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Development of biologically engineered corn growing technologies

Abstract. Agricultural producers use large quantities of mineral fertilisers and plant protection products, which leads to soil, seed and environmental pollution and reduces the profitability of production. Modern agriculture starts to shift its focus to biologisation, which includes the development and implementation of environmentally friendly alternative systems, the reduction of chemicals, the introduction of energy and resource-saving technologies, use of biological plant protection products and bio-organic fertilisers. The research aims to investigate the effectiveness of biological technologies for growing maize in an environmentally friendly way using various organic fertilisers. The following methods were used to study the new corn growing technology: analysis, synthesis, analogy, comparison, and generalisation; field and laboratory; calculation – assessment of economic and bioenergy efficiency. To study the effect of organic fertilisers of different biological origins on the assessment of the humus state of typical chernozems, field experiments were conducted to assess the impact on corn grain yield in the Ukrainian Steppe. After the application of organic fertiliser, the limits of organic carbon content in humus were 3.2-3.5%, humic acid 1.9-2.2%, and fulvic acid 0.7-1.0%. In the experimental samples of maize grain, the content of crude protein ranged from 13.5 to 14.0%, crude fat from 2.4 to 2.7%, crude fibre from 2.1 to 2.4%, crude ash from 1.3 to 1.7%, and nitrogen-free extractives from 64.7 to 67.4%, moisture from 12.0 to 14.9%. The grain yield in the control variant was 9.7 t/ha, and in the experimental plots, it was 11.5-13.4 t/ha. The data obtained can help in the development of biologically based maize cultivation technology following the ecological gradient of cultivation and yield with optimisation of the studied agrotechnical methods

Keywords: yield; humus; organic fertiliser; environmentally friendly products; grain quality

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INTRODUCTION

Climatic conditions have been changing rapidly in recent years, but to continue sustainable harvesting, it is necessary to improve crop production technologies. Modern grain growing technologies harm the technical, biochemical, and hygienic quality of the grain, and they also pollute the soil and the environment with toxic substances that reduce its biological activity and contribute to the accumulation of hazardous chemicals in groundwater. The dependence on chemicals and their indiscriminate use in modern agriculture can cause serious environmental problems: water eutrophication, soil acidification and air pollution.

Maintaining soil fertility with sufficient organic matter of animal origin and growing environmentally friendly products is one of the ways to develop cost-effective crop production. The use of biobased technologies to produce high-quality crops requires improving fertiliser systems and addressing the issue of plant protection against pests and diseases, so the development of new elements of environmentally friendly grain-growing technology and the improvement of existing ones is of great importance.

Demand for organic crop production and certified organic food is growing rapidly in economically developed countries, and according to the Organic Trade Association (2023), corn production is growing steadily every year. Ukraine needs to develop a strong production and scientific potential in the field of crop production with large-scale application of biological farming methods and production of environmentally friendly agricultural products, and a developed organic agriculture sector.

Corn is the main grain and fodder crop in Ukraine and is of strategic importance in agricultural production, as its grain is used in large volumes in the food, industrial, livestock and medical sectors. O. Garazha (2021) considers that an increase in the gross harvest of corn should be achieved exclusively by increasing crop yields and by introducing the latest innovative cultivation technologies that ensure the efficient use of agroclimatic, material and technological resources.

Where agronomic and biological weed control measures are ineffective, one of the most acceptable methods of control in maize crops is the

use of chemical protection products. O.H. Milenko *et al.* (2020) report that intensive cultivation of modern high-yielding maize hybrids involves the application of effective herbicides for weed control – Tornado, Zenkor, Prima, Roundup, Stellar, Harness, Master Power, Primexra Gold, but their main difference from other plant protection products is their high toxicity, in addition, they contain toxic organic and inorganic compounds that quickly penetrate weed tissues through the leaf apparatus and roots, inhibiting the synthesis of amino acids and stopping the vegetative processes of plants. According to B. Fuchs *et al.* (2022), the scope of application of biochemical herbicides is increasingly being improved, which are conventionally divided into four groups: microbial preparations of toxic action; crude extracts of plant or microbial origin; individual natural compounds and their mixtures with varying degrees of purification; synthetic analogues of natural compounds. Practical trials by O.P. Stetsiuk *et al.* (2022) reported that it is better to use effective herbicides but to mitigate the negative impact on the culture, it is recommended to use them in tank mixtures with Biocomplex AT, which is a culture liquid of living soil microorganisms *Azotobacter chroococcum*, *Bacillus subtilis*, *Bacillus megaterium* and organic elements in the form of chelated organic compounds.

