in the availability of phosphates in soils (Sharpley *et al.*, 2004). C.M. Nobile *et al.* (2020) found that with an increase in the pH value of the acidic soil environment, phosphorus desorption  $\text{Fe}_2\text{O}_3$  s  $\text{Al}_2\text{O}_3$  (or  $\text{Fe}(\text{OH})_3$  and  $\text{Al}(\text{OH})_3$  occurs, instead, phosphorus desorption in carbonate soils occurred with a decrease in the pH value of the soil medium.

J.K. Whalen & C. Chang (2001) considered the accumulation of phosphorus in treated soils due to constant annual applications of mounted manure from a large feeding cowshed over a long period. The study aims to understand how the long-term practice of adding manure from a feeding cowshed to agricultural soils affects the accumulation of phosphorus, which is important for crop growth but can also cause problems in the environment when it accumulates in excessive amounts. The availability of phosphate fractions in the soil also depends on the processes of interaction of soil organic matter with metal oxides. As a result of such processes, some of the phosphorus compounds bind and become less accessible to plants (Fink *et al.*, 2016; Kramer & Chadwick, 2018). Other studies have shown that changes in the composition of phosphate fractions are important for determining the effectiveness of various mineral fertilisers and help to better reveal the availability of phosphorus in soils (Mundus *et al.*, 2017). Only a few comprehensive quantitative studies have covered such research. Another important factor affecting the mobilisation of nutrients is soil microorganisms. Due to the fact that available P is constantly supplied due to insufficient dissolution, desorption, and mineralisation of organic

phosphorus, the level of available compounds depends on the specific soil and climatic conditions, the crop grown, and the date of soil sampling (Tiessen & Moir, 1993).

M.B. McGechan & D.R. Lewis (2002) found that studying the availability of phosphorus compounds is challenging because some of the phosphorus in fertilisers can be fixed by the soil. In those areas where phosphorous fertilisers were applied, the presence of mobile phosphates in the composition of soil colloids and/or bound to soil particles was noted. When applying phosphorous fertilisers, the content of mobile phosphates in the soil increases, the degree of their mobility and availability for plants increases. M. Kulhánek *et al.* (2007) showed a gradual increase in phosphorus concentrations when applying organic and mineral fertilisers. The absorption of phosphorus by barley plants ranged from 9 to 14.5 kg/ha, and an increase in the use of phosphorus led to an increase in the concentration of phosphorus in plants. The closest relationship was found for aqueous extracts and phosphorus uptake by plants when the coefficient of determination was 65%.

Thus, the issue of phosphorus in soils is extremely relevant and complex at the same time. There is no doubt about the role of phosphorus in shaping crop productivity, but in soils, a significant part of the phosphorus reserves cannot be used by plants, since they are in hard-to-reach forms. The conducted research revealed the impact of different levels of fertilisation on phosphate composition and yields.

## CONCLUSIONS

Based on the conducted studies, the influence of long-term fertilisation on the indicators of the phosphorous regime of meadow chernozem soil was established. The group and fractional composition of mineral phosphates according to the Chang-Jackson method in the Ginzburg-Lebedeva modification showed that the largest proportion is occupied by phosphorus compounds that are bound to iron: their content was 31.8–51.19 mg/100 g of soil. An increase in mineral fertilisation rates led to an increase in Al-phosphates. Fraction content (Ca-P), which is most accessible to plants, is noted in variant  $\text{N}_{27}\text{P}_{18}\text{K}_{20}$ . Naturally, the highest content of mobile

phosphates in the arable and sub-arable layers was at optimal fertiliser saturation (option with the highest rate of mineral fertilisers  $N_{81}P_{54}K_{62}$ ) and rated as high and very high respectively. It was 4.8 and 8.5 mg/100 g of soil, respectively. The content of mobile phosphates and the fractional composition of phosphorus compounds depend on the reaction of the soil medium. The lowest pH values (6.5) of meadow chernozem soil were found in the control, where a high content of mobile phosphates was detected; on fertiliser variants, the values were 6.9–7.3 pH units in the arable layer. At the same time, it is difficult to distinguish the effect of the soil reaction from the action of fertilisers, so studies on the dependence of the phosphate regime on pH in different soil conditions with similar fertilisation options will be promising. The minimum, average, and optimal fertiliser saturation on meadow

chernozem carbonate soil had a significant effect on the yield of both winter wheat (0.85-3.1 t/ha<sup>-1</sup>), and sunflower (0.60-2.05 t/ha<sup>-1</sup>).

