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THE IMPACT OF MINERAL FERTILIZATION ON THE ECONOMIC AND ENERGY INDICATORS OF SWEET PEPPER CULTIVATION UNDER DRIP IRRIGATION IN SOUTHERN UKRAINE

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The article is devoted to the impact of mineral fertilization on the economic and energy performance of sweet pepper cultivation under drip irrigation in southern Ukraine. The study examined the effect of three nutrient levels calculated based on the planned yield of sweet pepper: Rate 1 – for a yield of 35 t/ha (application rate N118P62), Rate 2 – for 45 t/ha (application rate N145P75), and Rate 3 – for 55 t/ha (application rate N163P84). The control variant (St) represented the natural soil fertility background without fertilizer application. A clear relationship was found between the level of mineral nutrition and the productivity of sweet pepper: yield increased from 35.3 t/ha in the control variant to 42.8 t/ha under the highest mineral background (Rate 3).

In addition to higher yields, the costs of cultivation also increased – from 154.47 thousand UAH/ha in the unfertilized variant to 219.14 thousand UAH/ha under Rate 3. This affected the cost price of production, which increased from 4376 UAH/t (control) to 5120 UAH/t. The highest profit was obtained in the control variant – 198,529 UAH/ha, which is attributed to the low level of expenses, although this variant did not provide the highest yield. The highest profitability level was also observed in the control – 128.5%, indicating the efficiency of resource-saving technologies. At the same time, as the nutrient level increased, the profitability gradually decreased – from 108.2% (Rate 1) to 95.3% (Rate 3), due to a faster growth of costs compared to profit.

Energy consumption per hectare increased from 14,663 MJ/ha in the control to 23,164 MJ/ha under Rate 3. At the same time, the amount of energy accumulated in the harvested crop also increased – from 38,401 MJ/ha (control) to 46,560 MJ/ha (Rate 3), indicating a higher overall energy potential of the crop under more intensive nutrition. However, the bioenergetic efficiency coefficient (Ke) showed a downward trend: the highest value (2.62) was recorded in the control, while under the maximum mineral background (Rate 3) it decreased to 2.01. The energy intensity of the product increased from 415.4 MJ/t (control) to 541.2 MJ/t (Rate 3), also indicating higher specific energy costs with more intensive fertilization.

Key words: *sweet pepper, mineral fertilizers, drip irrigation, economic efficiency, energy assessment.*

Шепель А.В. Вплив мінерального удобрення на економічні та енергетичні показники вирощування перцю солодкого при краплинному зрошенні на Півдні України

Стаття присвячена впливу мінерального удобрення на економічні та енергетичні показники вирощування перцю солодкого при краплинному зрошенні на півдні України. У роботі досліджено вплив трьох норм живлення, які були розраховані на заплановану врожайність перцю солодкого: норма 1 – на 35 т/га (норма внесення N118P62), норма 2 – на 45 т/га (норма внесення N145P75) і норма 3 – на 55 т/га (норма внесення N163P84). В якості контрольного варіанту (St) виступав природний фон родючості ґрунту. Виявлена чітка залежність між рівнем мінерального живлення та продуктивністю перцю солодкого: урожайність зростає від 35,3 т/га на контрольному варіанті без внесення добрив до 42,8 т/га за умови максимального мінерального фону (Норма 3). Крім цього, зростає не тільки врожайність культури, а і витрати на її вирощування: від 154,47 тис. грн./га у варіанті без добрив до 219,14 тис. грн./га за Норми 3. Це вплинуло на собівартість продукції, яка збільшилась із 4376 грн./т (контроль) до 5120 грн./т. Найвищий прибуток був отриманий на варіанті без добрив – 198529 грн./га, що пов'язано з низьким рівнем *витрат, хоча цей варіант не забезпечував максимального врожаю. Найвищий рівень рентабельності також спостерігався у контрольному варіанті – 128,5%, що свідчить про ефективність ресурсозберігаючих технологій. При цьому, зі зростанням фону живлення рівень рентабельності поступово знижується: від 108,2% (Норма 1) до 95,3% (Норма 3), що зумовлено стрімкішим ростом витрат порівняно з прибутком.*