Following T.Yu. Marchenko *et al.* (2021), biological products are used in the cultivation of corn for grain by treating seeds with Ecolist-grain at a dose of 4 l/t, Rostok-grain – 4 l/t, Nanomix-corn-seed treatment – 4 l/t, Reakom-SR-grain – 4 l/t, Quantum-grain – 4 l/t. According to K. Bhatt *et al.* (2022), organic production uses plant protection products against diseases and pests based on microbial biological products of endophytic bacteria *Azotobacter*, *Bacillus subtilis*, *Bacillus polymyxa*, *Latobacillus*, *Enterococcus* at the recommended dose for seed treatment before sowing – 2.0 l/t, during the growing season – 0.8 l/ha. The biopolymer and effective adhesive Liposam are applied at doses of 0.3 l/t and 0.4 l/ha. To ensure control of pests such as corn and meadow butterflies, Lepidocid is used – a biopesticide of spore protein crystals of bacteria *Bacillus thuringiensis var. Kurstaki*, which is sprayed on crops during the growing season at a

dose of 3.0 l/ha. Z. Zhang *et al.* (2022) found that to promote the degradation of cellulose residues and to reduce soil phytotoxicity, it is necessary to use complex biodegraders of stubble-containing enzyme complexes of cellulolytic action.

Given the analysed studies, the question of the effective use of available organic fertilisers of animal and plant origin arises, with a comparison of the main chemical parameters of soil composition and the impact on the yield of various crops. The research aims to study the effectiveness of biological technologies using organic fertilisers in growing corn for grain in an environmentally friendly way.

LITERATURE REVIEW

Global yields and productivity of corn (*Zea mays L.*) have doubled since the early 90s of the last centuries, and the significant increase in yields is mainly due to chemical fertilisers, breeding and crop care. According to the Agrarian Information Agency (Korol, 2022), a record corn harvest of 12.1 million tonnes was harvested in 2021-2022, which is 7.4% more than in previous seasons. About 32% of the world's corn is used for food, while the remaining 60% is used to produce livestock and poultry feed.

Maize is a plant with independent inflorescences, the structure of which differs from that of other cereals. The male inflorescence (anthers) is a pinnate inflorescence, and the female inflorescence (pistil) is a pointed inflorescence with three or four ears per plant, of different sizes and shapes. According to L. Wang *et al.* (2022), the characteristics of maize hybrids are given, they are represented by cobs of cylindrical and slightly conical shape, but the number of rows of grains in one ear varies from 8 to 20, but sometimes up to 30. Maize kernels are single-seeded fruits consisting of an endosperm embryo and an outer fruit coat. The colour of the seeds can be white, cream, yellow, orange, red, or even black. Depending on the maize hybrid, the weight of 1000 seeds ranges from 100-150 g to 300-400 g.

The commonly used system in Ukraine is the Food and Agricultural Organisation (2016) (FAO) maize hybrid classification, where the variety of varieties is divided into 900 units from 100 to 999. There are five maturity groups of corn hybrids: FAO 100-200, early maturity –

90-100 days; FAO 201-300 medium early maturity – 105-115 days; medium late maturity FAO 301-400 – 115-200 days; medium late maturity FAO 401-500 – 120-130 days; late maturity FAO 501-600 – 135-140 days.

Haphazard implementation of these measures and failure to consider predecessors and crops sown in subsequent years leads to low efficiency and field abandonment. According to S. Maitra *et al.* (2022), proper crop rotation is of great importance in biobased crop production technology, which provides favourable conditions for soil fertility and crop yields. Crop rotation is used for fertilisation systems, mechanical tillage or crop protection against weeds, pests, and pathogens. Since corn has a high nitrogen requirement, the main precursors should be legumes (peas, soya beans, fodder beans, chickpeas, and lupins), one- to two-year artificial grasses, green manure, and compost.

According to the study of J. Wagemans *et al.* (2022), biological plant protection products are selective, rapidly biodegradable chemicals for plant protection that are safe for the environment due to their properties. Biological plant protection products can be divided into the following groups: based on crude extracts of natural origin: alcohol extracts, aqueous extracts, essential oils, etc.; purified or individual natural compounds; the effect on pests is caused by toxins produced by microorganisms; synthetic derivatives or analogues of substances of natural origin.

