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Roman Lohosha[1], Vitalii Palamarchuk[2], Vadim Krychkovskyi[3], Nina Rudska[4]

The use of digestate for fertilizing corn as an element of sustainable development of rural areas in Ukraine

Abstract: This study examines the influence of energy-efficient and environmentally sustainable components of sustainable development on the production of bioorganic fertilizer "Effluent", derived from the anaerobic digestion of pig manure in a biogas facility. The research focuses on its application in corn cultivation technologies to enhance crop yield and quality. The authors considered the technologies of using liquid manure as an organic fertilizer, which is currently the most rational way of directly applying it to the fields after preliminary anaerobic fermentation in biogas plants. This fertilizer has been found to contain a significant amount of macro- and microelements and beneficial microflora. The application of such fertilizers addresses the environmental aspect of livestock waste management, particularly from pig farms, contributes to the energy sector through biogas production, and mitigates economic and social challenges within the agricultural industry. The findings of this study confirm that optimizing plant nutrition through

✉ Corresponding Author: Roman Lohosha; e-mail: romanlohosha@gmail.com

[1] Ministry of Education and Science of Ukraine, Vinnytsia National Agrarian University, Ukraine; ORCID iD: 0000-0001-6462-5083; e-mail: romanlohosha@gmail.com

[2] Ministry of Education and Science of Ukraine, Vinnytsia National Agrarian University, Ukraine; ORCID iD: 0000-0002-4906-3761; e-mail: vd-palamarchuk@ukr.net

[3] Ministry of Education and Science of Ukraine, Vinnytsia National Agrarian University, Ukraine; ORCID iD: 0000-0003-4415-0708; e-mail: organik.d.ltd@gmail.com

[4] Ministry of Education and Science of Ukraine, Vinnytsia National Agrarian University, Ukraine; ORCID iD: 0000-0001-5771-407X; e-mail: nina.rudska@gmail.com

a balanced supply of macro- and microelements can significantly enhance productivity, improve product quality, and contribute to soil fertility. The use of the bio-organic fertilizer “Effluent”, derived from digestate, presents a sustainable solution for the disposal of livestock waste from large industrial complexes, while simultaneously promoting the sustainable development of agriculture and local communities. This approach enables the production of organic plant and vegetable products while simultaneously managing livestock waste, optimizing the use of natural resources, reducing environmental pollution, and contributing to the nation’s food and energy security as well as the sustainable development of rural areas.

Keywords: digestate, energy independence, energy autonomy, biogas production, livestock waste, climate change, biogas stations

Introduction

Ukraine is among the world’s leading agricultural producers, cultivating plant-based products that not only meet domestic demand but also make a significant contribution to the global market. Currently, both our country and the global community are confronted with the challenge of improving the quality parameters of agricultural products while preventing adverse effects on soil fertility and the surrounding natural environment.

In recent years, the agricultural sector has undergone fundamental transformations. The introduction of new promising technologies in agriculture made it possible to intensify the industry, which increased the concentration of manure use on agricultural land and created an ecological threat to the environment (Lohosha et al. 2024a; Kaletnik et al. 2021). Theoretical generalization and a new solution to the scientific problem – improving the quality of agricultural products – consists in improving the fertilization system due to the use of the latest organic and mineral fertilizers. Such recommendations are a set of approaches to increase the productivity of corn hybrids and improve the quality of products.

The yield potential of agricultural crops under production conditions remains underutilized, despite the virtually unlimited potential of modern corn hybrids. Enhancing productivity, improving product quality, ensuring the availability of essential macro- and microelements, and fostering a favorable microbiological soil environment can only be achieved through the integration of organic fertilizers into contemporary crop cultivation technologies. One such fertilizer is the bioorganic product “Effluent”, derived from the anaerobic fermentation of pig manure in a biogas facility. These aspects are becoming increasingly relevant in the context of global climate change, the shortage of organic fertilizers, and the high costs and limited availability of mineral fertilizers in Ukraine.

Amid the ongoing financial and energy crisis affecting most agricultural enterprises, a critical approach to addressing soil enrichment with organic matter and essential macro- and microelements for plant growth and development is the integration of non-marketable crop rotation residues into the fertilization system. This strategy involves combining these residues with animal manure that has undergone anaerobic fermentation in biogas plants, ensuring efficient nutrient utilization and sustainable soil management (Scarlat et al. 2018; Act on the Promotion of the Use of Renewable Energy Sources 2022; Ali et al. 2022). Using livestock waste for biogas production and applying biogas slurry to agricultural land can solve the problems of livestock waste disposal and reduce the use of synthetic fertilizers (Bao et al. 2019; Chen et al. 2021; Eswaran et al. 2021). The importance of organic fertilizers is primarily determined by their positive impact on increasing humus content in the root zone, improving the physicochemical characteristics of the soil, and optimizing its nutrient regime by balancing macro- and microelement concentrations. One of the reserves for increasing the content of humus is the use of organic fertilizers with a positive agrochemical and microbiological composition, which are obtained by fermentation of livestock waste (pig manure) in biogas plants. Today, the number of agricultural enterprises interested in biogas production processes has increased. For farmers, the latest technologies for biogas production are becoming increasingly important in order to ensure energy autonomy and increase the profitability of production due to the consumption of biogas and the use of by-products in the production of biogas – organic fertilizer (digestate).

