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APPROACHES TO IMPROVE THE EFFICIENCY OF CROPS GROWING ON A SOD-PODZOLIC SOIL

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Abstract. *The article presents the results of field studies on the impact of mineral fertilizer, liming, application of sulfur-containing fertilizer and microelements on the yield and economic efficiency of growing crops on a sod-podzolic soil. The study was conducted in a stationary experiment of the Institute of Agriculture of Western Polissya in the following crop rotation: winter wheat, corn, spring barley, winter rapeseed. Limestone materials (dolomite and limestone flour) were applied in doses determined by the magnitude of hydrolytic acidity (Hh, mmol/100 g of soil) before the experiment was started, recommended doses of mineral fertilizers were applied to the crops annually, and foliar feeding with the micronutrient "Nutrivan Plus" was carried out. It has been established that the productivity of crops on this type of soil largely depends on the degree of its agrochemical conditions. The use of mineral fertilizer (NPK) alone provided limited yield increase, while the combination of fertilizers with liming with dolomite flour contributed to a significant increase in crop productivity. The highest yield (4.00 t/ha) and economic return (9.2 thousand UAH/ha) in winter wheat crop was ensured by the integrated use of NPK, dolomite flour (1.0 Hh), sulfur (S_{40}), and micronutrient fertilizers. For corn and winter rapeseed, the highest yield (9.04 and 2.94 t/ha) and profit (29.2 and 33.5 thousand UAH/ha), respectively, were obtained with the application of 1.5 Hh $CaMg(CO_3)_2$. It has been proven that growing crops without fertilizer or only with NPK is economically unprofitable. The obtained results confirm the feasibility of using an integrated system of fertilization and land reclamation on acidic soils to ensure sustainable agricultural production.*

Keywords: *chemical land reclamation, sulfur fertilizers, mineral fertilizers, yield, economic efficiency, sod-podzolic soils*

Relevance of the research. The problem of soil fertility remains relevant at present. One of the main indicators of the level of soil fertility is the reaction of soil solution, on which the formation of high yields depends.

If chemical land reclamation is ignored, 0.6–1.8 million tons of agricultural units of crop production on acidic soils are annually lost. Gross yields of winter wheat, spring barley, and winter rapeseed are reduced the most. According to the research performed by the Institute of Agriculture of Western Polissya, positive changes occurring in sod-podzolic soils under the influence of liming contribute to an increase in crop rotation's productivity by 24–42 %.

A specific feature of acidic soils is the inhibition of root system growth and microbiological activity in root-containing layer; the accumulation of mobile forms of aluminum, iron, and manganese harmful to plants; the deterioration of physical parameters; insufficient nutritional regime [1, 2].

Based on the above-mentioned, it is relevant to study the possibilities of optimizing the conditions of crop nutrition in crop rotations on sod-podzolic soils by improving the soil using crop fertilization systems and chemical land reclamation.

Analysis of recent research and publications. Violation of the laws of agriculture can lead to a stable dynamics of a decrease in the level of soil fertility, especially its humus condition – the main criterion for assessing its fertility [3, 4]. The most vulnerable to this is the territory of Polissya, where sod-podzolic soils of light texture are widespread, which is due to the predominance of the podzolic soil formation process in this zone.

They are characterized by low nutrient and organic matter content, and an acidic soil reaction. Sod-podzolic soils were formed mainly on sandy and sandy loam basis, in conditions of a rather humid climate and hilly-ridged relief. This entire complex of characteristics determines low natural fertility of sod-podzolic soils. Looking for approaches to increase the fertility of such soils is an important scientific and practical task, the solution of which determines the effectiveness of agricultural production in humid regions [5, 6]. The main direction of increasing their fertility is chemical and structural land reclamation, fertilizers, which are primarily aimed at improving the agrophysical, agrochemical, and physicochemical properties of the soil [7, 8].

The results of long-term studies have found out that for the most of the crops cultivating in the Polissya and Forest-Steppe zones of Ukraine, the optimal reaction of soil solution is within the pH_{KCl} range of 5.6–7.0 [4, 9]. It is practically impossible to achieve this level of soil reaction in natural conditions without liming. Therefore, environmentally safe and economically feasible agricultural use of these soils requires chemical reclamation and the application of fertilizers [10, 11]. Research conducted by the Institute of Agriculture of Western Polissya has established optimal doses of limestone, organic and mineral fertilizers in crop rotations on sod-podzolic soils, which ensure a productivity of 55–60 centners of feed units per hectare of crop rotation area.