Biological plant protection products can act as immune inducers, growth regulators, and detergents to help plants avoid serious damage from pest infestations. According to M.H. Saleem *et al.* (2022), minerals play an important role in the life of maize plants, as maize growth in the early stages before the formation of the first aboveground node is very slow, and the root system is poor and cannot intensively absorb nutrients from the soil. According to research by O. Voloshchuk *et al.* (2021), when developing fertiliser systems, it is necessary to consider that developing maize plants need zinc, boron, molybdenum, cobalt, manganese, and copper. The critical period of maize growth is the formation of seven to eight leaves, but mineral nutrition at this stage improves grain quality by increasing the grain size of the cobs.

W. Shi *et al.* (2020) noted that the use of different doses of mineral fertilisers on podzolic chernozems in field crop rotations can increase corn yields by up to 77%, with the highest figure reaching 13 t/ha and achieved when applying $N_{110}P_{60}K_{80}$ mineral fertilisers per 1 ha of crop rotation area, but the removal of the nitrogen component reduces corn yields by 47%, phosphorus by 25% and potassium by 19%.

Humus, peat, ash, compost, and poultry manure are common types of organic fertilisers, and sapropel, an organic silt, is relatively new. According to a study by C. Andorf *et al.* (2019), the use of organic fertilisers is an effective way to enrich the soil with organic matter, which turns into humus and significantly increases fertility, especially since 1 tonne of organic fertiliser produces 35-50 kg of humus. Organic fertilisers produce fulvic and humic acids in the soil, which directly affect plant productivity and resistance to stressful growing conditions.

MATERIALS AND METHODS

Theoretical methods were used in the study of biologically enhanced maize cultivation technologies: analysis and synthesis, comparison – to assess the economic and bioenergy efficiency of maize hybrids; statistical – to establish the reliability of the research results and their dependence on the influence of anthropogenic factors. Empirical methods: field – analysis of the interaction between the object and the natural environment in combination with yield measurement and biometric data; laboratory – measurement of soil and grain moisture, key grain quality indicators.

The meteorological conditions during the years of research fully reflected the climate of the Mykolaiv region. The climate is arid continental, hot, and windy, with frequent dry winds; the maximum direct solar radiation occurred in July with an average temperature ranging from 25 to 39°C.

The study was carried out at the Oasis farm in Ivanivka village, Pervomaiskyi district, Mykolaiv region, in 2021. The object of the study was a high-yielding medium-early hybrid of corn DN Slavytsia FAO 270, with an average yield of 10-12 t/ha. The recommended density for the harvesting period for the Southern Steppe region was 40-50 thousand plants/ha. According

to the recommendations made by M.I. Bakhmat *et al.* (2022), the seeding rate of maize in organic farming should be 10-11 seeds/m². The experimental variants were arranged in a split-plot design in three replications. The total experimental area was 2.44 hectares. During the research, we used the corn cultivation techniques recommended for the conditions of the region. During the experiment, a weed control strategy was developed: after sowing, blind harrowing was performed, and when the first, third and sixth leaves appeared, scheduled cultivation was carried out. To stimulate growth and avoid the harmful effects of the herbicide on maize seeds, they were treated with a culture liquid containing a composition of live soil microorganisms and organic elements *Azotobacter chroococcum*, *Bacillus subtilis*, *Bacillus megaterium* at a dosage of 1.5 l/t.

The maize parameters were determined by methods established by quality standards following the current regulatory documentation DSTU-4525:2006 (2007). During the laboratory test, special methods were used following generally recognised standards in biology and complex biochemical research edited by V.V. Vlizlo (2012): total Nitrogen content converted to crude protein by the Kjeldahl method; crude fat by the method of extraction with organic solvents, crude fibre, or dietary fibre; crude ash, nitrogen-free extractives (NFE).

The soil of the experimental site is a podzolised heavy loamy chernozem, characterised by a groundwater depth of 20-22 m, a humus percentage of 3.1-3.2%, acidity by pH 5.7-6.8, hydrolytic acidity 4.4-4.8 mg/equivalent, absorption capacity – 25.1-28.9 mg/equivalent, base saturation – 84-87%, alkaline-hydrolysed nitrogen compounds, mobile phosphorus, and potassium compounds – 8-11 mg, 9-12 mg, 12-16 mg per 100 g of soil, respectively.

Low natural soil fertility in the study area is one of the factors contributing to low maize yields, but increasing crop productivity can be achieved by using a balanced plant nutrition system (organic fertilisers and micronutrient fertilisers) that considers the hybrid's response to the proposed rates and adjustments at different stages of crop development. To improve the yield of maize hybrids in the arid zones of the Steppe, seven variants of control and experimental plots

were laid out in three replications with the application of high-quality organic fertiliser:

- 10 t/ha of semi-rotted cattle manure;
- 15 t/ha of semi-rotted cattle manure;
- 7 t/ha of semi-rotted sheep manure;
- 14 t/ha of semi-rotted sheep manure;
- grain straw in doses of 8 t/ha and 16 t/ha.

