DOI: https://doi.org/10.31073/mivg202401-380
Available at (PDF): https://mivg.iwpim.com.ua/index.php/mivg/article/view/380

UDC 631.8/631.821:633.11:631.445.21

THE EFFECT OF DIFFERENT LIME RATES ON THE YIELD AND QUALITY OF WINTER WHEAT UNDER MINERAL FERTILIZATION ON A SOD-PODZOLIC SOIL

M.Y. Shevchuk[1], Dr. of Agricultural Sciences, S.M. Golub[2], Ph.D. in Agricultural Sciences, H.F. Rovna[3]

[1] Lesya Ukrainka Volyn National University, Lutsk, Ukraine;
https://orcid.org/0009-0007-0768-6550; e-mail: Shevchuk.Myhaylo@vnu.edu.ua;
[2] Lesya Ukrainka Volyn National University, Lutsk, Ukraine;
https://orcid.org/0000-0001-6204-2570; e-mail: golub.sergiy@vnu.edu.ua;
[3] Institute of Agriculture of Western Polissia NAAS, 35325, p. Shubkiv, Rivne district, Rivne region, Ukraine;
https://orcid.org/0000-0002-7599-5650; e-mail: rivne_apv@ukr.net

Abstract. *Stable productivity, essential for winter wheat as a strategic crop, can only be achieved by meeting its growth and development requirements, especially nutrition. Soddy-podzolic soils, typically highly acidic in their natural state, are unsuitable for realizing winter wheat's full yield potential. Combined fertilizer and lime application is a key factor for grain yield and quality. While lime (CaCO3) is widely used to reclaim acidic soils, determining the optimal application rate, particularly in combination with mineral fertilizers, is crucial. This research investigated the effect of applying 0,5–2,0 lime norms based on soil hydrolytic acidity (Hh, mmol/100 g) combined with a moderate norm of N60P60K60 mineral fertilizers on winter wheat grain yield and quality. The soil had an initial pHKCl of 4.8 and a hydrolytic acidity of 2,3 mmol/100 g of soil. Field, laboratory, calculation, statistical, and generalization methods were employed. The experiment revealed the lowest grain yield in the control and N60P60K60 treatments without liming. Lime application at various rates with N60P60K60 increased grain yield by 0,74–0,89 t/ha compared to the control, with the 1,5 CaCO3 norm by Hh achieving the best results. The application of 2,0 norms of CaCO3 led to a statistical decrease in yield by 0,14 t/ha ($p \leq 0,05$) due to a reduction in available nutrient compounds in the soil. Liming also affected the main indicators of grain quality of winter wheat. An increase to the control was found for the weight of 1000 grains and protein content, while the actual weight of the grain decreased. As the most optimal treatment, regarding grain quality, was found out the option of 1,0 CaCO3 norm based on soil hydrolytic acidity in combination with N60P60K60, with the winter wheat grain yield of 3,54 t/ha and an increase in the protein content in it by 6,8 % to the background.*

Key words: *winter wheat, liming, mineral fertilizers, yield, protein, grain nature, grain weight*

Relevance of research. Acidic soils are a significant problem for Ukrainian agriculture, especially in the Polissia zone, where sod-podzolic soils predominate, with a soil reaction of 4,4–5,5 units. The main reasons for the formation of this acidic environment include the leaching type of soil water regime, low carbonate content in the parent rock, human activities such as the application of physiologically acidic mineral fertilizers, environmental pollution, acid rain, and an imbalance of calcium in soils. Global climate change and the spread of calciphilic crops in Polissia further intensify these negative acidification processes [1].

Liming, which restores soil pH to optimal ranges for crops, is an important agronomic measure to increase crop yields, particularly for winter wheat. This crop best realizes its potential productivity at pH 6,5–7,2. Losses in crop production due to excessive soil acidity exceed 2,0 million tons of grain annually, with an estimated cost of UAH 10–12 billion [2].