Витрати енергії на гектар зростали від 14663 МДж/га на контролі до 23164 МДж/га при Нормі 3. Водночас кількість акумульованої в зібраному врожаї енергії, також збільшувався – від 38401 МДж/га (контроль) до 46560 МДж/га (Норма 3), що свідчить про підвищення загального енергетичного потенціалу культури при інтенсивнішому живленні. Однак коефіцієнт біоенергетичної ефективності (Ке) демонструє зворотну динаміку: найвищий показник (2,62) зафіксовано на контролі, тоді як за умов максимального мінерального фону (Норма 3) він знизився до 2,01. Енергоємність продукції збільшилась з 415,4 МДж/т (контроль) до 541,2 МДж/т (Норма 3), що також свідчить про підвищення питомих енергетичних витрат при більш інтенсивному удобренні.

Ключові слова: *перець солодкий, мінеральні добрива, краплинне зрошення, економічна ефективність, енергетична оцінка.*

Problem Statement. In the context of global climate change and the growing scarcity of water and energy resources-characteristic of the southern regions of Ukraine – the issue of increasing the efficiency of agricultural production becomes particularly relevant. In Ukraine, especially in its southern areas, there is a persistent water deficit that complicates traditional irrigation methods, along with the necessity to conserve energy resources due to the high costs associated with irrigation and the application of fertilizers. In this context, drip irrigation combined with the rational use of mineral fertilizers appears to be one of the most effective agrotechnologies, capable of ensuring high crop yields while optimizing water and energy expenditures. A comparison with foreign studies reveals a number of significant differences in approaches to the use of drip irrigation and mineral fertilizers, which can be explained by differences in natural conditions, levels of technological development in the agricultural sector, and economic realities. For instance, in countries with temperate climates, such as Germany or the United States, the use of drip irrigation and fertilizers is part of a high-tech production system where access to water and energy resources is stable, and the cost of energy and fertilizers is considerably lower [1]. Sweet pepper (*Capsicum annuum* L.) is one of the most common vegetable crops grown in Ukraine, particularly in the southern regions. This crop is highly sensitive to the levels of mineral nutrition and water supply, which necessitates a precise approach to the use of agrochemicals and water resource management. According to FAOSTAT data, in 2023 the average global yield of pepper (Capsicum spp., including sweet pepper) was approximately 17.3 tons per hectare. However, these figures vary depending on the country and growing conditions: China – ~22 t/ha, Spain – ~30 t/ha, USA – ~25 t/ha, Ukraine – ~12–14 t/ha. These data indicate that Ukraine has the potential to increase sweet pepper yields to the level of leading countries, provided that modern agricultural technologies are implemented and growing conditions are optimized [2].

Analysis of Recent Studies and Publications. A study conducted in southern Ukraine evaluated the energy efficiency of sweet corn cultivation under drip irrigation with varying plowing depths, fertilizer rates, and plant densities. The highest energy efficiency (energy efficiency coefficient, EEC 2.44) was achieved with plowing at 20–22 cm, an NP rate of 120 kg/ha, and a plant density of 65,000 plants/ha [3, p. 885]. Another Ukrainian study showed that drip irrigation combined with mineral fertilization increased corn yield by 40% and improved the water use coefficient under optimal agronomic conditions [4]. The highest pepper yield (62.2 t/ha) was obtained with the application of 400 kg/ha of nitrogen and 360 kg/ha of potassium under drip fertigation irrigation [5, p. 54]. In another study, nutrient distribution in the soil during fertigation was assessed. The highest yield was also recorded with similar fertilizer doses, with high concentrations of NH_4^+ and K^+ near the emitters [6, p. 54].

In California farms, drip irrigation reduced energy consumption per unit of yield, while fertilizer application accounted for over 30% of total energy costs, indicating potential for further energy savings [7]. In India, drip irrigation reduced water consumption by 34% and increased water efficiency by 94% compared to traditional irrigation practices [8]. In China, fertigation regimes of 75% of ETc (reference evapotranspiration) and 150 kg/ha of nitrogen were found to be optimal for both yield and quality [9]. When calculating the rate of mineral fertilizers, it is necessary to plan weed control measures, as during 80 days of joint vegetation, weeds can absorb from the soil as many available forms of macronutrients (N, P_2O_5, K_2O) as would be sufficient to produce a sugar beet root yield of 45–55 tons per hectare [10, p. 178].