The studies of a number of domestic and foreign researchers [6, 11–14] have proven that effective liming with doses within 0.5–1.5 Hh (hydrolytic acidity) provides optimal conditions for crops growth, significantly reduces the mobility of toxic forms of aluminum, the excess of which on acidic soils can suppress the root system and reduce yield by 20–50 % [12, 13].

In addition to chemical land reclamation, the effective use of sod-podzolic soils requires an integrated approach, which also includes the application of organic and mineral fertilizers, micronutrients, and sulfur-containing compounds [14, 15]. In particular, sulfur is an important element in plant protein metabolism, and micronutrients (zinc, boron, manganese, copper, etc.) increase the resistance of crops to stress factors, activate enzymatic processes, and contribute to better absorption of essential nutrients [1, 15]. The results of scientific researches show that supplementing background doses of mineral fertilizers with foliar application of micronutrients ensures increasing in crops productivity in various soil and climatic conditions [16, 17].

However, the problem of modern agriculture is the steady decrease trend in the use of organic fertilizers, the deficiency of sulfur, calcium, and magnesium as the primary causes of low fertility of sod-podzolic soils. Therefore, the combined use of dolomite flour, sulfur-containing and microfertilizers deserves special attention, which will allow not only to effectively regulate soil acidity, but also to ensure balanced nutrition for crops, improve the physicochemical properties of soil environment and increase yield in the long term.

The aim of the study was to determine the effect of different forms and doses of chemical ameliorants in combination with fertilizers on the yield and economic efficiency of growing agricultural crops on a sod-podzolic soil in the conditions of Western Polissya.

Materials and research methods. The field studies were conducted in a stationary experiment of the Institute of Agriculture of Western Polissya of NAAS in a short crop rotation on sod-podzolic soil. The crop rotation was as follows: winter wheat, corn, spring barley, winter rapeseed. The technology of growing agricultural crops is generally accepted for the Polissya zone. Protection from pests, diseases, and weeds was carried out using intensive technology.

Mineral fertilizers were applied in recommended doses: $N_{120}P_{60}K_{90}$ for winter wheat, $N_{120}P_{90}K_{120}$ for corn for grain, $N_{90}P_{90}K_{90}$ for spring barley, $N_{120}P_{90}K_{120}$ for winter rapeseed in the form of ammonium nitrate, ammophos, potassium chloride. Chemical ameliorants – dolomite ($CaMg(CO_3)_2$) and limestone ($CaCO_3$) flours – were applied before the establishment of the stationary experiment according to the experiment scheme in doses calculated by the hydrolytic acidity index of the soil (Hh, mmol/100 g of soil): 0.5–1.5 Hh.

The foliar fertilization of crops with microfertilizers “Nutrivant Plus Cereal” and “Nutrivant Oilseed” (2 kg/ha) were carried out in the phases of spring tillering and emergence into the tube of winter wheat, in the phase of 4–5 and 6–8 leaves for corn, in the phase of tillering and emergence into the tube for spring barley, and in the phase of spring rosette and the beginning of budding for winter rapeseed.

The harvest was recorded by plots, by continuous weighing of the obtained harvest with subsequent conversion to per area units. Statistical processing of the obtained research results was carried out by the ANOVA variance analysis method using the computer programs Microsoft Office Excel, and Statistica 10.0.

Weather conditions over the years of research indicate that this period was characterized by an

increase in the average monthly air temperature and sharp fluctuations in the amount and intensity of precipitation. Quite often, long droughts were replaced by rains, which negatively affected the processes of plant growth, development, and the formation of an appropriate level of winter wheat productivity.

Despite the change in temperature and humidity regimes, weather conditions for crops in the Western region were close to average long-term values, which led to the formation of relatively high-yield crops production on sod-podzolic soils.