Scientifically based application of organic fertilizers contributes to a significant improvement of physical and water-physical properties of the soil, optimization of water-air regime, and physicochemical fertility indicators. In particular, the soil's buffering and absorption capacity is enhanced, creating favorable conditions for the nutrition of vegetable and melon crops (Kaletnik et al. 2020; Liu et al. 2021). In this context, the study of the microbiological and agrochemical properties of the bioorganic fertilizer "Effluent" obtained on the basis of digestate, as well as the assessment of its impact on the growth, development and formation of the vegetative mass of corn, taking into account weather factors and their interaction, is important for determining the energy and environmental aspects of cultivation technology. Establishing the optimal rate of application of bioorganic fertilizers (digestate) is a key factor in growing corn hybrids, ensuring an increase in their productivity and the environmental safety of agricultural production.

1. Literature review

The use of organic fertilizers is determined by their efficiency and low cost, compared to synthetic fertilizers, due to the content of macro- and microelements. The presence of useful microorganisms and nutrients in organic fertilizers increases soil fertility and humus content. Long-term use of mineral fertilizers contributes to the mineralization of organic matter and the reduction of humus, and, as is known, humus contains micro- and macroelements, physiologically active substances. In addition, humus absorbs pesticides and heavy metals like a sponge. The content of humus determines the main agronomically valuable properties of the soil, and due to the content of structure-forming elements calcium and magnesium, its water and air properties (Kapoor et al. 2019; Nguyen et al. 2021; Hamalainen et al. 2022).

The rapid pace of development of scientific and technical progress, which is aimed at increasing energy intensity and ensuring comfortable conditions for human work and life, increasingly leads to the disruption of natural processes, depletion of the biotic potential of ecosystems, and a decrease in the bioproductive capacity of natural and cultural landscapes (Ustak and Munoz 2018; Palamarchuk et al. 2021; Yan et al. 2021). Therefore, it is necessary to pay special attention today to the study of the relationship between the results of anthropogenic activity and the natural processes of biota and soils at different levels of localization. Digestate, an organic substrate remaining after fermentation in biogas plants, is rich in nutrients, making it highly suitable for soil fertilization.

Biomass is available in rural areas, mainly in agricultural waste; in particular, livestock waste is present in large quantities. Biogas can be produced from solid household and livestock waste, providing affordable clean energy for rural areas (Tokarchuk et al. 2021, Honcharuk et al. 2023; Gontaruk et al. 2024). Despite a number of advantages of using biogas, its contribution to the provision of energy in rural areas is insignificant, because there are a number of barriers that are the reason for the slow introduction of biogas technologies. The introduction of biogas plants in rural areas of Bangladesh has proven to be an effective alternative to traditional energy sources, providing significant benefits for both public health and the environment. The purpose of this study is to analyze the agronomic and economic aspects of the use of domestic biogas plants and to assess their functional efficiency (Chen et al. 2021; Bedana et al. 2022).

The study of the functional features of macro- and microelements in the vital activity of a plant organism for agricultural crops in different agro-ecological conditions of Ukraine has not only scientific, but also practical value. Numerous studies, both foreign and domestic (Lohosha et al. 2024b, 2024c), have proven the influence of the fertilization system, in particular the use of biofertilizers (digestate), on crop formation, adaptability, stress resistance, and product quality, regarding studies on the effectiveness of the influence of bio-organic fertilizers (digestate) on specific agricultural crops, their fertility level, the balance of nutrients, and the complex of agronomically valuable soil characteristics.

2. Materials and methods

The field research (experimental component) was conducted between 2019 and 2021 at the experimental fields of LLC "Organik-D" and the Research and Experimental Farm "Agronomichne" of Vinnytsia National Agrarian University. These sites are geographically situated in the Forest-Steppe zone of Right-Bank Ukraine, in accordance with the established research methodology. The soil of the experimental fields is gray forest in the forest with a medium-loamy mechanical composition, and the depth of the arable horizon is 30 cm. According to the results of the laboratory analysis, it was found that the agrochemical characteristics of this type of soil are as follows: humus content (according to Tyurin) – 1.5%; nitrogen content – 9.6–14.3 mg/100 g of soil (according to Kornfield); mobile phosphorus content – 7.5–13.9 mg/100 g and exchangeable potassium – 10.3–23.0 mg/100 g of soil (according to Chirikov).

According to agrometeorological conditions, 2019 and 2021 were generally favorable for the growth and development of corn and other crops. In 2020, a significant increase in temperature indicators and uneven precipitation during the growing season of corn was noted, which ultimately negatively affected its productivity. The characteristics of meteorological conditions during the years of research are presented in Figures 1 and 2.