Drip irrigation combined with mineral fertilization significantly increases crop yields, reduces water and energy consumption, and improves the economic viability of sweet pepper cultivation, especially under the conditions of southern Ukraine. Moreover, studying the efficiency of different doses of mineral fertilizers and their impact on yield and energy efficiency under drip irrigation in Ukraine can help address several important challenges: technology adaptation – it is necessary to adapt foreign technologies to the specific conditions of Ukraine, taking into account soil types, climatic conditions, and water availability; economic efficiency – comparing the costs of fertilizer application and irrigation in Ukraine and abroad will help identify optimal options in terms of profitability and energy efficiency. Thus, conducting scientific research on the energy and economic evaluation of mineral fertilizer application in sweet pepper cultivation in Ukraine is an important step toward developing agronomic practices adapted to local conditions, ensuring production efficiency.

Research Objective. The aim of this study is to conduct an economic and energy assessment of the efficiency of mineral fertilizer application in sweet pepper cultivation under drip irrigation in the conditions of the southern Steppe of Ukraine. To achieve this goal, the following tasks must be accomplished:

1. To study the effect of different doses of mineral fertilizers on the productivity of sweet pepper under drip irrigation conditions.
2. To carry out an economic analysis of costs and profits depending on the fertilization regime.
3. To assess the energy inputs required for crop cultivation under different fertilizer doses and to determine the energy efficiency coefficient (EEC).
4. To formulate recommendations for optimizing mineral nutrition to achieve maximum economic and energy efficiency.

Presentation of the Main Research Material. Pepper was introduced to the territory of Ukraine at the end of the 16th century, originating from Iran and Turkey. However, the widespread cultivation of this crop in Ukraine only took place in the 18th century. Industrial cultivation of pepper gained significance in Ukraine by the mid-19th century. In the 1940s, pepper began to be grown in the Odesa region, where it was brought by Bulgarian settlers. A major boost to its popularity came with the development of the canning industry, where pepper fruits became widely used for canned product manufacturing. Today, sweet pepper is cultivated in all countries where climatic conditions meet its biological requirements. The largest producers of this crop are China, Mexico, Turkey, Spain, the United States, the Netherlands, and Israel. Sweet pepper is notable for its high vitamin content, surpassing all other vegetable crops in terms of vitamin C content – even exceeding that of lemons. Vitamin C was actually discovered thanks to pepper: in the 1930s, American biochemist Albert Szent-Györgyi isolated crystalline ascorbic acid from pepper, for which he was awarded the Nobel Prize.

Pepper is an important raw material for the canning industry, where it is used to enrich canned products with vitamins. In many countries, dried pepper fruits are used to produce a powder that serves as a concentrated vitamin-rich supplement with a characteristic aroma. Sweet pepper is recommended as an effective remedy for combating scurvy and atherosclerosis, strengthening blood vessel walls, removing cholesterol from the body, improving digestion, stimulating appetite, and treating anemia. Sweet pepper juice helps normalize the permeability and elasticity of blood vessels. In recent decades, Ukraine has seen a steady increase in pepper consumption. To meet consumer demand, Ukrainian farmers are expanding the cultivation area of pepper both in open fields and in greenhouses. According to official statistics, the area under pepper cultivation ranges from approximately 15,000 to 45,000 hectares. At the same time, new high-yielding hybrids of foreign breeding are gradually being added to the traditional conical varieties, becoming increasingly popular and replacing outdated cultivars.

Pepper crops require specific nutrients for proper growth and high yield. The main macronutrients essential for the development of this plant include nitrogen, phosphorus, potassium, calcium, and magnesium. Nitrogen supports the formation of leaves and stems, while phosphorus is crucial for root development, as well as the formation of flowers and fruits. Potassium helps maintain the overall health of the plant and enhances its resistance to diseases and pests. Calcium and magnesium play key roles in strengthening cell walls and supporting photosynthesis processes.

