

ECONOMIC EFFICIENCY OF MAIZE CULTIVATION USING DIGESTATE IN UKRAINE*

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Abstract. This article presents the results of a study on the economic efficiency of growing corn for grain, silage, and biomethane production, with the corresponding quality of the products obtained. The research was conducted on the experimental field of Vinnytsia National Agrarian University under ORGANIC-D TOV conditions in 2023-2024. The cultivation techniques included elements that are generally accepted for the cultivation area, with the exception of the factors under study. The yield of grain and green mass, the quality of the products obtained, and the yield of biomethane from corn silage were determined in accordance with established methods. Harvesting and yield accounting were carried out manually on each experimental plot. The fertilisation options studied involved the use of mineral fertilisers ($N_{90}P_{90}K_{90}$), micronutrients (Nanovit corn) and digestate obtained through anaerobic fermentation in biogas plants. Digestate was applied at different times: basic, pre-sowing fertilisation and top dressing at a rate of 60 t/ha. It was established that the indicators of the gross grain production value, by the studied maize hybrids, averaged as follows: Amaros (FAO 230) – 51,380.3 UAH/ha, P 8754 (FAO 240) – 52,521.5 UAH/ha, Bigbit (FAO 290) – 69,193.7 UAH/ha, Bohatyr (FAO 290) – 79,784.3 UAH/ha, KWS 381 (FAO 350) – 80,730.6 UAH/ha, KWS Intelligence (FAO 380) – 84,515.9 UAH/ha, DN Anshlag (FAO 420) – 83,875.8 UAH/ha, and P 0217 (FAO 460) – 84,088.8 UAH/ha. The application of digestate from biogas plants increased the gross production value of grain maize by 8,621–19,392.9 UAH/ha (14.6–26.5%) and of silage maize by 5,448.5–9,804.3 UAH/ha. The use of mineral fertilisers in combination with the microfertiliser “Nanovit Corn” increased these values by 10,270.5–18,954.5 UAH/ha (16.4–27.6%) and 3,359.0–8,804.0 UAH/ha, respectively, compared to the control where no fertilisers were applied. The highest profitability of grain maize cultivation was recorded with triple digestate application (main, pre-sowing, and top dressing): Amaros (FAO 230) – 103.7%, P 8754 (FAO 240) – 118.5%, Bigbit (FAO 290) – 150.3%, and Bohatyr (FAO 290) – 191.6%. For KWS 381 (FAO 350), KWS Intelligence (FAO 380), and P 0217 (FAO 460), the maximum profitability values (186.7–195.5%) were obtained when digestate was applied only as a pre-sowing fertiliser. The hybrid DN Anshlag (FAO 420) demonstrated the highest profitability (183.5%) under the mineral fertiliser + microfertiliser “Nanovit Corn” scheme. A similar trend was observed for the cultivation of silage mass of the studied maize hybrids. The biogas yield from 1 hectare of the studied maize hybrids, corresponding to the respective green mass productivity, ranged from 6,645 to 10,111 m³. Such variations in biogas volume also affected the value of the produced output. The highest profitability indices for cultivating silage maize for biogas production were recorded under triple digestate application (main, pre-sowing fertilisation, and top dressing). For the hybrids, these values amounted to: Amaros (FAO 230) – 200.6%, P 8754 (FAO 240) – 209.0%, Bigbit (FAO 290) – 189.6%, Bohatyr (FAO 290) – 221.8%, KWS 381 (FAO 350) – 237.3%, KWS Intelligence (FAO 380) – 224.8%, DN Anshlag (FAO 420) – 208.8%, and P 0217 (FAO 460) – 210.3%.

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which exceeded the level of the control variant without fertilisers by 40.6–67.3%. From the point of view of economic feasibility, medium-late maturity hybrids are the most effective for growing silage maize.

Keywords: maize, yield, digestate, mineral fertilisers, grain, green mass, profitability, profit, cost price, microelements, fertilisation, biogas.

JEL Classification: O13, Q16, Q42

1. Introduction

Ukraine currently plays an important role in the global economy as a producer of agricultural products. The production of large quantities of agricultural products creates favourable conditions for converting some of it into alternative energy. In order to maintain and strengthen Ukraine's position as an important player in the global agricultural market and a producer of renewable energy, it is necessary to improve crop cultivation technologies, increase their productivity, reduce production costs, and improve economic efficiency indicators.

Scientists note (Jaime A. Teixeira da Silva, Koblianska, Kucher, 2023; Palamarchuk, Krychkovskyi, Rudska, Kolisnyk, 2023; Arreyndip, 2025) that Ukraine is one of the three largest corn producers in the world. The large volumes of corn production are due to favourable soil and climatic conditions, socio-economic indicators, and the availability of technological resources.

Stable demand for agricultural products from Ukraine on the global market is driven by competitive prices and the country's favourable geographical location relative to major importing countries (Maliarchuk, Kotelnikov, Shepel, 2016; Lohosha, Mykhalchyshyna, Prylutskyi, Kubai, 2020; Hontaruk, Furman, Bondarenko, Riabchyk, Nepochatenko, 2024).