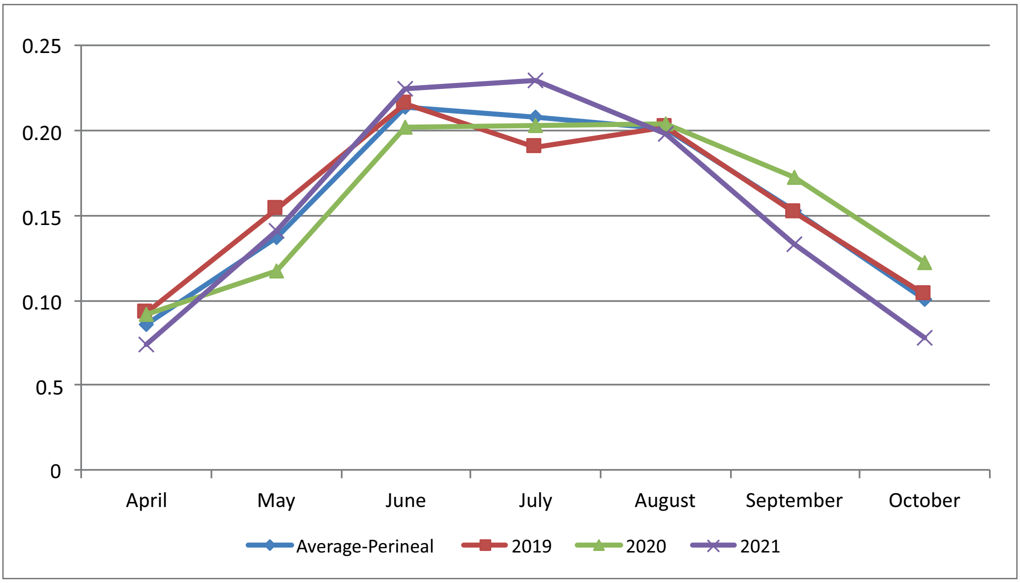

Fig. 1. Monthly average temperature in the city of Vinnytsia and the Vinnytsia district in 2019–2022 [mm]
Source: according to data from the Vinnytsia Regional Center for Hydrometeorology

Rys. 1. Średnia miesięczna temperatura w mieście Winnica i powiecie winnickim w latach 2019–2022 [mm]

To obtain digestate, the anaerobic fermentation process of pig manure (animal waste) lasted for 14 days. Pig manure for the biogas plant was obtained from the livestock complex of Subekon LLC. This process resulted in the bioorganic fertilizer "Effluent", which is certified in accordance with TU U 20.1-38731462-001:2018 and patented in Ukraine (patent UA 144732). This digestate-based fertilizer exhibits an alkaline reaction (pH 8.5), a high moisture content (98.4% by weight), and a notable concentration of nitrate nitrogen (18.2 mg/kg), zinc (32 mg/kg), copper (4.6 mg/kg), manganese (20 mg/kg), and iron (120 mg/kg). In terms of active ingredients, "Effluent" bio-organic fertilizer contains 2.9 kg of nitrogen, 0.9 kg of phosphorus, 3.2 kg of potassium, 3.5 kg of calcium, and 0.42 kg of magnesium per 1 ton (Table 1). The application of

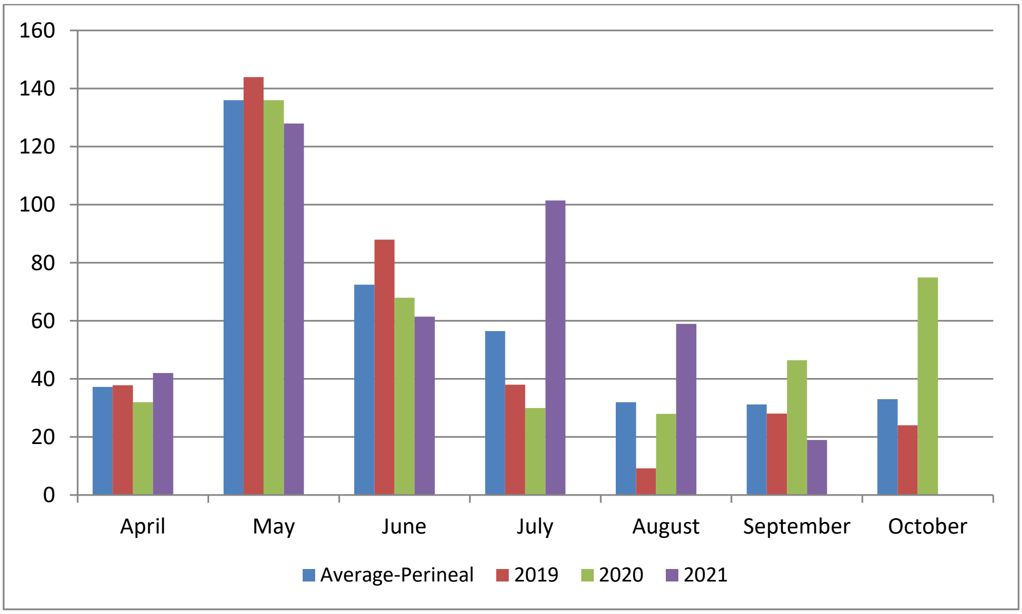

Fig. 2. Monthly precipitation in the city of Vinnytsia and the Vinnytsia district in 2019–2022 [mm]
Source: according to data from the Vinnytsia Regional Center for Hydrometeorology

Rys. 2. Miesięczne opady w mieście Winnica i obwodzie winnickim w latach 2019–2022 [mm]

this fertilizer enhances the availability of macro- and microelements for plants and significantly improves the agronomic properties of soils.