Determining the pepper plant's needs for these elements is critically important for the timely and proper application of fertilizers, which contributes to achieving maximum yield. A nutrient deficiency in peppers can lead to serious disruptions in plant development. For example, nitrogen deficiency causes leaf yellowing and stunted growth; phosphorus deficiency results in delayed growth and lack of fruiting; and calcium or magnesium deficiency can lead to blossom end rot, where the tips of the fruits turn black and rot. Such conditions negatively impact both yield and plant health. Therefore, regular monitoring of plant conditions and timely fertilization are essential for ensuring healthy development. The average yield of modern F1 sweet pepper hybrids in open field conditions ranges from 35 to 40 tons per hectare. When optimal agronomic practices are followed, the crop is capable of reaching very high yield levels. Specifically, in open fields, yields can exceed 100 t/ha (or 10 kg/m^2); in plastic-covered greenhouses, yields can surpass 240 t/ha (24 kg/m^2); and in modern automated greenhouses, yields can reach as high as 350–450 t/ha (35–45 kg/m^2).

For non-hybrid pepper varieties, the average yield typically ranges from 25 to 30 t/ha, but with proper care, this figure can increase to 40–45 t/ha. The average yield of hot pepper is 20–25 t/ha; however, with high-quality care and the use of modern F1 hybrids in greenhouse conditions, yields can reach 100–200 t/ha. For sweet pepper, achieving high productivity largely depends on effective business planning, which includes the implementation of modern global technologies, proper selection and calculation of the fertilizer system, the use of plant protection products, and continuous monitoring of crop conditions. Only with a comprehensive approach to these factors can consistently high results be achieved and the maximum economic benefit from pepper cultivation ensured.

Proper fertilizer application is a key factor in achieving high yields. Chemical fertilizers can be applied at various stages of plant growth to maintain an optimal nutrient level in the soil. It is important to follow the recommended rates and application schedule, taking into account the developmental stages of the plants and their specific needs. Overuse of fertilizers can disrupt the nutrient balance in the soil, lead to environmental pollution, and reduce product quality, while insufficient fertilization results in low yields and weakened plants. In addition, regular weeding, irrigation, and soil care are essential components of integrated plant management. [11]. The main goal of modern agricultural production is to obtain a high and economically justified yield [12, p. 10].

According to the set objective, three fertilization rates were studied, which were calculated based on the planned crop yield: Rate 1 – for 35 t/ha (calculated rate N118P62), Rate 2 – for 45 t/ha (calculated rate N145P75), and Rate 3 – for 55 t/ha (calculated rate N163P84). The control variant (St) represented the natural soil fertility background. The results of the economic efficiency of sweet pepper cultivation depending on the fertilization levels are presented in Table 1.

Table 1

Economic efficiency results of sweet pepper cultivation depending on the rate of mineral fertilizer application (Year 2023)

Experimental variants	Yield, t/ha.	Cultivation costs, thousand UAH/ha.	Cost of grown yield, UAH/t.	Profit, UAH/ha.	Profitability level, %.
1. Without fertilizers – St	35.3	154471	4376	198529	128.5
2. Rate 1	37.0	177679	4802	192321	108.2
3. Rate 2	40.1	195406	4873	205594	105.2
4. Rate 3	42.8	219143	5120	208857	95.3
LSD $_{0.5}$, tons per hectare	0.5	-	-	-	-

Source: compiled by the author

According to the results of the study (Table 1), there is a clear relationship between the level of mineral nutrition and the productivity of sweet pepper. Yield increased from 35.3 t/ha in the control variant without fertilizer application to 42.8 t/ha under the highest mineral background (Rate 3). The least significant difference (LSD $_{0.5}$) was 0.5 t/ha, indicating statistically significant differences between the variants. However, with the increase in fertilizer rates, cultivation costs also rose – from 154.47 thousand UAH/ha in the unfertilized variant to 219.14 thousand UAH/ha under Rate 3. This affected the cost price of the product, which increased from 4376 UAH/t (control) to 5120 UAH/t. The highest profit was obtained in the control variant – 198,529 UAH/ha, due to the low-cost level, although this variant did not ensure the highest yield. The highest profitability level was also observed in the control – 128.5%, indicating the efficiency of resource-saving technologies. At the same time, with an increase in the fertilization background, the profitability level gradually decreased: from 108.2% (Rate 1) to 95.3% (Rate 3), which is due to the faster growth of costs compared to profit.