The experiment used a simply improved corn hybrid DN Slavytisia for grain, developed by the Institute of Grain Farming of the National Academy of Agrarian Sciences of Ukraine, which is characterised by high yield, and drought resistance and is recommended for cultivation in the Ukrainian Steppe. The corn hybrid DN Slavitsa is characterised by a powerful root system that effectively uses the natural fertility of soils; it is resistant to root and

stems rot, callus, helminths, rust, and lodging; it is suitable for cultivation with minimal or no tillage; it forms a flinty-toothed grain type suitable for cultivation technology in areas of insufficient moisture; it quickly releases moisture when fully ripe.

Semi-rotted manure was used as organic fertiliser, which is formed 3-4 months after manure collection and storage, resulting in a homogeneous mass with losses of nitrogen and organic matter of up to 50%. Humus is a source of energy for all biological processes and an adsorbent for pesticides and heavy metals in the soil. Organic fertilisers applied: semi-rotted cattle manure, semi-rotted sheep manure, and grain straw. Table 1 shows the quality of typical chernozem in the 0-20 soil layer.

Table 1. Humus fractional composition

Experiment variant	Total humus content, %	Organic contents of carbon footprint, %	Humic acid content, %	Fulvic acid content, %
Control	5.28	3.07	1.81	0.81
Semi-rotted cattle manure 10 t/ha	5.41	3.54	1.87	0.92
Semi-rotted cattle manure 15 t/ha	5.28	3.48	1.98	0.97
Semi-rotted sheep manure 7 t/ha	5.67	3.49	2.10	0.84
Semi-rotted sheep manure 14 t/ha	5.80	3.45	2.21	0.89
Cereal straw 8 t/ha	5.82	3.38	2.00	0.75
Cereal straw 16 t/ha	5.48	3.18	2.05	0.80

Source: compiled by the authors

Soil quality was determined according to DSTU 7855:2015 (2016), based on the group composition of humus by the Turin method as modified by Kononova and Belchikova. Harvesting and accounting of the crop were carried out manually from each experimental plot using the gravimetric method at the stage of whole grain ripening. Grain moisture was measured from samples of 30 cobs taken during harvesting. The sowing qualities of maize hybrid seeds were determined according to DSTU 2240-93 (1994) and DSTU 4138-2002 (2004). The results of the study were processed using a computer and information systems software, using the methods of analysis of variance, correlation, and statistical analysis. The study was conducted in compliance with the requirements of the Convention on Biological Diversity (1992).

RESULTS

Technical process planning should consider the realisation of weather and economic conditions, clearly define the potential of the growing area of specific fields and reduce the impact of stress factors. Since improper selection and inappropriate use of hybrids are one of the reasons for low yields, it is necessary to study ways to optimise growing conditions for different plant biotypes, as well as the adaptive function and agronomic stability of hybrids. The situation at each experimental site requires careful development of weed control technology, and one of the most commonly used methods in maize crops is currently the use of chemical protection products. At the beginning of the growing season, maize plants develop very slowly and are unable to compete with weed species adapted to cool spring days. In biobased organic production

technology, the main soil cultivation is carried out by ploughing, harrowing, and then planning the sowing, allowing weed seeds to move to deeper layers that cannot germinate from a depth of 1 cm – by 30%, from a depth of 4 cm – by 95%.

The agro-climatic conditions and the length of the growing season of maize hybrids allow for the cultivation of different maturity groups of maize hybrids. Corn hybrids should be selected based on their adaptability to the conditions of a particular soil and climatic zone, high and stable yields, and low pre-harvest moisture content. In the Southern Steppe zone, 30–35% of corn grain is recommended for early and mid-season groups and 50–70% for medium-late groups. Medium and late-ripening corn varieties differ in the total temperature required to achieve biological ripeness from the panicle ejection phase to the onset of biological ripeness of the grain. In 2021, the sum of the active temperatures from sowing to harvesting of corn varied from 2644°C to 2758°C.