The study of the agrochemical and microbiological composition of bioorganic fertilizer obtained on the basis of digestate was carried out in accredited and certified laboratories of Ukraine. The scheme of the experiment provided for the study of the fertilization system using different rates of digestate on fertility, biological activity of the soil, growth, and development of grain corn. In the four experimental variants, only the bioorganic fertilizer "Effluent" based on digestate was used at rates of 25, 35, 45, and 55 t/ha. For a comparative assessment of fertilizer efficiency, an additional variant involved the application of only the mineral fertilizer nitroamophoska at a dose of $N_{90}P_{90}K_{90}$.

The assessment of grain corn structure and biological yield from the experimental plot was conducted following the established methodology (Avramenko et al. 2011).

The biological yield of corn was determined by the formula:

$$Ub = M \cdot Ch : 1000000 \text{ [t/ha]}$$

where:

M – the mass of grain from one productive ear,

Ch – the number of productive cobs from 1 ha [pcs].

Table 1. Agrochemical analysis of bioorganic fertilizer "Effluent" obtained on the basis of digestate (for 2019–2021)

Tabela 1. Analiza agrochemiczna nawozu bioorganicznego „Effluent" uzyskanego na bazie digestatu (za lata 2019–2021)

No	Agrochemical indicators, units of measurement	Test results
1.	Saline pH	8.2–8.5
2.	Dry matter [%]	1.6–2.5
3.	Mass fraction of moisture [%]	97.5–98.4
4.	Content of organic matter in nature/in absolutely dry matter [%]	1.00/62.7
5.	Ash content in nature/in absolutely dry matter [%]	0.60/34.5–37.3
Macroelements		
6.	Total nitrogen [kg/t]	2,900–4,100
7.	Nitrate nitrogen [mg/kg]	18.2 (0.06%)
8.	Ammonium nitrogen [kg/t]	2,300–3,000
9.	Phosphorus in terms of P_2O_5 [kg/t]	900–1,300
10.	Potassium in terms of K_2O [kg/t]	1,800–3,200
11.	Sulfur in terms of SO_3 [kg/t]	1,100–3,500
11.	Magnesium in terms of MgO [kg/t]	420–520
12.	Calcium in terms of CaO [kg/t]	540
Microelements		
13.	Zinc [mg/kg]	32.0–43.0
14.	Copper [mg/kg]	4.6–19.0
15.	Molybdenum [mg/kg]	0.23
16.	Iron [mg/kg]	45.1–120.0
17.	Manganese [mg/kg]	14.9–20.0

Source: according to the data provided by the Service and Analytical Center of the Separate Structural Subdivision of Agrochemical Factory LLC "Institute of Plant Health".

3. Results and discussion

The study determined the effectiveness of a fertilization system incorporating bioorganic fertilizer derived from digestate alongside mineral fertilizers in shaping the structural components and yield of the Kamponi KS corn hybrid.

The formation of high and high-quality corn grain yields is influenced by fundamental structural components, including the 1000-grain weight, the number of grain rows, the number of grains per row, cob length and diameter, grain size, grain yield per cob, grain weight per cob, the number of cobs per plant, and grain moisture content. These parameters exhibit significant variability during corn cultivation, depending on the genetic traits of the hybrid, applied agrotechnical measures, and environmental conditions characteristic of a particular growing season.

According to biological characteristics, 1–2 cobs are laid on a corn stalk to a greater extent, rarely more than two cobs. In the conditions of production, hybrids are grown that are prone to multi-cobs, forming plants with three and, as an exception, even four cobs.

The number of cobs on a corn plant is a hereditary trait that can be influenced by selection, as well as, to some extent, agrotechnical practices, creating better growing conditions. In unfavorable growing conditions, although multi-stemmed hybrids do not form two cobs, they have a much smaller number of sterile plants, and with the optimal balance of nutrients in the soil, moisture supply, pre-harvest plant density and biological features, such hybrids are able to form two economically suitable cobs.

The findings of the study confirmed that the fertilization system and vegetation conditions had a significant impact on the number of normally developed cobs per corn plant (Fig. 3).