Research results and their discussion. It has been found out that the yield of agricultural crops on sod-podzolic soils largely depends on the degree of their amelioration, which includes the complex impact of several factors: mineral fertilizer (NPK), liming, application of sulfur-containing fertilizer and micronutrients. Thus, in the variant without applying any of these measures (control), the average crop yield was for winter wheat – 1.29 t/ha, for corn – 4.05 t/ha, for spring barley – 1.39 t/ha, and for winter rapeseed – 0.85 t/ha. These results indicate low productivity of sod-podzolic soils without liming and mineral nutrition, because of their high acidity, weak buffering capacity, and nutrient deficiency [2, 5, 7].

1. Productivity of crops in the rotation depending on fertilizer and doses of chemical ameliorants, average for 2016–2020, t/ha

Option	Winter wheat		Corn for grain		Spring barley		Winter rapeseed	
	yield	± before control	yield	± before control	yield	± before control	yield	± before control
Without fertilizers – control	1.29	–	4.05	–	1.39	–	0.85	–
NPK – background	2.32	1.03	5.06	1.01	2.43	1.04	1.34	0.49
Background + $CaMg(CO_3)_2$ (0,5 H_g)	3.13	1.84	6.73	2.68	3.19	1.80	1.95	1.10
Background + $CaMg(CO_3)_2$ (1,0 H_g)	3.61	2.32	7.53	3.48	3.71	2.32	2.30	1.45
Background + $CaMg(CO_3)_2$ (1,0 H_g) + S_{40}	3.80	2.51	7.92	3.87	3.87	2.48	2.56	1.71
Background + $CaMg(CO_3)_2$ (1,0 H_g) + S_{40} + micronutrient	4.00	2.71	8.40	4.35	3.98	2.59	2.66	1.81
Background + $CaMg(CO_3)_2$ (1,5 H_g)	3.90	2.61	9.04	4.99	4.08	2.69	2.94	2.09
Background + $CaCO_3$ (1,0 H_g)	3.38	2.09	7.41	3.36	3.57	2.18	2.22	1.37
HIP_{05}	0.13		0.47		0.14		0.11	

The application of mineral fertilizers (NPK) as an independent agricultural tool contributed to a statistically significant increase in the yield by 0,49–1,04 t/ha, depending on the crop. However, even with a positive impact on productivity, this effect was insufficient, and unilateral fertilizer application without land reclamation could deepen the processes of the acidification of soil solution [11, 13]. This is confirmed by the level of crop yield after liming, which is consistent with previous scientific results of the Institute [4].

Significant improvement in crop yields was achieved when combining NPK with liming with dolomite flour in doses of 0.5–1.5 Hh. The results show that for all crops, yield increases were statistically significant both relative to the background (NPK) and between each subsequent applied dose of dolomite flour (0.5; 1.0; 1.5 Hh), which was confirmed by the HIP_{05} criterion. The highest increases in comparison with the background were provided by the dose of 1.5 Hh: winter wheat – +1.68 t/ha, corn – +3.34 t/ha, spring barley – +1.55 t/ha, winter rapeseed – +1.60 t/ha.

A comparative assessment of the effect of a dose of 1,0 Hh $CaCO_3$ and $CaMg(CO_3)_2$ on the background of mineral fertilizer according to the HIP_{05} index showed the advantage of the latter for winter wheat (+0.23 t/ha) and spring barley (+0.14 t/ha). The effectiveness of dolomite flour in growing cereals is explained by the content of not only calcium, but also magnesium – a key mesoelement that participates in photosynthesis, protein synthesis, and metabolism regulation in plants. In the cases with corn and winter rapeseed, a trend towards increased yield was also observed. Improvement in mineral nutrition conditions, especially on soils with magnesium deficiency, provided an additional increase in yield by 2–7 % compared to the limestone flour option, which emphasizes the higher agrochemical efficiency of dolomite in fertilization systems on sod-podzolic soils.

The greatest synergistic effect on crop yields when applying dolomite flour in a dose of 1,0 Hh was observed with the combined impact of NPK, sulfur-containing fertilizer (S_{40}), and foliar feeding with micronutrients. In variants with their simultaneous use, the yield of winter wheat increased up to 4.00 t/ha, of corn – up to 8.40 t/ha, of spring barley – up to 3.98 t/ha, and of winter rapeseed – up to 2.66 t/ha. This represented significant increases compared to the "Background + $CaMg(CO_3)_2$ 1.0 Hh" option for all crops. However, they were insignificant or lower compared to the "Background + $CaMg(CO_3)_2$ 1,5 Hh" option.