Literature review. One of the reserves for increasing corn productivity is optimising the supply of nutrients to plants through the use of traditional and alternative types of fertilisers. Optimal provision of plants with macro- and microelements, as well as the creation of favourable agrophysical conditions for their growth and development, taking into account the principles of resource conservation and environmental safety, contributes to increasing the potential productivity of modern grain and silage corn hybrids (Palamarchuk, 2019; Lohosha, Palamarchuk, Krychkovskyi, 2022; Lohosha, Palamarchuk, Krychkovskyi, 2023). The importance of these issues has grown particularly in the context of a shortage of traditional organic fertilisers, the high cost of mineral resources, the deterioration of soil fertility due to intensive mineralisation of humus, and the increase in erosion processes, which have been significantly exacerbated by Russia's military aggression against Ukraine (Honcharuk, Gontaruk, Pantsyryeva, 2024; Lohosha, Lutkovska, Pidvalna, Pronko, Kolesnyk, 2025).

In a system where plants are provided with nutrients through fertilisation, increasing the cost-effectiveness of mineral fertilisers and irrigation water, as well as reducing the consumption of fuel, lubricants and other resources, is becoming increasingly important in modern crop cultivation technologies. This is particularly relevant in the context of growing water and energy shortages (Pasternak, 2015; Adamchyk, Kravchenko, Kolisnyk, Aralova, Protasov, Dubovyk, Dubovyk, Stavytskyi, 2024).

It should be emphasised that improving the economic efficiency of agricultural production is only possible if the technological processes involved in growing crops are improved, in particular by optimising individual elements of the technology, taking into account the biological characteristics of maize (Ushkarenko, Vozhehova, Holoborodko, Kokovikhin, 2014).

In order to prevent the irrational use of production resources when developing corn cultivation technology, it is advisable to take into account the specifics of production, its main tasks and the available resource potential of agricultural enterprises, which determines their orientation towards intensification or resource conservation. For example, resource-saving technologies aim to achieve maximum efficiency in resource use, ensuring the highest return on investment, while intensive technological approaches are aimed at maximising profits while maintaining a sufficient level of production profitability (Kaminskyi, Saiko, Dushko et al., 2017; Kaminskyi, Asanishvili, 2020; Tokarchuk, Pryshliak, Tokarchuk, Mazur, 2020).

For large commodity producers, it is important to ensure the possibility of obtaining uniform quality products based on the development and implementation of modern cultivation technologies, taking into account the type and specialisation of the agricultural enterprise and its resource base (Kaminskyi, Asanishvili, 2020; Talavyria, Furman, Alexandrov, Drabovskyi, 2025).

High corn productivity is primarily based on increasing the intensity of production, which involves the rational use of resources and the introduction of effective agricultural technologies (Kaminskyi, Asanishvili, 2020; Koval, Atstaja, Filipishyna, Udovychenko, Kryshchal, Gontaruk, 2025). Among the means of intensification in the structure of variable costs in corn cultivation using intensive technologies, the largest share is accounted for by fertiliser costs,

which is due to this crop's high demand for macro- and microelements to achieve significant yields (Baliuk, 2010; Kaminskyi, Asanishvili, 2020).

2. Materials and Methodology

Field studies were conducted during 2023-2024 at the experimental field of the Department of Plant Growing and Horticulture of the Faculty of Agronomy, Horticulture and Plant Protection of the Educational and Scientific Institute of Agrotechnology and Nature Management of Vinnytsia National Agrarian University, based at Organic D TOV.

The results of the final round of agrochemical testing showed that the farm's grey forest soils have an acidic and slightly acidic soil solution reaction (pH 5.4–5.9). In this regard, to improve the mobility of nutrients, it is advisable to combine fertiliser application with chemical reclamation, in particular liming.

In 2023, climatic conditions differed significantly from the long-term average, particularly in spring, during the first and second decades of April, when temperatures dropped, limiting the possibility of early corn sowing. As a result, corn hybrids were sown in the third ten days of April and the first ten days of May. Throughout April, there was a moisture deficit, which negatively affected the uniformity of plant emergence, although subsequently there was almost no difference in development between plants.

Unlike 2023, the climatic conditions of 2024 were significantly below optimal in terms of temperature and precipitation distribution during the growing season, which ultimately had a negative impact on the productivity of all agricultural crops, including corn. A gradual increase in temperatures and uniform precipitation was observed in the spring, but starting in June, there was a sharp rise in temperatures and a prolonged absence of precipitation until September. Already during the July–August period, the temperature values reached 42–47 °C, which in maize plants was often accompanied by loss of turgor and wilting of the leaf blades in the lower leaf layers.

Field trials were conducted in accordance with generally accepted recommendations set out in the "Methodology for conducting field trials with corn" (Lebid, Tsykov, Pashchenko et al., 2008). The accounting area of the plots used in the studies was 25.0 m². The variants were arranged using the randomised block method with four repetitions.