The influence of organic fertilisers on the qualitative composition of humus showed that the content of humic acid fractions changed in all studied varieties compared to the control. All maize hybrids did not show a tendency to decrease the total content of humic substances in the soil compared to the control. However, it

should be noted that the limits of organic carbon content were 3.2–3.5%, compared to the control of 3.1%; humic acids – 1.9–2.2% compared to the control of 1.8%; fulvic acids – 0.7–1.0% compared to the control of 0.8%.

Phenological observations indicate that hydrothermal conditions during the growing season of 2021 influenced the timing of the main phases of maize hybrids' development. As a result of the research, the timing of the interphase period of maize hybrid development was established: when the hybrid was sown on 22 April, the sowing-germination period was maximum and equal to 12 days; from germination to panicle flowering, it was noted as long – 59 days; from panicle flowering to milk ripeness of grain – 14 days; from milk ripeness to full grain ripeness – 27 days.

Organic fertilisers are one of the most important elements of modern crop cultivation technologies, allowing not only to significantly increase yields but also to improve their quality. For maize, as a crop with high individual productivity and low ability to compensate for nutrient deficiencies, it is important to evaluate the following parameters: cob length, cob diameter, number of rows of seeds, number of seeds per row, weight of 1000 seeds of the structure is the average number of seeds per cob, the data of the experiment are shown in detail in Table 2.

Table 2. Elements of maize yield structure under organic fertiliser application

Experiment variant	Cob length, cm	Cob diameter, cm	Number of rows of seeds, pcs.	Number of seeds per row, pcs.	Mass of 1000 seeds, g
Control	15.2	3.7	13.5	30.4	223
Semi-rotted cattle manure 10 t/ha	16.2	3.8	13.7	34.1	263
Semi-rotted cattle manure 15 t/ha	16.6	3.9	13.9	34.6	267
Semi-rotted sheep manure 7 t/ha	16.1	3.0	13.8	33.9	263
Semi-rotted sheep manure 14 t/ha	16.8	4.0	13.0	33.0	270
Cereal straw 8 /ha	15.4	3.7	13.3	30.1	238
Cereal straw 16 /ha	15.6	3.8	13.5	30.9	244

Source: compiled by the authors

The number of rows of seeds in a cob is a genetically determined always paired trait, in different hybrids it is more often from 12 to 14 pcs., but to a lesser extent depends on the growing conditions. In the experiment, the number of seeds in a row ranged from 30.4 to 34.6 pcs.

Analysis of the number of rows of seeds (13.0–13.9 pcs.) significantly affects the supply of plants with moisture and temperature, but also affects the efficiency of the use of applied nutrients.

An important structural indicator characterising productivity was the weight of 1000 seeds,

which depended on the morphological characteristics of the hybrid itself and fertiliser options. The control sample without fertilisers and irrigation had the lowest weight of 1000 maize seeds – 223 g, but with the introduction of 15 t/ha of semi-rotted cattle manure, the figure was 267 g, which is 44 g more than in the control. When analysing the weight of 1000 seeds by years of

research, it should be noted that weather conditions during the growing season of 2021 affected the efficiency of nutrient use from the soil.

Grain yield is an important final indicator of the efficiency of maize cultivation technology, which informs how efficiently the plant absorbed solar energy and used energy resources at the end of the growing season, as shown in Table 3.

Table 3. The yield of corn grown for grain in 2021, t/ha

Experiment variant	Repetition			Average
	1	2	3	
Corn grain, control	9.45	10.13	9.53	9.70±0.37
Corn grain, semi-rotted cattle manure 10 t/ha	12.19	13.37	12.01	12.52±0.74
Corn grain, semi-rotted cattle manure 15 t/ha	12.90	14.28	13.15	13.44±0.74
Corn grain, semi-rotted sheep manure 7 t/ha	11.15	12.56	11.82	11.84±0.71
Corn grain, semi-rotted sheep manure 14 t/ha	12.00	13.88	12.67	12.85±0.95
Corn grain, grain straw 8 t/ha	11.15	12.46	10.86	11.49±0.85
Corn grain, grain straw 16 t/ha	11.34	12.16	11.44	11.64±0.45

Source: compiled by the authors

The data in Table 3 show that the grain yield of maize hybrid DN Slavytsia in three replications, which in the control variant was 9.7 t/ha, in the experimental variant – 11.9 t/ha. The use of bioorganic fertilisers in the form of semi-rotted cattle manure, semi-rotted sheep manure

and grain straw increased the yield by 1.4-2.8 t/ha compared to the control. A common analysis in agriculture is the determination of the main nutrients listed in Table 4: protein, fat, ash, fibre, and NFE. Nutrient components are called crude because they are not pure and contain impurities.