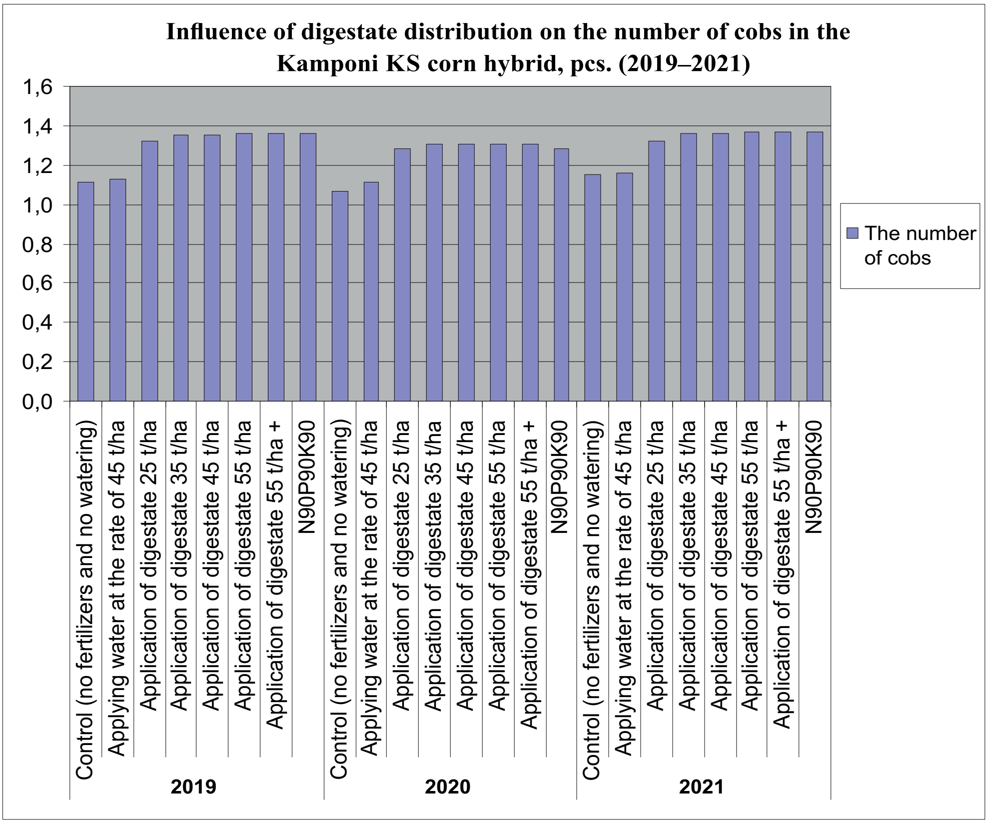

Fig. 3. The number of cobs in the Kamponi KS corn hybrid, depending on the fertilization system [pcs.] (for 2019–2021 ±Sr)

Rys. 3. Liczba kolb w hybrydzie kukurydzy Kamponi KS, w zależności od systemu nawożenia [szt.] (dla lat 2019–2021 ±Sr)

Analyzing the data in Table 2, it should be noted that the number of normally developed cobs per plant in the Kamponi KS corn hybrid, on average over three years, ranged from 1.11 to 1.35, and in 2019 it amounted to 1.11–1.36 pcs. In the control (without watering and fertilization), the number of optimally developed cobs of cabbage was 1.11 pcs. The introduction of digestate from biogas plants based on anaerobic digestion of pig manure and mineral fertilizers contributed to an increase in this indicator by 0.21–0.25 pcs. The maximum number of cobs of cabbage, which amounted to 1.36 pcs. was recorded in the variant of joint application of digestate of biogas plants at a rate of 55 t/ha and mineral fertilizers at a rate of $N_{90}P_{90}K_{90}$.

An analysis of the number of cabbage cobs formed on the plants in 2020 indicated a decrease to 1.07–1.31 units. This reduction in the number of cobs observed in 2020 was primarily due to the irregular distribution of precipitation during the corn growing season.

The number of grain rows on a cob is a genetically determined trait, always even, varying among different hybrids from 8 to 16 (most commonly 12–14), and is relatively less influenced by growing conditions. The impact of the fertilization system and the application rate of bioorganic fertilizer derived from digestate on the number of grain rows in the Kamponi KS corn hybrid is presented in Figure 4.

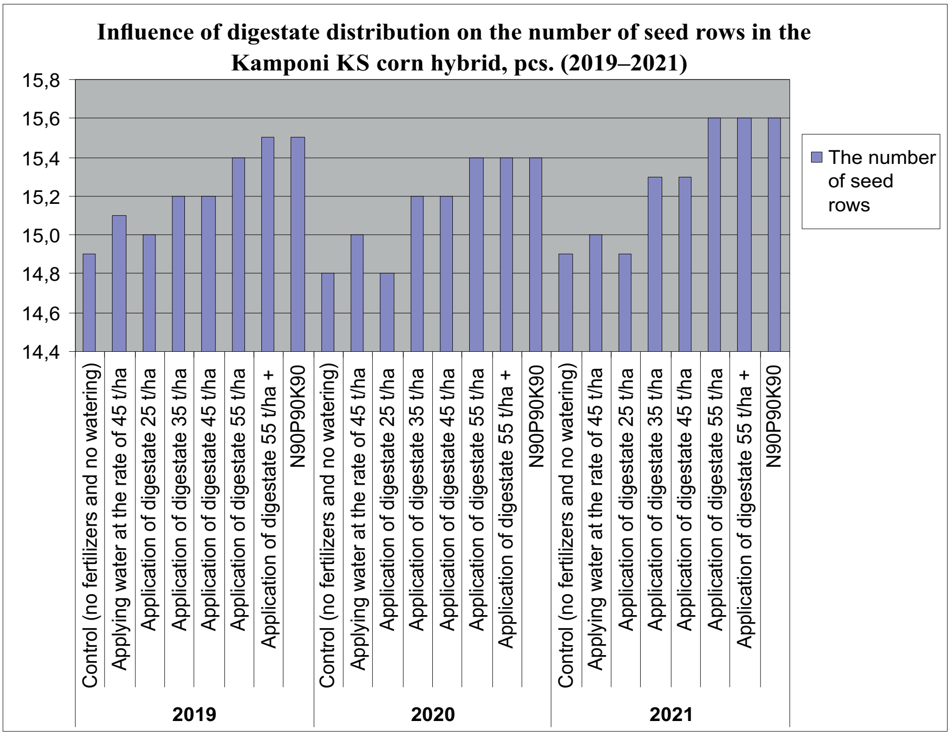

Fig. 4. The influence of the fertilization system on the number of rows of cob grains in the Kamponi KS corn hybrid [pcs.] (for 2019–2021 ±Sr)

Rys. 4. Wpływ systemu nawożenia na liczbę rzędów ziaren kolb w hybrydzie kukurydzy Kamponi KS [szt.] (dla lat 2019–2021 ±Sr)

The findings of the study fully corroborate the literature data regarding the genetic control of the trait "number of grain rows" in the examined corn hybrid (see Table 3). Analyzing the research years, it was observed that the number of grain rows in the Kamponi KS hybrid ranged from 14.9 to 15.5 in 2019, from 14.8 to 15.4 in 2020, and from 14.9 to 15.6 in 2021.