The grain and green mass yield of maize from the study area was recorded in accordance with the requirements of the methodology developed by V. V. Vovkodav (2001), V. O. Yeshchenko (2014) and the methodology for maize (Lebid, Tsykov, Pashchenko et al., 2008).

The biological yield of corn hybrids was calculated using the following formula (1) (Avramenko, Tsekhmeistruk, Hlubokyi et al., 2011):

$$Y_b = M \times K : 1000000 \text{ (t/ha)}, \quad (1)$$

where,

M is the weight of grain from one economically valuable (productive) cob;

K is the number of economically valuable heads per 1 hectare, pcs.

To determine the volume of biogas output from 1 hectare of agricultural crops, the following equation (2) is used:

$$F = \frac{U \cdot c \cdot q}{100} \quad (2)$$

where,

F is biogas output, thousand m³/ha;

U is the yield of green mass, t/ha;

c is the dry matter content in plants, %;

q is the specific yield of biogas from 1 kg of dry matter, m³/kg (corn silage 0.4-0.6 m³/kg) (Medvedovskiy, Ivanenko, 1988; Hrabovskiy, Vakhnii, Khakhula et al., 2021).

The economic efficiency of growing the studied corn hybrids, taking into account different fertilisation systems, was assessed using technological maps that contained a detailed list of costs, including fertilisers, seeds, pesticides, fuel and lubricants, and also took into account yield and other indicators. All costs were estimated based on 2024 prices. The cost of production was taken at the actual selling price (10,150 UAH/tonne) at the end of 2024 and beginning of 2025 (Kaminskyi, Saiko, Dushko et al., 2017; Opria, 2011; Kovalchuk, 2018; Kamenshchuk, 2020).

The experiment employed the conventional maize cultivation technology typical for the soil and climatic conditions of the region, except for the elements under study (fertilisation variants). Soybean served as the preceding crop. After its harvesting, the primary tillage included stubble cultivation with a heavy disc harrow BDT-7, followed by ploughing with a mounted three-bottom plough PLN-3-35 in combination with a DTZ-1204 tractor (120 hp).

To ensure uniform and rapid maize emergence, pre-sowing soil preparation was carried out using a soil compactor AKPK-3 (Europack type) with a working width of 3 m and an operating speed of 10–12 km/h. A single pass of this unit provided soil crushing, levelling, loosening, and the formation of a seedbed at the required depth.

The studies involved maize hybrids from the companies "Pioneer" and "KWS": early-medium – Amaro (FAO 230), P 8754 (FAO 240), Bigbit (FAO 290), Bohatyr (FAO 290); medium – KWS 381 (FAO 350), KWS Intelligence (FAO 380); and medium-late – DN Anshlag (FAO 420), P 0217 (FAO 460). Sowing was carried out when the soil temperature at the seed placement depth reached 10–12 °C, using an eight-row pneumatic seeder John

Deere 7000 at a seeding rate of 70,000 kernels per hectare.

The fertilisation options studied involved the use of mineral fertilisers ($N_{90}P_{90}K_{90}$), micronutrients (Nanovit corn) and digestate obtained through anaerobic fermentation in biogas plants. Digestate was applied at different times: basic, pre-sowing fertilisation and top dressing at a rate of 60 t/ha.

The studies used digestate obtained by 14-day anaerobic fermentation of pig manure in a biogas reactor. The manure came from pigs raised on a probiotic diet without the use of antibiotics, which contributed to the more active development of methanotrophic microorganisms. The resulting digestate had a balanced content of macroelements (nitrogen, phosphorus, potassium, calcium, magnesium, sulphur) and microelements (copper, zinc, manganese, iron, molybdenum), and was also characterised by a favourable microbiological composition.

Nanovit Corn is a liquid complex microfertiliser suitable for use on sorghum and corn crops. It contains macronutrients (nitrogen (N), phosphorus (P_2O_5), magnesium (MgO), sulphur (S)), microelements (zinc (Zn) and copper (Cu)), and the biologically active complex "NANOACTIV". In addition, this microfertiliser contains 15 L-amino acids (glycine, lysine, proline, alanine, cystine, valine, methionine, isoleucine, leucine, tyrosine, tryptophan, histidine, phenylalanine, glutamine, glutamic acid), phytohormones, monosaccharides, and organic acids. In addition, Nanovit Corn microfertiliser contains a polysaccharide adhesive.

The crops were treated with Nanovit Corn microfertiliser at the 5-7 leaf stage of the crop at a rate of 1.5 l/ha, simultaneously with the application of Melagro herbicide (active ingredient – nicosulfuron) in combination with Trend adhesive to control annual and perennial dicotyledonous and grass weeds at a rate of 1.25 l/ha, using a backpack sprayer with a working solution consumption of 5 l per 100 m². Spraying of the experimental plots was carried out in the morning or evening using a backpack sprayer, with a working fluid application rate of 5 l/100 m².