Table 4. Chemical composition of corn kernels in terms of natural substance, %

Experiment variant	Humidity	Protein	Fat	Fibre	Ash	Nitrogen-free extractives
Corn grain, control	13.18	13.19	2.63	2.40	1.60	67.00
Corn grain, semi-rotted cattle manure 10 t/ha	12.88	13.50	2.74	2.33	1.65	66.90
Corn grain, semi-rotted cattle manure 15 t/ha	14.87	13.88	2.68	2.20	1.66	64.71
Corn grain, semi-rotted sheep manure 7 t/ha	13.66	13.50	2.57	2.23	1.74	66.30
Corn grain, semi-rotted sheep manure 14 t/ha	13.88	14.00	2.49	2.12	1.34	66.17
Corn grain, grain straw 8 t/ha	12.96	13.56	2.75	2.24	1.57	66.92
Corn grain, grain straw 16 t/ha	12.03	13.94	2.74	2.15	1.69	67.46

Source: compiled by the authors

T.P. Shepilova *et al.* (2021) found that fertilisation increases grain moisture and may require additional drying costs. During the harvesting period, the moisture content of corn hybrids can reach more than 40%, and drying 1 tonne of corn grain to a conditional moisture content of 14% requires a large amount of energy, i.e. fuel

consumption is 60-70% of the total demand for corn growing, so when growing corn, it is necessary to rely on externally controlled factors to create optimal conditions for the growth, development and maturation of corn. In the control, the moisture content was 13.2%, and in the experimental corn grain, it ranged from 12.0% to

14.9%, while the use of organic fertilisers provided an increase in moisture content in the experiments with the addition of semi-rotted cattle and sheep manure compared to the control.

The actual content of nutrients provides reliable information about the amount but does not guarantee a more complete absorption by the animal. In terms of natural substances, the crude protein content of corn grain in the experimental samples ranged from 13.5 to 14.0%, especially in the control, where it was 13.2%, indicating a progressive accumulation of nitrogen-containing substances. The crude fat content was in the range of 2.4-2.7%, crude fibre – 2.1-2.4%, crude ash – 1.3-1.7% and NFE – 64.7-67.4%.

According to the results of the research, it was found that the early maturing hybrid DN Slavytzia, with the addition of semi-rotted cattle manure to the soil, obtained the highest yield of 13.4 t/ha, which is 27.6% higher than the control. The prospect of further research is the study of biologically based technologies for growing hybrids in different maturity groups in the Southern Steppe of Ukraine, with the improvement of plant protection methods and soil cultivation from weeds.

DISCUSSION

The high popularity of corn is the result of the interaction of genetic, environmental, and agronomic factors. The growth in overall corn yields in Ukrainian agriculture is driven by an increase in sown areas and the rational use of hybrid varieties with different growing season lengths. The focus on improving cultivation technology with an emphasis on preserving soil fertility and improving the ecological state of the environment is currently a relevant direction outlined in experimental studies. According to R. Ostapenko *et al.* (2020), in Ukraine, farmers who choose organic production earn higher profits than conventional production. For example, the price of organic corn is 29% higher than that of conventional corn, as well as winter wheat by 26%, pork by 45%, and milk by 7%. However, as the differences in profitability show, the price difference is not yet high enough to support the development of organic agriculture. S. Zhang *et al.* (2019) also confirmed the need to address the complex set of interrelated issues related to increasing

yields on organic farms while reducing prices and preserving the environmental benefits of organic farming.

According to the established technology, regardless of the previous crop, semi-rotted manure and straw were applied in recommended doses of 7 to 25 t/ha during tillage. It should be noted that organic fertilisers applied in autumn can mineralise after harvest, contributing to the risk of nitrate nitrogen leaching in winter. Therefore, it is usually recommended to apply pre-sowing treatments in spring to promote better growth efficiency. When growing maize, the elements of nitrogen, phosphorus and potassium introduced into the soil are of great importance, so organic fertilisers were added to the experimental plots according to the established norms: semi-rotted cattle manure at doses of 10 t/ha and 15 t/ha; semi-rotted sheep manure at 7 t/ha and 14 t/ha; grain straw at 8 t/ha and 16 t/ha.

In addition, it was established that all by-products from crop cultivation should remain on the field, namely straw, stalks, tops, etc. Y. Hamid *et al.* (2020) report on an effective organic soil amendment containing: 40% manure, 10% plant residues, 20% residues from agricultural processing, 25% silt from clean water bodies, and 5% poultry manure. At the same time, the height of the corn plant at the time of harvesting in the control variant without fertilisers was 228.6 cm, the average weight of the cobs was 102 g, and the weight of 1000 seeds was 229 g.