The results of the energy efficiency of sweet pepper cultivation depending on the fertilization levels are presented in Table 2.

As a result of the conducted research, the impact of mineral fertilization rates on the energy efficiency indicators of sweet pepper cultivation was established (Table 2). Energy consumption per hectare increased from 14,663 MJ/ha in the control to 23,164 MJ/ha under Rate 3. This increase is attributed both to the energy-intensive nature of fertilizer synthesis and transportation, as well as to higher energy requirements for technological operations [13, p. 563]. At the same time, the energy output, i.e., the amount of energy accumulated in the harvested yield, also increased – from 38,401 MJ/ha (control) to 46,560 MJ/ha (Rate 3), indicating an increase in the overall energy potential of the crop under more intensive nutrition [14, p. 436].

Table 2

Energy efficiency results of sweet pepper cultivation depending on the rate of mineral fertilizer application (Year 2023)

Experimental variants	Yield, t/ha.	Energy consumption, MJ/ha.	Energy input, MJ/ha.	Bioenergetic efficiency coefficient, Ke	Energy intensity of the product, MJ/t.
1. Without fertilizers – St	35.3	14663	38401	2.62	415.4
2. Rate 1	37.0	17889	40250	2.25	483.5
3. Rate 2	40.1	20972	43622	2.08	523.0
4. Rate 3	42.8	23164	46560	2.01	541.2
LSD $_{0.5}$, tons per hectare	0.5	-	-	-	-

Source: compiled by the author

However, the bioenergetic efficiency coefficient (Ke) showed an opposite trend: the highest value (2.62) was recorded in the control variant, whereas under the maximum mineral background (Rate 3), it decreased to 2.01. This indicates a decrease in the efficiency of converting the consumed energy into yield energy with the increasing intensity of the technology [15, p. 288]. The energy intensity of the product, which reflects the amount of energy spent per unit of yield, increased from 415.4 MJ/t (control) to 541.2 MJ/t (Rate 3), also indicating higher specific energy costs under more intensive fertilization.

Conclusions and Recommendations. The application of mineral fertilizers ensures an increase in crop yield but is accompanied by higher production costs and a decrease in profitability. The most economically feasible option was the variant without fertilizer application, although the highest yield was recorded under Rate 3. The optimization of mineral nutrition should consider not only productivity but also economic efficiency, requiring a balance between yield and expenditures.

The use of higher rates of mineral fertilizers results in increased sweet pepper yields; however, it is also associated with a significant rise in energy consumption. The highest bioenergetic efficiency coefficient (2.62) was achieved without the use of fertilizers, indicating the advantage of an extensive approach from the standpoint of energy conservation. An optimal balance between yield and energy consumption was observed under moderate fertilization rates (Rate 1), where a relatively high Ke (2.25) was maintained along with an increased yield. To improve the efficiency of sweet pepper cultivation in southern Ukraine, it is advisable to apply calculated mineral fertilization rates, taking into account not only profitability but also the energy parameters of the agricultural technology.

REFERENCES:

1. EU key indicators. URL: https://ec.europa.eu/eurostat (дата звернення 09.04.2025).

2. Crops and livestock products. URL: https://www.fao.org/faostat/en/#data/QCL (дата звернення 10.04.2025).

3. Вожегова Р., Ушкаренко В., Коковіхін С. та ін. Енергетична ефективність вирощування цукрової кукурудзи при краплинному зрошенні в залежності від глибини обробітку ґрунту, удобрення та густоти рослин. *Bulgarian Journal of Agricultural Science*, 26 (4), 2020.С. 885–889. URL: https://consensus.app/papers/energy-efficiency-of-sweet-corn-cultivation-at-drip-vozhehova-ushkarenko/def1bbd19f3a5d489cef7be5389a518f/?utm (дата звернення 11.04.2025).

4. Вожегова Р., Лиховид П., Ушкаренко В. та ін. Водоспоживання солодкої кукурудзи за краплинного зрошення залежно від глибини оранки, норм добрив та густоти рослин. *AgroLife Scientific Journal*. 2022. URL: https://consensus.app/papers/dripirrigated-sweet-corn-water-use-depending-on-the-depth-vozhehova-lykhovyd/e10a2af0f27c5fe5bbf5ec636fa96f00/?utm_(дата звернення 10.04.2025).