The experiments were carried out in accordance with stage II of the applied research project "Development of environmentally friendly technologies for growing bioenergy crops to ensure energy independence and soil conservation for climate neutrality" (state registration number 0124U000483, completion date 2024-2025), which is funded by the state budget.

3. Research Results

An analysis of the economic feasibility of using different fertilisation options for silage and grain corn hybrids of different maturity groups, depending on the application of digestate from biogas plants and the

use of mineral fertilisers in combination with Nanovit Corn microfertiliser, was carried out based on actual production costs on the farm. The calculations were made in accordance with technological charts and analytical data collected over years of research, reflecting the volume of costs, production results and sales of the products obtained. During economic calculations for corn cultivation, the cost of production was determined based on current sales prices for the current year – 8,350 UAH/tonne of grain and 1,800 UAH/tonne of green mass. The price of biogas was calculated by equating it to the exchange value of natural gas on the ICE (London) platform, which in March 2025 was 520 EUR per 1,000 m³.

The calculation of the economic efficiency of corn cultivation technology for green mass, grain and biogas under different fertilisation options is presented in Tables 1-3.

On average, over two years of research, the grain yield of the studied hybrids varied between 5.05 and 11.55 t/ha. Such fluctuations in yield led to differences in the value of gross production per hectare, which was due to the biological characteristics of the hybrids and the fertilisation options used.

The indicators of the gross production value, by the studied maize hybrids, averaged as follows: Amaros (FAO 230) – 51,380.3 UAH/ha, P 8754 (FAO 240) – 52,521.5 UAH/ha, Bigbit (FAO 290) – 69,193.7 UAH/ha, Bohatyr (FAO 290) – 79,784.3 UAH/ha, KWS 381 (FAO 350) – 80,730.6 UAH/ha, KWS Intelligence (FAO 380) – 84,515.9 UAH/ha, DN Anshlag (FAO 420) – 83,875.8 UAH/ha, and P 0217 (FAO 460) – 84,088.8 UAH/ha.

The application of digestate from biogas plants increased the value of gross production by 8,621-19,392.9 UAH/ha (14.6-26.5%), and the use of mineral fertilisers in combination with the microfertiliser Nanovit Corn increased it by 10,270.5-18,954.5 UAH/ha (16.4-27.6%) compared to the control, where no fertilisers were used.

Production costs in cultivation technologies with different fertilisation options ranged from 24,970.0 to 32,950.0 UAH/ha.

The conditional net profit of the studied maize hybrids, corresponding to their respective yield levels, amounted to: Amaros (FAO 230) – 23,719.5 UAH/ha, P 8754 (FAO 240) – 25,129.8 UAH/ha, Bigbit (FAO 290) – 40,217.0 UAH/ha, Bohatyr (FAO 290) – 49,620.9 UAH/ha, KWS 381 (FAO 350) – 50,653.1 UAH/ha, KWS Intelligence (FAO 380) – 54,122.6 UAH/ha, DN Anshlag (FAO 420) – 53,529.1 UAH/ha, and P 0217 (FAO 460) – 53,771.3 UAH/ha.

The application of digestate from biogas plants increased the conditional net profit by 5,905.1-17,022.9 UAH/ha, while the use of mineral fertilisers in combination with the microfertiliser

Table 1

**Economic efficiency of corn hybrid cultivation technology for grain under different fertilisation options
(average for 2023-2024)**