Maize hybrids fertilised with more nitrogen had lower relative stem yields and significantly increased the specific size of cobs and kernels per plant. According to D.M. Zeffa *et al.* (2019), corn should be fertilised with organic fertilisers, as soil enrichment with nutrients contains the elements necessary for plant nutrition: total nitrogen – 3.2%, phosphorus – 2.6%, potassium – 2.0%.

R.P. Lollato *et al.* (2019) argue that at least 40 t/ha of organic fertiliser should be applied to the soil, if possible, with 1 t of fertiliser, the soil receives 5 kg of nitrogen, 2.5-3 kg of phosphorus, 5-6 kg of potassium and a certain amount of macro- and microelements. As noted by C.B. Lobo *et al.* (2019), corn is quite demanding for increased mineral nutrition, as it is a slow-forming crop, i.e., to grow 1 tonne of corn

grain, on average, 25-28 kg of nitrogen, 11-13 kg of phosphorus and 26-29 kg of potassium are required. Thus, to produce 10-12 t/ha of corn, an average of 145-185 kg of nitrogen, 65-85 kg of phosphorus and about 140-185 kg of potassium are removed from the soil.

When growing maize, additional labour costs must be considered, mainly related to mechanical weed control. In maize, the period from germination to the emergence of three or four leaves is the most critical for high yields and stress resistance, as the root system is actively developing during this period, planning its potential yield level. If weeds are not controlled at this time, there is a risk of at least 10% yield loss, gradually increasing to 50%. Y. Shang *et al.* (2019) note that the transpiration coefficient of corn is 320, but that of weeds: couch grass – 470, wheatgrass – 560, thistle – 666, quinoa – 805, mustard – 865.

According to P. Yu *et al.* (2021), it is added that during biobased maize cultivation, rotary harrows or cultivators should be used as a relatively inexpensive but effective solution. Rotary harrows are used before and after emergence. The needle-shaped working part gently combs out the first wave of weeds and dead wood, providing good conditions for the growth of corn seedlings. Ridge harrows, on the other hand, not only loosen the soil between the rows to optimise the conditions for corn seedlings to grow but also physically destroy most weeds and litter. According to C.F. Chukwuneme *et al.* (2020), the use of herbicides against dicotyledonous weeds is allowed to a certain extent, depending on the stage of crop development and the type of harmful plant, in tank mixtures with systemic herbicides: Prima 911 Special Edition (SE) with an application rate of 0.4-0.6 l/ha; Esteron 600 ES – 0.7-0.8 l/ha; Pik 75 WG 0.7-0.8 l/ha; Lancelot 450 WG 0.4-0.5 l/ha; Callisto 480 SC – 0.4-0.6 l/ha.

It should be noted that it is possible to discover herbicides that can be used in organic agriculture in the future. During the experimental study of seeds and stimulation of crop growth, the treatment with a culture liquid in the composition of live soil microorganisms and organ elements *Azotobacter chroococcum*, *Bacillus subtilis*, *Bacillus megaterium* at a dosage of 1.5 l/t was carried out. In B. Kumari *et al.* (2019)

reported that a rather complex multicomponent symbiotic preparation, including 86 regenerative microorganisms, was created to activate maize growth. The preparation, when applied to the soil, gives a healthy direction to the rest of the microbiota, contributing to the fertility of any soil, and even the poorest soil can be revived in 4-5 years.

It should also be noted that climate experts emphasise that climate change in Ukraine will develop in the direction of continental and even sharp continental, and therefore moisture deficit will increase, especially in southern Ukraine. The experiment was quite successful in using a simple modified corn hybrid developed by the Grain Institute of the National Academy of Agrarian Sciences – DN Slavvysia, which was noted for its high productivity in arid regions. One of the ways to increase drought tolerance in maize is to widely use early maturing genotypes that correspond to the FAO 200-290 mid-early hybrid group (2016).

L. Muntean *et al.* (2022) report that to date, breeders have created new maize hybrids with FAO scores ranging from 200 to 500, which are capable of yielding more than 12.0-14.0 t/ha. At the same time, the grain moisture content of the new corn hybrids averages 12-14%, providing opportunities for energy-saving harvesting with minimal drying costs. Given the biological characteristics of corn, it is necessary to implement modern cultivation methods without harming the environment, but the production of the latest breeding hybrids will help to significantly increase grain yields, adjust the length of the growing season, and resist adverse environmental conditions. However, corn productivity can also decline by 20-50% after prolonged stress caused by a lack of nutrients and water in the climatic conditions of the Southern Steppe of Ukraine.