At the same time, it is worth distinguishing between the impact of sulfur and micronutrient fertilizers. Adding only S_{40} to NPK and $CaMg(CO_3)_2$ (1.0 Hh) provided significant increases for winter wheat (+0.19 t/ha), spring barley (+0.16 t/ha), and winter rapeseed (+0.26 t/ha). While a significant additional effect of microfertilizer (compared to the option without it) was established for wheat (+0.20 t/ha) and corn (+0.48 t/ha). Therefore, the multifactorial effect of the combination of liming, NPK, sulfur, and microelements proved to be the most effective. This indicates that the agrochemical effect was not formed by the isolated influence of individual factors, but through their synergistic effect, which is consistent with the other results [4, 10, 13, 15].

In the modern conditions of a market economy, the determining factor in the feasibility of using agrotechnical methods for crops growing is their economic efficiency. The choice of optimal technological options should be based not only on yield indicators, but also on a systematic analysis of the impact of technology elements on crops productivity, the quality of the resulting products, and the level of their production costs [17].

In order to substantiate the most effective combination of agricultural measures taken for the study, the economic efficiency of fertilizer and chemical land reclamation options was calculated using 2024 prices. It was found out that the cost of the resulting products changed similarly to the yields level, demonstrating a clear relationship between agricultural measures and financial indicators (Table 2).

Conducted economic assessment of the efficiency of crops growing on the sod-podzolic soil with the application of different doses of chemical

2. Indicators of economic efficiency of agricultural crops growing depending on different doses of liming on the background of fertilization on the sod-podzolic soil, average for 2016–2020, thousand UAH/ha

Option	Winter wheat		Corn for grain		Spring barley		Winter rapeseed	
	cost of yield	cultivation costs	cost of yield	cultivation costs	cost of yield	cultivation costs	cost of yield	cultivation costs
Without fertilizers – control	10.3	15.2	30.4	30.5	11.1	14.5	17.9	19.8
NPK – background	18.6	21.2	38.0	37.9	19.4	20.6	28.1	27.2
Background + $CaMg(CO_3)_2$ (0,5 H_g)	25.0	21.5	50.5	38.2	25.5	21.0	41.0	27.5
Background + $CaMg(CO_3)_2$ (1,0 H_g)	28.9	21.9	56.5	38.6	29.7	21.3	48.3	27.9
Background + $CaMg(CO_3)_2$ (1,0 H_g) + S_{40}	30.4	22.2	59.4	38.9	31.0	21.6	53.8	28.2
Background + $CaMg(CO_3)_2$ (1,0 H_g) + S_{40} + micronutrient	32.0	22.8	63.0	39.5	31.8	22.3	55.9	28.8
Background + $CaMg(CO_3)_2$ (1,5 H_g)	31.2	22.2	67.8	38.6	32.6	21.7	61.7	28.3
Background + $CaCO_3$ (1,0 H_g)	27.0	21.6	55.6	38.3	28.6	21.0	46.6	27.6

ameliorants on the background of fertilization showed that is a profitable measure. The highest conditional net profit of 9.2 thousand UAH/ha for winter wheat was provided by the application of 1.0 dose of Hh $CaMg(CO_3)_2$ on the background of $N_{120}P_{60}K_{90} + S_{40}$ + microfertilizer (Fig. 1).

The use of 1,5 doses of Hh $CaMg(CO_3)_2$ on the background of NPK contributed to both an increase in the yield of corn for grain, spring barley, and winter rapeseed, and the economic efficiency of their cultivation with a conditional net profit of 29.2 thousand UAH, 11.0 thousand UAH, and 33.5 thousand UAH, respectively.

On average, the costs of agricultural crops growing for the crop rotation amounted to 20.0–28.4 thousand UAH/ha, and the conditional net profit for different doses of chemical ameliorants on the background of fertilization was within 8.4–20.7 thousand UAH/ha (Fig. 2).

Crops growing on the sod-podzolic soil without fertilizer and chemical melioration and against the background of fertilization in the average for the crop rotation turned out to be economically unprofitable with the loss amounted up to 2.6 thousand UAH/ha and 0.7 thousand UAH/ha, respectively.

Conclusions. On the sod-podzolic soils of Western Polissya, the application of only mineral fertilizers (NPK) without liming provides a limited increase in crops yields (0.49–1.04 t/ha), which indicates the low efficiency of such approach on acidic soils.