Hybrid name	Fertilisation option	Grain yield, t/ha	Gross production value, UAH/ha	Production costs, UAH/ha	Cost of 1 tonne of products, UAH.	Conditional net profit, UAH/ha	Profitability level, %
Amaros (FAO 230)	1 (K)	5,26	43921,0	25270	4804,2	18651,0	73,8
	2	6,85	57197,5	28080	4099,3	29117,5	103,7
	3	6,04	50434,0	27955	4628,3	22479,0	80,4
	4	6,33	52855,5	27960	4417,1	24895,5	89,0
	5	5,95	49682,5	27950	4697,5	21732,5	77,8
	6	6,49	54191,5	28750	4429,9	25441,5	88,5
P8754 (FAO 240)	1 (K)	5,05	42167,5	24970	4944,6	17197,5	68,9
	2	7,48	62458,0	28580	3820,9	33878,0	118,5
	3	6,08	50768,0	27970	4600,3	22798,0	81,5
	4	6,85	57197,5	28410	4147,4	28787,5	101,3
	5	5,69	47511,5	25670	4511,4	21841,5	85,1
	6	6,59	55026,5	28750	4362,7	26276,5	91,4
Bigbit (FAO 290)	1 (K)	6,46	53941,0	25630	3967,5	28311,0	110,5
	2	9,47	79074,5	31590	3335,8	47484,5	150,3
	3	8,79	73396,5	29520	3358,4	43876,5	148,6
	4	8,84	73814,0	29630	3351,8	44184,0	149,1
	5	7,65	63877,5	28010	3661,4	35867,5	128,1
	6	8,51	71058,5	29480	3464,2	41578,5	141,0
Bohatyr (FAO 290)	1 (K)	7,69	64211,5	27990	3639,8	36221,5	129,4
	2	11,28	94188,0	32300	2863,5	61888,0	191,6
	3	9,55	79742,5	30100	3151,8	49642,5	164,9
	4	9,98	83333,0	30250	3031,1	53083,0	175,5
	5	8,88	74148,0	29980	3376,1	44168,0	147,3
	6	9,95	83082,5	30360	3051,3	52722,5	173,7
KWS 381 (FAO 350)	1 (K)	7,75	64712,5	28120	3628,4	36592,5	130,1
	2	10,70	89345,0	32180	3007,5	57165,0	177,6
	3	9,84	82164,0	29990	3047,8	52174,0	174,0
	4	10,35	86422,5	30140	2912,1	56282,5	186,7
	5	9,40	78490,0	29650	3154,3	48840,0	164,7
	6	9,97	83249,5	30385	3047,6	52864,5	174,0
KWS Intelligence (FAO 380)	1 (K)	8,29	69221,5	28440	3430,6	40781,5	143,4
	2	11,55	96442,5	32950	2852,8	63492,5	192,7
	3	10,33	86255,5	30130	2916,7	56125,5	186,3
	4	10,66	89011,0	30240	2836,8	58771,0	194,3
	5	9,34	77989,0	29970	3208,8	48019,0	160,2
	6	10,56	88176,0	30630	2900,6	57546,0	187,9
DN Anshlag (FAO 420)	1 (K)	8,48	70808,0	28750	3390,3	42058,0	146,3
	2	11,16	93186,0	32630	2923,8	60556,0	185,6
	3	10,17	84919,5	30090	2958,7	54829,5	182,2
	4	10,23	85420,5	30110	2943,3	55310,5	183,7
	5	9,90	82665,0	30070	3037,4	52595,0	174,9
	6	10,33	86255,5	30430	2945,8	55825,5	183,5
P 0217 (FAO 460)	1 (K)	8,77	73229,5	28840	3288,5	44389,5	153,9
	2	11,19	93436,5	32590	2912,4	60846,5	186,7
	3	9,90	82665,0	29960	3026,3	52705,0	175,9
	4	10,71	89428,5	30260	2825,4	59168,5	195,5
	5	9,40	78490,0	29510	3139,4	48980,0	166,0
	6	10,41	86923,5	30385	2918,8	56538,5	186,1

Note: **Fertilisation option:** 1 – Control (without fertilisers); 2 – Basic fertilisation with digestate (60 t/ha) + pre-sowing application of digestate (60 t/ha) + top dressing with digestate (60 t/ha); 3 – Top dressing with digestate (60 t/ha); 4 – Pre-sowing fertilisation with digestate (60 t/ha); 5 – Main fertilisation with digestate (60 t/ha); 6 – Application of mineral fertilisers (N₉₀P₉₀K₉₀) in combination with Nanovit corn microfertiliser (phase S-7 corn leaves, application rate 1.5 l/ha).

Nanovit Corn increased it by 6,790.5-16,764.5 UAH/ha compared to the control without fertilisers.

The profitability level of cultivating the studied maize hybrids, depending on the fertilisation systems, ranged from 68.9 % to 195.5 %. The highest profitability was recorded under the triple application of digestate (basic, pre-sowing, and top dressing): Amaros (FAO 230) – 103.7 %, P 8754 (FAO 240) – 118.5 %, Bigbit (FAO 290) – 150.3 %, and Bohatyr (FAO 290) – 191.6 %. For KWS 381 (FAO 350), KWS Intelligence (FAO 380), and P 0217 (FAO 460), the maximum values (186.7–195.5 %) were obtained when digestate was applied only as a pre-sowing fertiliser. The hybrid DN Anshlag (FAO 420) demonstrated the highest profitability (183.5 %) under the treatment combining mineral fertiliser with the microfertiliser "Nanovit Corn".

Table 2 shows the economic efficiency of growing silage corn hybrids depending on the fertilisation option.

The corn hybrids involved in the research were suitable for grain and silage production. Over the years of research, the average green mass yield of these hybrids ranged from 42.91 to 72.49 t/ha.

The gross output value of green mass among the studied maize hybrids was as follows: Amaros (FAO 230) – 87,033.0 UAH/ha, P 8754 (FAO 240) – 91,038.0 UAH/ha, Bigbit (FAO 290) – 99,969.0 UAH/ha, Bohatyr (FAO 290) – 108,420.0 UAH/ha, KWS 381 (FAO 350) – 115,911.0 UAH/ha, KWS Intelligence (FAO 380) – 119,550.0 UAH/ha, DN Anshlag (FAO 420) – 121,377.0 UAH/ha, and P 0217 (FAO 460) – 125,697.0 UAH/ha. It was established that an increase in the vegetation period (FAO) contributes to the rise not only in green mass yield but also in the gross product value. In particular, hybrids of the medium-late maturity group (FAO 420–460) exceeded the values of medium-early hybrids (FAO 230–240) by 12,957.0–34,344.0 and 17,277.0–38,664.0 UAH/ha, respectively. Therefore, the use of such hybrids is more appropriate for silage production compared with medium-early hybrids with a low FAO index (230–240).