CONCLUSIONS

The biologisation of crop production and farming involves the introduction of environmentally friendly alternative systems and resource-saving technologies with a reduction in the use of mineral fertilisers, herbicides, insecticides, and fungicides. As a result of the research, corn-growing technology elements were

optimised, with organic fertiliser added to the experimental soils.

As a result of the proposed technology, the regularities of crop productivity formation were revealed, and the relevant conclusions were drawn. The maize cultivation process was based on weed control by blind harrowing, with 1, 3, and 6 leaves by planned cultivation. Organic fertilisers of semi-rotted cattle and sheep manure and grain straw were applied to the soil, and the seed was saturated with live soil microorganisms. Soil testing revealed that the organic carbon content ranged from 3.2-3.5%, humic acids from 1.9-2.2%, and fulvic acids from 0.7-1.0%. In the corn grain samples, the crude protein content ranged from 13.5 to 14.0%, crude fat from 2.4 to 2.7%, crude fibre from 2 to 2.4%, crude ash from 1 to 1.7%, NFE from 64.0 to 67.4%, and moisture from 12.0 to 14.9%. Corn grain yield was 9.7 t/ha in the control and 11.5-13.4 t/ha in the experimental plots. The elements of the maize yield structure under the application of organic fertilisers were evaluated by the following indicators: cob length, cob diameter, number of rows of seeds, number of seeds per row, weight of 1000 seeds, which increased by 6.2%, 2.6%,

1.5%, 10.9%, 15.2%, respectively, compared to the control.

The information on the use of biological corn-growing technology is of practical importance and indicates the need for further research on the productivity of corn for grain. The use of microbiological preparations due to the activity of compositions of microorganisms *Azotobacter chroococcum*, *Bacillus subtilis*, and *Bacillus megaterium* increase the amount of nutrients available to maize plants, promoting the activation of cell division and enhancing photosynthetic activity with the growth of the leaf surface of crops.

The data obtained can be used to optimise agronomic practices that are currently relevant. Therefore, one of the promising areas for future research is a detailed study of new drugs to develop biologically based technologies for growing maize according to the ecological gradient of cultivation and maintaining high yields.

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CONFLICT OF INTEREST

None.

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Розроблення біологізованих технологій вирощування кукурудзи

Анотація. Сільськогосподарські виробники використовують багато мінеральних добрив та засобів захисту рослин, що призводить до забруднення ґрунту, насіння та навколишнього середовища та знижує рентабельність виробництва. Сучасне сільське господарство починає звертати увагу на біологізацію, що включає розробку та впровадження екологічно чистих альтернативних систем, зменшення використання хімікатів, впровадження енерго- та ресурсозберігаючих технологій, використання біологічних препаратів для захисту рослин та біоорганічних добрив. Метою цього дослідження є вивчення ефективності біологізованих технологій для вирощування кукурудзи в екологічно чистий спосіб за допомогою різноманітних органічних добрив. Під час дослідження нової технології вирощування кукурудзи використовували методи: аналізу, синтезу, аналогії, порівняння та узагальнення; польові та лабораторні; розрахунку – оцінки економічної та біоенергетичної ефективності. Для вивчення дії різного біологічного походження органічних добрив на оцінку гумусного стану типових чорноземів було проведено польові досліді впливу на врожайність зерна кукурудзи в умовах українського Степу. Після внесення органічного добрива межі вмісту органічного вуглецю у гумусі становили 3,2-3,5 %, гумінової кислоти 1,9-2,2 %, фульвокислоти 0,7-1,0 %. В експериментальних зразках зерна кукурудзи вміст сирого протеїну коливався від 13,5 до 14,0 %, сирого жиру від 2,4 до 2,7 %, сирої клітковини від 2,1 до 2,4 %, сирої золи від 1,3 до 1,7 % та безазотисті екстрактивні речовини від 64,7 до 67,4 %, вологості від 12,0 до 14,9 %. Урожайність зерна у контрольному варіанті становила – 9,7 т/га, дослідних ділянках в межах – 11,5-13,4 т/га. Отримані дані можуть допомогти в розробці біологізованої технології вирощування кукурудзи відповідно до екологічного градієнта обробітку та врожайності з оптимізацією досліджуваних агротехнічних прийомів

Ключові слова: урожайність; гумус; органічне добриво; екологічно чиста продукція; якість зерна