5. Nijamudeen, Singh M., Khanna M. et al. N and K fertilizer application rate under drip-fertigation for greenhouse grown sweet pepper. *Indian Journal of Horticulture*, 2013. 70, С. 54–59. URL: https://consensus.app/papers/n-and-k-fertilizer-application-rate-under-dripfertigation-nijamudeen-singh/a203181183965b30acf0a4f823a66a82/?utm_(дата звернення 12.04.2025).

6. Singh M., Khanna M., Balraj Singh et al. Nitrogen and potassium distribution in the soil profile of sweet pepper crop with different drip fertigation methods. 2013. URL: https://consensus.app/papers/nitrogen-and-potassium-distribution-in-the-soil-profile-of-singh-khanna/59d4044cf7e157b896e301118b113471/?utm_ (дата звернення 11.04.2025).

7. Styles S., Burt C. Evaluation of subsurface drip irrigation on peppers.1999. URL: https://consensus.app/papers/evaluation-of-subsurface-drip-irrigation-on-peppers-styles-burt/199ba47af95e5ecb88afedfde7d45a08/?utm_ (дата звернення 12.04.2025).

8. Kumari R., Kaushal A., Singh K. Water use efficiency of drip fertigated sweet pepper under different fertilizer levels. *Indian Journal of Science and Technology*, 2014. Vol. 7, 1538–1543. URL: https://consensus.app/papers/water-use-efficiency-of-drip-fertigated-sweet-pepper-under-kumari-kaushal/3f7020591fe95a01b35bb575749101f6/?utm_ (дата звернення 10.04.2025).

9. Wang H., Xiang Y., Zhang F. et al. Responses of yield, quality and water-nitrogen use efficiency of greenhouse sweet pepper to different drip fertigation regimes. *Agricultural Water Management*. 2022. URL: https://consensus.app/papers/responses-of-yield-quality-and-waternitrogen-use-wang-xiang/0cfcc56db2d257fe88d3741842f8dd57/?utm_ (дата звернення 10.04.2025).

10. Минкін М.В., Минкіна Г.О. Забур’яненість посівів буряку цукрового залежно від агротехнічних факторів при зрошенні в умовах півдня України. *Таврійський науковий вісник. Сільськогосподарські науки*. Херсон, 2024. Вип. 140. С. 178–183. URL: DOI https://doi.org/10.32782/2226-0099.2024.140.24 дата звернення 13.04.2025).

11. Сучасна технологія вирощування перцю. URL: https://uapg.ua/blog/suchasna-tehnologiya-viroshhuvannya-percju/ (дата звернення 11.04.2025).

12. Аверчев О.В., Йосипенко І.В., Нікітенко М.П. Економічні аспекти вирощування та виробництва гречки, проса та рису в Україні. *Таврійський науковий вісник. Сільськогосподарські науки*. Херсон. 2023. № 129. С. 10–19. URL: DOI https://doi.org/10.32851/2226-0099.2023.129.2 (дата звернення 13.04.2025).

13. Левкіна Р.В. Новий підхід до використання результатів енергетичного аналізу в овочівництві. *Проблеми ефективного функціонування АПК в умовах нових форм власності та господарювання*: кол. монографія. / За ред. П.Т. Саблука, В.Я. Амбросова, Г.Є. Мазнєва. К.: ІАЕ УААН, 2001. Т. 2. С. 563–566.

14. Левкіна Р.В. Вплив типів технологій на енергетичні витрати на вирощування овочевих культур. *Ринкова трансформація економіки АПК*. Кол. монографія. / За ред. П.Т. Саблука, В.Я. Амбросова, Г.Є. Мазнєва. К.: ІАЕ УААН, 2002. Ч. 2. С. 435–438.

15. Левкіна Р.В. Напрямки вдосконалення методики енергетичної оцінки в овочівництві. *Ринкова трансформація економіки АПК.* кол. монографія. / За ред. П.Т. Саблука, В.Я. Амбросова, Г.Є. Мазнєва. К.: ІАЕ УААН, 2002. Ч. 3. С. 287–289.