The costs of growing silage maize of the studied hybrids ranged from 45,150 to 51,320 UAH/ha. An increase in costs was recorded for variants with the application of digestate and mineral fertilisers, which is also associated with their effect on the pre-harvest moisture content of the grain.

The cost price of the grown green mass ranged from 707.96 to 1052.20 UAH/t. The increase in the yield of vegetative mass of the studied hybrids contributes to a reduction in the cost price of the produced products.

The analysis showed that the conditional net profit of different maize hybrids varied considerably depending on their biological characteristics.

The average profit indicators were as follows: Amaros (FAO 230) – 39,610.2 UAH/ha, P 8754 (FAO 240) – 43,043.0 UAH/ha, Bigbit (FAO 290) – 51,400.7 UAH/ha, Bohatyr (FAO 290) – 59,401.7 UAH/ha, KWS 381 (FAO 350) – 66,547.7 UAH/ha, KWS Intelligence (FAO 380) – 69,866.7 UAH/ha, DN Anshlag (FAO 420) – 71,662.0 UAH/ha, and P 0217 (FAO 460) – 75,372.0 UAH/ha.

The application of digestate from biogas plants resulted in an increase in net profit of 5,448.5-9,804.3 UAH/ha, while the use of mineral fertilisers in combination with the microfertiliser Nanovit Corn contributed to an increase in profit of 3359.0-8804.0 UAH/ha compared to the control without fertiliser application.

The highest level of profitability was observed under the triple application of digestate (basic, pre-sowing fertilisation, and top dressing) across all studied maize hybrids, averaging: Amaros (FAO 230) – 99.0 %, P 8754 (FAO 240) – 102.4 %, Bigbit (FAO 290) – 112.8 %, Bohatyr (FAO 290) – 127.0 %, KWS 381 (FAO 350) – 141.5 %, KWS Intelligence (FAO 380) – 146.6 %, DN Anshlag (FAO 420) – 150.3 %, and P 0217 (FAO 460) – 154.3 %. In the control treatment without fertiliser application, the profitability level was 1.5–14.7 % lower, amounting respectively to 71.1 %, 82.7 %, 102.7 %, 119.9 %, 128.4 %, 133.9 %, 136.4 %, and 142.4 %.

In the present study, the economic efficiency of silage corn cultivation as a raw material for biogas production, contingent on the fertilisation option, was calculated (see Table 3). As with the cultivation of corn for bioethanol production, growing corn for biogas production is more profitable than for grain and feed purposes, as evidenced by the profitability levels obtained.

The biogas yield per hectare of the studied corn hybrids, with the corresponding green mass yield, ranged from 6.645 to 10.111 m³. Such fluctuations in biogas volume also affected the cost of production.

It should be noted that significant increases in yield and, accordingly, biogas output were accompanied by an increase in resource intensity of production, which led to some growth in production costs. The total costs of growing green corn mass and producing biogas amounted to 62,680-69,320 UAH/ha (see Table 3).

The average level of conditional net profit for the studied period was as follows: Amaros (FAO 230) – 108,959.3 UAH/ha, P 8754 (FAO 240) – 113,196.7 UAH/ha, Bigbit (FAO 290) – 108,091.8 UAH/ha, Bohatyr (FAO 290) – 130,655.2 UAH/ha, KWS 381 (FAO 350) – 136,090.8 UAH/ha, KWS Intelligence (FAO 380) – 134,842.5 UAH/ha, DN Anshlag (FAO 420) – 127,834.8 UAH/ha, and P 0217 (FAO 460) – 128,585.5 UAH/ha.

The application of digestate from biogas plants contributed to an increase in net profit by 18,409.5-

Table 2

**Economic efficiency of silage corn hybrid cultivation technology under different fertilisation options
(average for 2023-2024)**