Maintaining an optimal pH level improves the physical and chemical properties of the soil, stimulates microbial activity and increases the availability of nutrients [3]. Liming can have a complex effect on soil organic matter. Research by Malynovska [4] shows that it both weakens the mineralization process and stimulates overall biological activity in the soil. Specifically, the study found that liming decreased the mineralization of soil organic matter: without mineral fertilizer – by 2,1 times, with mineral fertilizer – by 4,07 times, and against the background of plowing green manure biomass and by-products of the predecessor – by 1,36 times.

Analysis of the latest research and publications. Studies by domestic and foreign

scientists show that the liming of acidic soils can lead to a significant increase in winter wheat yields. Polovyi V. and Yashchenko L. [5] found that applying $N_{120}P_{60}K_{90}$ increased wheat grain yield by 1,04 t/ha compared to the control. However, this increase was not enough to be economically beneficial for acidic sod-podzolic soils. The researchers found that only the combined use of fertilizers and limestone materials provided a significant yield increase in their experiment. Warner J. et al. [6] indicate that a change in pH from 5,5 to 6,5 increases wheat grain yield by 22 %, and at lower levels, the use of nitrogen fertilizers is less cost-effective.

Jelic M. et al. [7] found that the combined use of $N_{120}P_{100}K_{60}$, 5 t/ha of lime ($CaCO_3$), and 20 t/ha of manure significantly reduces aluminum levels in grain and increases winter wheat yield. Similar results were obtained by Chauhan N. et al. [8], who recorded the highest wheat yield (2.8 t/ha) with the recommended fertilizer rate (120 kg N, 26 kg P, 25 kg K) combined with 10 t/ha of manure, although it was statistically comparable to the NPK + lime variant (2,6 t/ha). These studies collectively demonstrate that the integrated use of lime together with chemical fertilizers is crucial for both maintaining the productivity of acidic soils and improving the quality of winter wheat products [9].

Despite the proven effectiveness of liming, some farmers hesitate due to the upfront cost of limestone materials. However, liming is a long-term investment that not only significantly increases winter wheat yields in the current year, but also improves soil fertility for many years to come, ultimately leading to greater returns on investment.

The purpose of the study is to investigate the response of winter wheat yield to different norms of lime: this will allow us to develop recommendations for optimizing its use and increasing the efficiency of agricultural production on acidic sod-podzolic soils.

Materials and methods of research. To evaluate the response of winter wheat to different rates of lime, the field experiment on the sod-podzolic soil of Western Polissia, employed the following treatments:

1. Control (without fertilizers).
2. $N_{60}P_{60}K_{60}$ – background.
3. Background + 0,5 norms of $CaCO_3$ by hydrolytic acidity (Hh) (0,5 $CaCO_3$).
4. Background + 1,0 norm of $CaCO_3$ by Hh (1.0 $CaCO_3$).
5. Background + 1,5 norms of $CaCO_3$ by Hh (1,5 $CaCO_3$); 6. Background + 2,0 norms of $CaCO_3$ by Hh (2,0 $CaCO_3$).

Winter wheat was grown in an 8-month crop rotation, with alfalfa as a predecessor. The soil of the experimental plot was sod-podzolic sandy, characterized by the following agrochemical parameters: humus content 1.2 %, mobile nutrients (mg/kg soil): P_2O_5 (according to Kirsanov) – 62,0; K_2O (according to Kirsanov) – 75,0, pH_{KCl} – 4,8; hydrolytic acidity – 2,3 mmol/100 g of soil; degree of saturation with bases – 62 %.

The area of the plots in the experiment was 198 m^2 (33×6) and 100 m^2 (25×4). Replication: three times.

Mineral fertilizers were applied in the form of ammonium nitrate, granular superphosphate, and potassium chloride. Phosphorus-potassium fertilizers were applied for autumn plowing, nitrogen fertilizers – half the norm for plowing, and the rest in spring as fertilizing. Chemical reclamation was carried out by ground lime with an active ingredient content in terms of $CaCO_3$ of 83,7–92,1 %.

The grain harvest was recorded by continuous mowing and weighing from the recorded area. Grain quality was determined according to generally accepted methods [10]. The statistical difference of the data was determined using a one-factor ANOVA analysis with the subsequent calculation of Fisher's test at $p \leq 0,05$.