The fertilization system exerted the most significant influence on the number of grains per row (Fig. 5).

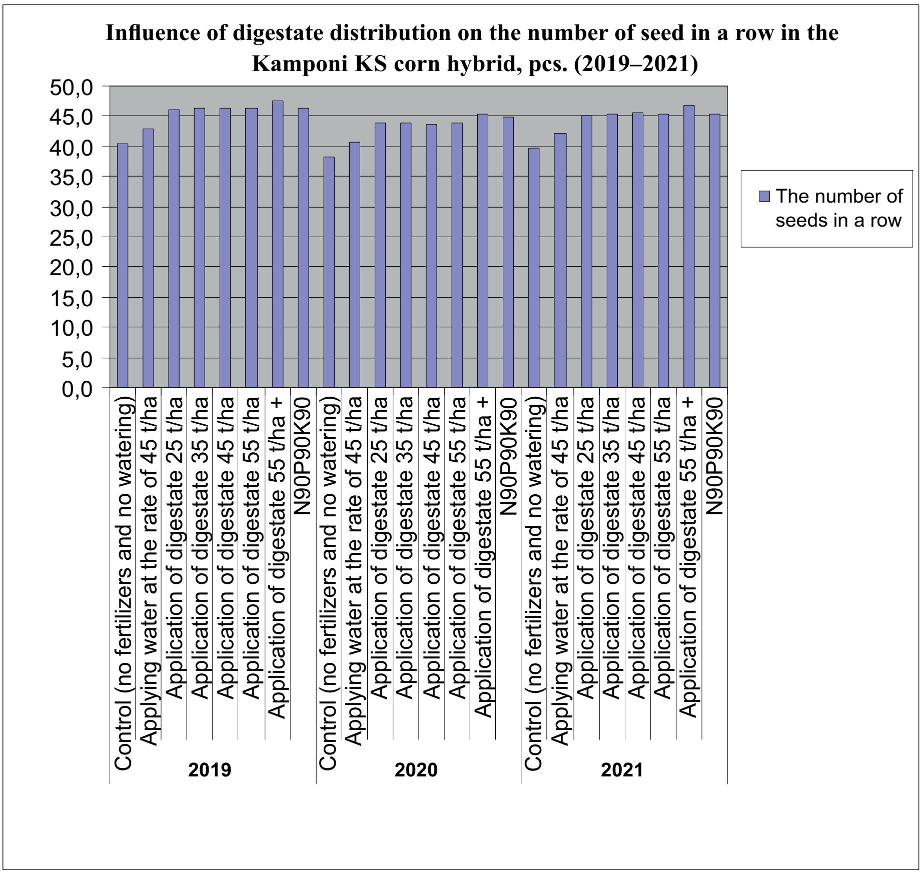

Fig. 5. The number of grains in a row in the Kamponi KS corn hybrid, depending on the fertilization system [pcs.] (for 2019–2021 ±Sr)

Rys. 5. Liczba ziaren w rzędzie w hybrydzie kukurydzy Kamponi KS, w zależności od systemu nawożenia [szt.] (dla lat 2019–2021 ±Sr)

The study established that the number of grains per row in the Kamponi KS corn hybrid ranged from 40.5 to 47.5 in 2019, from 38.2 to 45.4 in 2020, and from 39.4 to 46.6 in 2021. The application of organic and mineral fertilizers resulted in an increase in the number of grains per row by an average of 5.7–7.2 grains over the research years compared to the control, where this parameter was 39.4 grains. Across the research period, a notable decrease in the number of grains per row was observed in 2020 (43.0 grains), which was associated with stressful rainfall conditions, in contrast to 2019 (45.3 grains) and 2021 (44.4 grains). 2019 and 2021 turned out to be the most favorable according to meteorological indicators for the formation of this sign, while 2020 turned out to be stressful in terms of moisture distribution during the growing season of corn, which ultimately affected a significant decrease in the number of grains in a row.

The weight of 1,000 seeds is a specific indicator that largely depends on the biological characteristics of the hybrid and the conditions of seed formation. Thus, in our research, the weight of 1000 seeds in the Kamponi KS corn hybrid depended on the morphological characteristics of the hybrid itself and on the fertilization options (Fig. 6).