Hybrid name	Fertilisation option	Grain yield, t/ha	Gross production value, UAH/ha	Production costs, UAH/ha	Cost of 1 tonne of products, UAH.	Conditional net profit, UAH/ha	Profitability level, %
Amaros (FAO 230)	1 (K)	42,91	77238	45150	1052,20	32088,0	71,1
	2	53,92	97056	48765	904,40	48291,0	99,0
	3	48,27	86886	47820	990,68	39066,0	81,7
	4	51,45	92610	47895	930,90	44715,0	93,4
	5	45,83	82494	46997	1025,46	35497,0	75,5
	6	47,73	85914	47910	1003,77	38004,0	79,3
P8754 (FAO 240)	1 (K)	45,91	82638	45240	985,41	37398,0	82,7
	2	55,34	99612	49210	889,23	50402,0	102,4
	3	52,44	94392	48620	927,15	45772,0	94,1
	4	53,49	96282	48690	910,26	47592,0	97,7
	5	46,83	84294	48150	1028,19	36144,0	75,1
	6	49,45	89010	48060	971,89	40950,0	85,2
Bigbit (FAO 290)	1 (K)	51,43	92574	45680	888,20	46894,0	102,7
	2	59,05	106290	49950	845,89	56340,0	112,8
	3	56,68	102024	49120	866,62	52904,0	107,7
	4	57,09	102762	49220	862,15	53542,0	108,8
	5	52,63	94734	48150	914,88	46584,0	96,7
	6	56,35	101430	49290	874,71	52140,0	105,8
Bohatyr (FAO 290)	1 (K)	56,23	101214	46030	818,60	55184,0	119,9
	2	63,58	114444	50420	793,02	64024,0	127,0
	3	60,85	109530	49350	811,01	60180,0	121,9
	4	62,47	112446	49825	797,58	62621,0	125,7
	5	58,31	104958	49100	842,05	55858,0	113,8
	6	59,96	107928	49385	823,63	58543,0	118,5
KWS 381 (FAO 350)	1 (K)	59,45	107010	46850	788,06	60160,0	128,4
	2	68,34	123012	50940	745,39	72072,0	141,5
	3	65,38	117684	49530	757,57	68154,0	137,6
	4	66,87	120366	49910	746,37	70456,0	141,2
	5	61,77	111186	49280	797,80	61906,0	125,6
	6	64,56	116208	49670	769,36	66538,0	134,0
KWS Intelligence (FAO 380)	1 (K)	60,96	109728	46920	769,69	62808,0	133,9
	2	70,06	126108	51130	729,80	74978,0	146,6
	3	67,36	121248	49670	737,38	71578,0	144,1
	4	68,79	123822	50480	733,83	73342,0	145,3
	5	64,56	116208	49580	767,97	66628,0	134,4
	6	66,77	120186	50320	753,63	69866,0	138,8
DN Anshlag (FAO 420)	1 (K)	61,79	111222	47050	761,45	64172,0	136,4
	2	71,00	127800	51050	719,01	76750,0	150,3
	3	68,20	122760	49860	731,09	72900,0	146,2
	4	69,49	125082	49950	718,81	75132,0	150,4
	5	66,40	119520	49710	748,64	69810,0	140,4
	6	67,71	121878	50670	748,34	71208,0	140,5
P 0217 (FAO 460)	1 (K)	63,62	114516	47240	742,53	67276,0	142,4
	2	72,49	130482	51320	707,96	79162,0	154,3
	3	71,32	128376	50980	714,81	77396,0	151,8
	4	71,61	128898	51090	713,45	77808,0	152,3
	5	69,70	125460	50950	730,99	74510,0	146,2
	6	70,25	126450	50370	717,01	76080,0	151,0

Note: **Fertilisation option:** 1 – Control (without fertilisers); 2 – Basic fertilisation with digestate (60 t/ha) + pre-sowing application of digestate (60 t/ha) + top dressing with digestate (60 t/ha); 3 – Top dressing with digestate (60 t/ha); 4 – Pre-sowing fertilisation with digestate (60 t/ha); 5 – Main fertilisation with digestate (60 t/ha); 6 – Application of mineral fertilisers ($N_{90}P_{90}K_{90}$) in combination with Nanovit corn microfertiliser (phase 5-7 corn leaves, application rate 1.5 l/ha).

Table 3

Economic assessment of growing silage corn hybrids for biogas production depending on fertilisation options (for 2024)