Research results and discussion. The application of various chemical amendments and fertilizers can create variations in the growing environment for winter wheat plants. These factors significantly impact plant nutrition, ultimately affecting crop yields [11].

Research has shown that applying mineral fertilizers at $N_{60}P_{60}K_{60}$ rates without liming can decrease soil fertility. This decline is caused by the acidifying effect of these fertilizers, which deteriorates the soil's physical and chemical properties. Consequently, the crop yield obtained with $N_{60}P_{60}K_{60}$ without liming (2,62 t/ha) was statistically similar to the yield achieved with the natural fertility of sod-podzolic soil (Table 1).

Liming significantly increased crop productivity compared to both the control and the background. However, different rates of lime provided different yield increases in both absolute and relative units. The use of 0.5 $CaCO_3$ on the $N_{60}P_{60}K_{60}$ background contributed to a 29.4 % increase in yield compared to the background. Further increase in the lime rate provided a statistically significant difference in yield only at 1.5 $CaCO_3$.

The yield increase compared to the control was 1,08 t/ha or 40,8 %. When applying 2,0 $CaCO_3$, grain yield decreases compared to the previous variant.

1. Average yield of winter wheat in crop rotation at different norms of lime on sod-podzolic soil

Treatments	Grain yield, t/ha	Yield to control ratio	
		t/ha	%
Control (without fertilizers)	2,65	–	–
$N_{60}P_{60}K_{60}$ – background	2,62	–0,3	–
Background + 0,5 $CaCO_3$	3,39	0,74	27,9
Background + 1,0 $CaCO_3$	3,54	0,89	33,6
Background + 1,5 $CaCO_3$	3,73	1,08	40,8
Background + 2,0 $CaCO_3$	3,59	0,89	35,5
LSD_{05}	0,13		

Gospodarenko G. and O. Karnaukh [12] explain this by the occurrence of microelements due to the increased amount of calcium that enters the soil with limestone material. Excessive amounts of calcium supplied with a high rate of lime can reduce the availability of a number of nutrients for plants, which causes their deficiency in crop nutrition, especially when their content in the soil is low.

Liming of soddy-podzolic soil affected the quality indicators of winter wheat products (Table 2).

Important technological indicators of wheat grain quality that affect the milling and baking properties of the grain are the weight of 1000 grains, the nature of the grain, and the protein content. The weight of 1000 grains is to a greater extent a genetic trait of the wheat variety. In the experiment, this criterion ranged from 37,0–39,1 g. Depending on the norm, liming increased the weight of 1000 grains compared to the background by 3,8–7,9 relative %. The highest absolute weight index was obtained under the application of 2,0 rates of $CaCO_3$ – 39,9 g. It should be noted that there was no statistical difference between the weight of 1000 grains in the variants with 1,0 and 1,5 norms of lime.

It was determined that the application of 0,5–2,0 lime norms decreased the actual grain weight by 0,7–2,0 %, which was within the error of the experiment. This is due to the formation of a larger number of grains, which become less filled. A significant decrease in the natural weight was obtained against the background of mineral fertilization compared to the control and variants with lime.

The protein content of wheat grain is significantly affected by the level of nitrogen nutrition. In the experiment the introduction of $N_{60}P_{60}K_{60}$ contributed to an increase in protein content by 0,5 absolute % compared to the control. Compared to the background, 1,0 and 2,0 norms of $CaCO_3$ had a significant effect on increasing the protein content, while at a 1,5 Hh, norms this quality indicator decreased, which may be due to growth dilution for the formation of the highest grain yield in this variant.

Prospects for further research should focus on optimizing crop nutrition conditions to further increase winter wheat yield and grain quality. This could involve improving the soil nutrient profile and identifying economically viable fertilizer application norms.

Conclusions. When growing winter wheat on sod-podzolic soil with a medium acid reaction of the soil solution, liming is a prerequisite for increasing crop productivity. Based on the results obtained, the application of 1,5 norms of $CaCO_3$ on the background of $N_{60}P_{60}K_{60}$ resulted in 3,73 t/ha of winter wheat grain. However, taking into account the quality indicators, the best option should be considered the use of 1,0 norm of $CaCO_3$ established by the hydrolytic acidity of the soil, which contributes to grain yield at the level of 3,54 t/ha and an increase in protein content in grain by 6,8 % compared to the background.