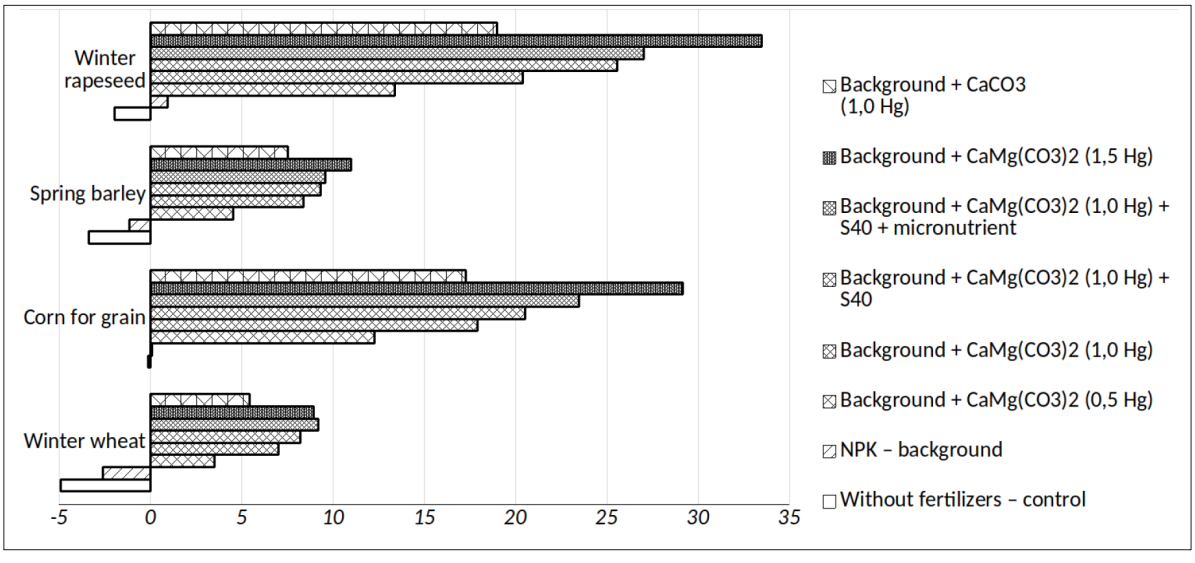

Fig. 1. Conditional net profit for agricultural crops growing depending on different doses of liming on the background of fertilization on the sod-podzolic soil, average for 2016–2020, thousand UAH/ha

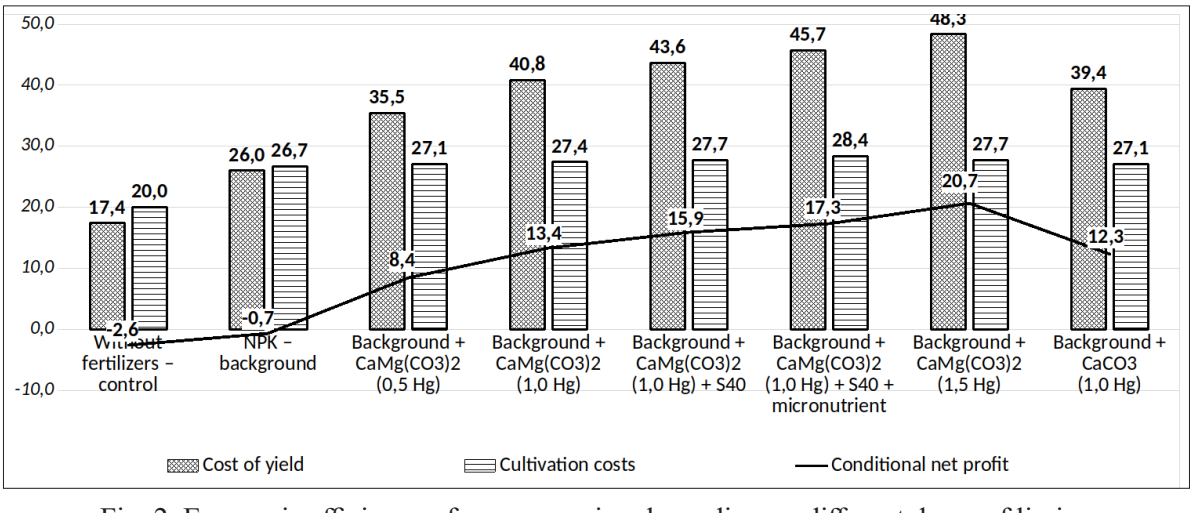

Fig. 2. Economic efficiency of crops growing depending on different doses of liming on the background of fertilization on the sod-podzolic soil, on average per the crop rotation (2016–2020), thousand UAH/ha