Hybrid name	Fertilisation option	Grain yield, t/ha	Gross production value, UAH/ha	Production costs, UAH/ha	Cost of 1 tonne of products, UAH.	Conditional net profit, UAH/ha
Amaros (FAO 230)	1 (K)	6,645	152835	63150	89685,0	142,0
	2	8,725	200675	66765	133910,0	200,6
	3	7,435	171005	65820	105185,0	159,8
	4	7,655	176065	65895	110170,0	167,2
	5	7,092	163116	64997	98119,0	151,0
	6	7,939	182597	65910	116687,0	177,0
P8754 (FAO 240)	1 (K)	6,658	153134	63340	89794,0	141,8
	2	9,030	207690	67210	140480,0	209,0
	3	7,872	181056	66620	114436,0	171,8
	4	8,395	193085	66690	126395,0	189,5
	5	6,860	157780	66150	91630,0	138,5
	6	7,935	182505	66060	116445,0	176,3
Bigbit (FAO 290)	1 (K)	6,722	154606	62680	91926,0	146,7
	2	8,305	191015	65950	125065,0	189,6
	3	7,597	174731	64930	109801,0	169,1
	4	7,787	179101	65220	113881,0	174,6
	5	6,815	156745	64150	92595,0	144,3
	6	7,851	180573	65290	115283,0	176,6
Bohatyr (FAO 290)	1 (K)	7,597	174731	64030	110701,0	172,9
	2	9,572	220156	68420	151736,0	221,8
	3	8,386	192878	67350	125528,0	186,4
	4	8,820	202860	67825	135035,0	199,1
	5	7,972	183356	67100	116256,0	173,3
	6	9,220	212060	67385	144675,0	214,7
KWS 381 (FAO 350)	1 (K)	7,771	178733	64850	113883,0	175,6
	2	10,111	232553	68940	163613,0	237,3
	3	8,510	195730	67530	128200,0	189,8
	4	9,124	209852	67910	141942,0	209,0
	5	8,084	185932	67280	118652,0	176,4
	6	9,475	217925	67670	150255,0	222,0
KWS Intelligence (FAO 380)	1 (K)	7,724	177652	64820	112832,0	174,1
	2	9,620	221260	68130	153130,0	224,8
	3	8,573	197179	67670	129509,0	191,4
	4	9,153	210519	68480	142039,0	207,4
	5	8,380	192740	67580	125160,0	185,2
	6	9,335	214705	68320	146385,0	214,3
DN Anshlag (FAO 420)	1 (K)	7,587	174501	65050	109451,0	168,3
	2	9,271	213233	69050	144183,0	208,8
	3	8,264	190072	67860	122212,0	180,1
	4	8,787	202101	67950	134151,0	197,4
	5	8,022	184506	67710	116796,0	172,5
	6	9,082	208886	68670	140216,0	204,2
P 0217 (FAO 460)	1 (K)	7,625	175375	65080	110295,0	169,5
	2	9,353	215119	69320	145799,0	210,3
	3	8,435	194005	68980	125025,0	181,2
	4	8,785	202055	69090	132965,0	192,5
	5	8,204	188692	68950	119742,0	173,7
	6	8,959	206057	68370	137687,0	201,4

Note: **Fertilisation option:** 1 – Control (without fertilisers); 2 – Basic fertilisation with digestate (60 t/ha) + pre-sowing application of digestate (60 t/ha) + top dressing with digestate (60 t/ha); 3 – Top dressing with digestate (60 t/ha); 4 – Pre-sowing fertilisation with digestate (60 t/ha); 5 – Main fertilisation with digestate (60 t/ha); 6 – Application of mineral fertilisers (N₉₀P₉₀K₉₀) in combination with Nanovit corn microfertiliser (phase 5-7 corn leaves, application rate 1.5 l/ha).

24,627.5 UAH/ha (or by 15.6-25.1%), while the use of mineral fertilisers in combination with the microfertiliser Nanovit Corn increased it by 23,357.0-36,372.0 UAH/ha (or by 21.3-26.7%) compared to the control (without fertiliser application). A similar trend was observed in profitability: the highest indicators were recorded with three applications of digestate (basic, pre-sowing fertilisation and top dressing). For the hybrids, the values were as follows: Amaros (FAO 230) – 200.6 %, P 8754 (FAO 240) – 209.0 %, Bigbit (FAO 290) – 189.6 %, Bohatyr (FAO 290) – 221.8 %, KWS 381 (FAO 350) – 237.3 %, KWS Intelligence (FAO 380) – 224.8 %, DN Anshlag (FAO 420) – 208.8 %, and P 0217 (FAO 460) – 210.3 %, which exceeded the profitability level of the control treatment without fertiliser by 40.6–67.3 %.

4. Conclusions

The profitability level of maize hybrid cultivation technologies for grain under different fertilisation treatments ranged from 68.9 % to 195.5 %. The highest profitability values for grain maize were recorded under the triple application of digestate (basic, pre-sowing fertilisation, and top dressing) for the following hybrids: Amaros (FAO 230) – 130.7 %, P 8754 (FAO 240) – 118.5 %, Bigbit (FAO 290) – 150.3 %, and Bohatyr (FAO 290) – 191.6 %.

It was established that prolongation of the vegetation period (FAO) positively affects not only the green mass yield but also the gross product value. In particular, for the medium-late maturity hybrids DN Anshlag and P 0217 (FAO 420–460), the value was higher by 30,339.0–34,344.0 UAH/ha and 34,659.0–38,664.0 UAH/ha, respectively, compared with the medium-early hybrids with the lowest FAO indices (230–240). Therefore, the use of such hybrids is more advisable for silage production than the cultivation of medium-early hybrids with low FAO values.

The application of biogas plant digestate increased the conditional net profit from silage maize cultivation by 5,448.5–9,804.3 UAH/ha, while the use of mineral fertilisers combined with the microfertiliser "Nanovit Corn" contributed to an increase of 3,359.0–8,804.0 UAH/ha compared with the control treatment without fertilisation.

The biogas yield per hectare of the studied maize hybrids, corresponding to their green mass productivity, ranged from 6,645 to 10,111 m³, which also influenced the overall product value.

Thus, in maize cultivation technologies for both grain and silage, fertilisation systems involving biogas digestate and mineral fertilisers in combination with the microfertiliser "Nanovit Corn", although requiring higher input costs, prove to be the most profitable due to increased plant productivity.

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