Future studies may consider different types of fertilisers and their impact on the phosphorus regime and plant yield. Learning the optimal fertiliser combinations can be useful for maximising yields and efficient use of resources. Further studies may also focus on the investigation of various plant species that are grown on meadow chernozem carbonate soils. This will allow understanding how the effect of mineral fertilisers can differ for different crops.

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### CONFLICT OF INTEREST

None.

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## **Оцінка впливу мінеральних добрив на фосфатний режим лучно-чорноземного карбонатного ґрунту та урожайність соняшнику і пшениці озимої**

**Анотація.** Актуальність дослідження полягає в необхідності збереження оптимального рівня рухомого фосфору у карбонатних ґрунтах для підтримки здорового росту та розвитку рослин, оскільки саме в таких ґрунтах він може переходити у менш рухомі форми. Метою дослідження було оцінити вплив різних довгострокових стратегій внесення добрив на вміст різних форм фосфору в ґрунті для покращення цієї доступності. Дослідження проводили у 2019-2022 рр. у стаціонарному досліді у Відокремленому підрозділі Національного

університету біоресурсів і природокористування України «Агрономічна дослідна станція» Київської області на лучно-чорноземному карбонатному малогумусному грубопилувато-легкосуглинковому ґрунті у п'ятипільній сівозміні, де вивчали вплив різних рівнів насиченості добривами (без добрив, мінімальний, середній і оптимальний) на показники фосфатного режиму ґрунту і урожайність пшениці озимої сорту Етана і соняшнику гібриду Суміко. Зразки ґрунту відбирали з шарів 0-20 і 20-40 см, у них визначали групово-фракційний склад фосфатів за методом Чанга-Джексона, вміст рухомих фосфатів за методами Чирикова та Мачигіна. Згідно з аналізом групово-фракційного складу фосфатів ґрунту встановлено, що у лучно-чорноземному карбонатному грубопилувато-легкосуглинковому ґрунті серед усіх фракцій переважає вміст фосфатів заліза за довготривалого внесення добрив. Результати досліджень показали збільшення вмісту фосфатів алюмінію у поверхневому шарі ґрунту 0-20 см двох варіантів за довготривалого внесення добрив, а також підвищення вмісту другої фракції розчинних фосфатів кальцію ( $\text{Ca-P}_{II}$ ), у мінімальній насиченості ( $\text{N}_{27}\text{P}_{18}\text{K}_{20}$ ) відмічено найбільше доступної фракції фосфатів для рослин ( $\text{Ca-P}_I$ ). Уміст рухомих фосфатів був максимальним за оптимальної насиченості добривами ( $\text{N}_{81}\text{P}_{54}\text{K}_{62}$ ) і складав 4.8 і 8.5 мг/100 г ґрунту, післядія органічних добрив позитивно впливала на накопичення рухомих фосфатів у ґрунті. Найбільша урожайність пшениці озимої (7,55 т/га) і соняшнику (4,28 т/га) отримана за оптимальної насиченості добривами, найменша без застосування добрив, де вона склала 4,45 т/га для пшениці озимої та 2,23 т/га у соняшника. Результати дослідження можуть бути використані для розробки більш стійких та ефективних стратегій використання фосфору в ґрунтах, що може сприяти збереженню ґрунтових ресурсів та запобіганню можливого забрудненню водних джерел внаслідок надмірного внесення фосфору

**Ключові слова:** групово-фракційний склад; рухомі фосфати; реакція ґрунтового середовища; мобілізація фосфатів; доступний фосфор

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