The liming with dolomite flour in doses of 0.5–1.5 Hh in combination with NPK contributes to a significant increase in the yields of all crops in the rotation. The additional application of sulfur (S_{40}) during liming (1.0 Hh $CaMg(CO_3)_2$) and NPK fertilization provided a significant increase in yield for winter wheat, spring barley, and winter rapeseed. The addition of the microfertilizer "Nutrivant Plus Cereal" proved to be effective for winter wheat and corn, which emphasizes the feasibility of a differentiated approach to their use depending on the crop, especially in conditions of chemical soil reclamation.

The highest agronomic efficiency for winter wheat was provided by the combination of NPK, dolomite flour (1,0 Hh), sulfur-containing fertilizer (S_{40}), and foliar feeding with microelements. This approach made it possible to increase the crop yield up to 4.00 t/ha and increase the conditional net profit up to 9.2 thousand UAH/ha.

In the case of corn for grain, winter rapeseed, and spring barley, the highest yields were achieved with the combined application of 1.5 Hh $CaMg(CO_3)_2$ and NPK. Economic analysis showed the highest profitability of this option for corn (29.2 thousand UAH/ha) and winter rapeseed (33.5 thousand UAH/ha). Therefore, complex agrochemical technology for acidic soils is not only an agronomically effective, but also economically feasible measure.

Conflicts of interest: the authors declare no conflict of interest.

Use of artificial intelligence: the authors confirm that they did not use artificial intelligence technologies during the creation of this work.

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ШЛЯХИ ПОКРАЩЕННЯ ЕФЕКТИВНОСТІ ВИРОЩУВАННЯ СІЛЬСЬКОГОСПОДАРСЬКИХ КУЛЬТУР НА ДЕРНОВО-ПІДЗОЛИСТОМУ ҐРУНТІ

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Анотація. *У статті представлено результати польових досліджень щодо впливу мінерального удобрення, вапнування, внесення сірковмісного добрива та мікроелементів на врожайність і економічну ефективність вирощування сільськогосподарських культур на дерново-підзолистому ґрунті. Дослід проведено у стаціонарному досліді Інституту сільського господарства Західного Полісся у сівозміні: пшениця озима, кукурудза, ячмінь ярий, ріпак озимий. Вапнякові матеріали (доломітове та вапнякове борошно) вносили у дозах визначених за величною гідролітичної кислотності (Нг, ммоль/100 г ґрунту) перед закладкою досліду, щорічно під культури вносили рекомендовані дози мінеральних добрив та проводили позакореневі підживлення мікродобривом «Нутріван плюс». Установлено, що продуктивність культур на цьому типі ґрунтів значною мірою залежить від ступеня його агрохімічного окультурення. Застосування лише мінерального удобрення (NPK) забезпечило обмежене зростання врожайності, тоді як поєднання добрив із вапнуванням доломітовим борошном сприяло достовірному підвищенню продуктивності культур. Найвищу врожайність (4,00 т/га) і економічну віддачу (9,2 тис. грн/га) у посівах пшениці озимої забезпечило комплексне застосування NPK, доломітового борошна (1,0 Нг), сірки (S_{40}) та мікродобрива. Для кукурудзи та ріпаку озимого найбільшу урожайність (9,04 і 2,94 т/га) і прибуток (29,2 і 33,5 тис. грн/га) відповідно отримано за внесення 1,5 Нг $CaMg(CO_3)_2$. Доведено, що вирощування культур без удобрення або лише за фону NPK є економічно збитковим. Отримані результати підтверджують доцільність застосування інтегрованої системи удобрення й меліорації на кислих ґрунтах для забезпечення сталого агровиробництва.*

Ключові слова: *хімічна меліорація, сірковмісні добрива, мінеральне удобрення, врожайність, економічна ефективність*