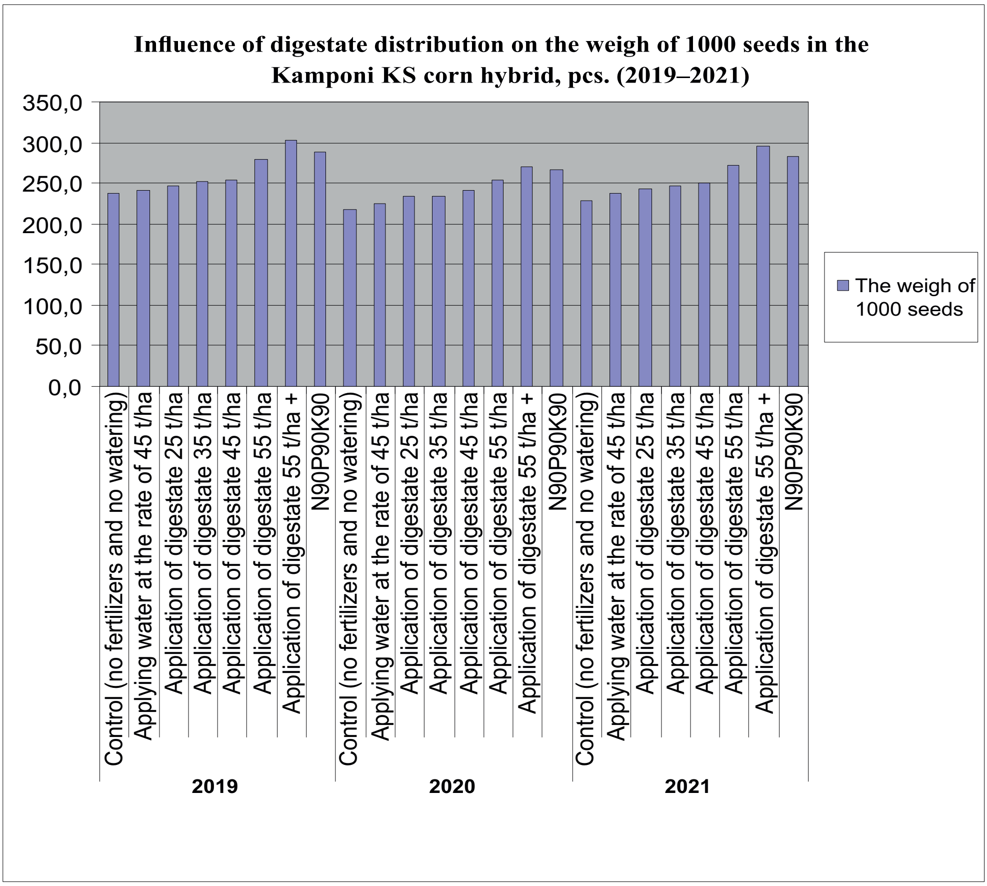

Fig. 6. Weight of 1000 seeds in the Kamponi KS corn hybrid, depending on the fertilization system [g] (for 2019–2021 ±Sr)

Rys. 6. Masa 1000 nasion hybrydy kukurydzy Kamponi KS w zależności od systemu nawożenia [g] (dla lat 2019–2021 ±Sr)

The analysis of data presented in Table 5 demonstrates that, in the absence of organic and mineral fertilizers and irrigation, the mid-season maize hybrid Camponi KS exhibited a low 1,000-seed weight, amounting to 236.8 g in 2019, 218.2 g in 2020, and 229.3 g in 2021. It was established that this parameter varied depending on the weather conditions during the growing season and the availability of nutrients from both the soil and fertilizers. The highest 1,000-seed weight was recorded in 2020 (218.2–269.5 g), which was likely a result of stressful conditions, particularly the uneven distribution of moisture throughout the growing season, compared to 2019 (236.8–303 g) and 2021 (228.1–289.4 g). The use of digestate from biogas plants, obtained by anaerobic digestion of pig manure, at a rate of 55 t/ha in combination with mineral fertilizers, contributed to the maximum increase in the weight of 1000 seeds, providing an increase of 12.7–61.3 g on average over the years of research.

Yield is the final indicator that allows you to determine the effectiveness of the applied cultivation technology or its individual elements; it shows the effectiveness of the indicator of solar energy assimilation by corn plants.

The study confirmed that the fertilization system exerted a significant influence on the biological productivity of the Kamponi KS corn hybrid. This effect can be attributed to the enhanced availability of macro- and microelements, which positively impacts not only the growth and development of corn but also its overall yield potential (Table 2).

Table 2. Yield of the Kamponi KS corn hybrid depending on the fertilization system [t/ha] (for 2019–2021 ±Sr)

Tabela 2. Plon hybrydy kukurydzy Kamponi KS w zależności od systemu nawożenia [t/ha] (dla lat 2019–2021 ±Sr)

Fertilizer option	Yield [t/ha]			
	2019	2020	2021	average, ± Sr
Control (no fertilizers and no watering)	7.23	6.02	7.09	6.78±0.66
Applying water at the rate of 45 t/ha	8.04	6.98	7.94	7.65±0.59
Application of digestate 25 t/ha	10.29	8.83	9.82	9.65±0.75
Application of digestate 35 t/ha	10.90	9.33	10.62	10.28±0.84
Application of digestate 45 t/ha	11.03	9.58	10.78	10.47±0.78
Application of digestate 55 t/ha	12.36	10.25	12.03	11.55±1.14
$N_{90}P_{90}K_{90}$	12.87	10.76	12.54	12.06±1.13
Application of digestate 55 t/ha + $N_{90}P_{90}K_{90}$	13.83	11.26	13.49	12.86±1.40
LSD 0.05	0.85	1.00	0.88	0.95

Source: author's research.

From the data in Table 2, it can be seen that the lowest grain yield of the Kamponi KS corn hybrid was on the control variant without fertilizers and irrigation, and was 6.78 t/ha on average over three years. The introduction of bio-organic fertilizer based on digestate and mineral fertilizers contributed to the increase in productivity by 2.87–6.08 t/ha, compared to the control option.

The highest productivity of the mid-ripening corn hybrid Kamponi KS (12.86 t/ha) was achieved in the treatment involving the application of 55 t/ha of bioorganic fertilizer based on digestate combined with mineral fertilizer at a rate of $N_{90}P_{90}K_{90}$ per hectare annually. However, the increase in productivity was not significantly influenced by the sole application of organic fertilizer at the rate of 55 t/ha, which resulted in a yield of 11.55 t/ha.

Conclusions

The application of bio-organic fertilizer derived from digestate, in combination with mineral fertilizers, improves the nutrient supply for corn plants, resulting in an increase in the number of cobs per plant by 0.20–0.24 compared to the control. However, the moisture deficit recorded in 2020 led to a significant reduction in the number of cobs per plant (by 0.02–0.09 units) in comparison to 2019 and 2021, which experienced more favorable moisture conditions during the growing season.

The application of bio-organic fertilizer based on digestate at a rate of 55 t/ha, together with mineral fertilizer ($N_{90}P_{90}K_{90}$), led to a slight increase in the number of grain rows, but this change was not statistically significant, ranging from 0.1 to 0.7 units compared to the control. Given that the number of grain rows is a genetically determined trait, its variation was relatively limited. However, the use of bio-organic fertilizer and mineral fertilizers at a rate of $N_{90}P_{90}K_{90}$ resulted in an increase in the number of grains per row, averaging 5.7–7.2 units over the research years, compared to the control, where this parameter was 39.4 units.

The highest 1,000-grain weight was recorded in the treatment where 55 t/ha of bio-organic fertilizer based on digestate was applied in combination with mineral fertilizer ($N_{90}P_{90}K_{90}$), reaching 303 g in 2019, 267.2 g in 2020, and 279.9 g in 2021, exceeding the control values. The application of bio-organic fertilizer based on digestate at a rate of 55 t/ha resulted in a grain yield of 11.55 t/ha, while the combination of this rate with mineral fertilizer ($N_{90}P_{90}K_{90}$) further increased the yield to 12.86 t/ha.

The findings of this study confirm that optimizing plant nutrition through a balanced supply of macro- and microelements can significantly enhance productivity, improve product quality, and contribute to soil fertility. The use of the bio-organic fertilizer "Effluent", derived from digestate, presents a sustainable solution for the disposal of livestock waste from large industrial complexes, while simultaneously promoting the sustainable development of agriculture and local communities.

The Authors have no conflicts of interest to declare.

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Roman Lohosha, Vitalii Palamarchuk, Vadim Krychkovskyi, Nina Rudska

Wykorzystanie digestatu do nawożenia kukurydzy jako element zrównoważonego rozwoju obszarów wiejskich w Ukrainie

Streszczenie

W niniejszym badaniu przeanalizowano wpływ energooszczędnych i ekologicznych elementów zrównoważonego rozwoju na produkcję nawozu bioorganicznego „Effluent", pochodzącego z beztlenowego rozkładu odchodów świń w biogazowni. Badania skupiają się na jego zastosowaniu w technologiach uprawy kukurydzy w celu zwiększenia plonów i poprawy jakości upraw. Autorzy uwzględnili technologie wykorzystania gnojowicy jako nawozu organicznego, co jest obecnie najbardziej racjonalnym sposobem bezpośredniego stosowania jej na polach po wstępnej fermentacji beztlenowej w biogazowniach. Stwierdzono, że nawóz ten zawiera znaczną ilość makro- i mikroelementów oraz pożyteczną mikroflorę. Stosowanie takich nawozów rozwiązuje problem środowiskowy związany z gospodarką odpadami pochodzącymi z hodowli zwierząt, zwłaszcza z hodowli świń, przyczynia się do rozwoju sektora energetycznego poprzez produkcję biogazu oraz łagodzi wyzwania gospodarcze i społeczne w rolnictwie. Wyniki niniejszego badania potwierdzają, że optymalizacja odżywiania roślin poprzez zrównoważone dostarczanie makro- i mikroelementów może znacznie zwiększyć wydajność, poprawić jakość produktów i przyczynić się do żyzności gleby. Zastosowanie nawozu bioorganicznego „Effluent", pochodzącego z digestatu, stanowi zrównoważone rozwiązanie w zakresie utylizacji odpadów pochodzących z hodowli zwierząt w dużych kompleksach przemysłowych, jednocześnie promując zrównoważony rozwój rolnictwa i społeczności lokalnych. Podejście to umożliwia produkcję ekologicznych produktów roślinnych i warzywnych, a jednocześnie pozwala zarządzać odpadami pochodzącymi z hodowli zwierząt, optymalizować wykorzystanie zasobów naturalnych, zmniejszać zanieczyszczenie środowiska oraz przyczyniać się do bezpieczeństwa żywnościowego i energetycznego kraju, a także zrównoważonego rozwoju obszarów wiejskich.

Słowa kluczowe: digestat, niezależność energetyczna, autonomia energetyczna, produkcja biogazu, odpady pochodzenia zwierzęcego, zmiany klimatyczne, stacje biogazowe