2. Average quality indicators of winter wheat grain in crop rotation at different norms of lime on sod-podzolic soil

Treatments	1000 grain weight, g	Grain nature, g/l	Protein content, %
Control (without fertilizers)	38,4	750	11,8
$N_{60}P_{60}K_{60}$ – background	37,0	720	12,3
Background + 0,5 $CaCO_3$	38,4	745	12,1
Background + 1,0 $CaCO_3$	39,2	740	12,6
Background + 1,5 $CaCO_3$	39,2	735	12,2
Background + 2,0 $CaCO_3$	39,9	735	12,5
LSD_{05}	0,27	13,6	0,18

References

1. Tkachenko, M. A., Kondratiuk, I. M., & Borys, N. Ye. (2019). Khimichna melioratsiia kyslykh gruntiv: Monohrafiia. [Chemical reclamation of acidic soils]. Vinnytsia: TOV "TVORY". 318 p. [in Ukrainian].

2. Khodakivska, O., Hladunenko, R., Korchynska, S., & Tkachuk, L. (2021). Khimichna melioratsiia kyslykh gruntiv: orhanizatsiino-ekonomichni zakhody ta suchasni tekhnolohichni rishennia. [Chemical reclamation of acidic soils: organizational and economic measures and modern technological solutions]. *Ekonomika APK*, 4. https://doi.org/10.32317/2221-1055.202104040 [in Ukrainian].

3. Barvinskyi, A. V. (2020). Ekoloho-ekonomichna efektyvnist khimichnoi melioratsii kyslykh zemel [Ecological and economic efficiency of chemical reclamation of acidic lands]. Vdoskonalennia ekonomiky ta finansovoi systemy na zasadakh konkurentospromozhnosti, innovatsiinosti ta stalosti : materialy dopovidei Mizhnarodnoi naukovo-praktychnoi konferentsii. Zaporizhzhia: Klasychnyi pryvatnyi universytet, 128. Retrieved from: https://sci.ldubgd.edu.ua/bitstream/123456789/9149/1/Макет_11%20квітня.pdf#page=60 [in Ukrainian].

4. Malynovska, I. M. (2023). Mikrobiolohichni protsesy u siromu lisovomu hrunti za mineralnoho udobrennia, vapnuvannia ta zaoriuvannia pobichnoi produktsii roslynnytstva [Microbiological processes in gray forest soil under mineral fertilization, liming and plowing of crop by-products]. *Grunty, stalyi rozvytok ta ukrainske gruntoznavstvo*: materialy Mizhnarodnoi naukovoi konferentsii, prysviachenoi 120-richchiu vid Dnia Narodzhennia Hryhoriia Andrushchenka. Lviv-Dubliany: LNUP, 138–141.

5. Polovyi, V.M., & Yashchenko, L.A. (2021). Optimization of growing conditions for winter wheat on sod-podzolis soil by the fertilization and melioration in Western Polissia of Ukraine. *Achievements of Ukraine and the EU in ecology, biology, chemistry, geography and agricultural sciences*: Collective monograph. Vol.3, 90–108. Riga, Latvia: "Baltija Publishing". https://doi.org/10.30525/978-9934-26-086-5-38 [in Ukrainian].

6. Warner, J. M., Mann, M. L., Chamberlin, J., & Tizale, C. Y. (2023). Estimating acid soil effects on selected cereal crop productivities in Ethiopia: Comparing economic cost-effectiveness of lime and fertilizer applications. *PLOS ONE*, 18 (1). e0280230. https://doi.org/10.1371/journal.pone.0280230

7. Jelic, M., Milivojevic, J., Nikolic, O., Djekic, V., & Stamenkovic, S. (2015). Effect of long-term fertilization and soil amendments on yield, grain quality and nutrition optimization in winter wheat on an acidic pseudogley. Romanian Agricultural research, 32. Retrieved from: http://incda-fundulea.ro/rar/nr32/rar32.20.pdf

8. Chauhan, N., Sankhyan, N. K., Sharma, R. P., Singh, J., & Gourav (2020). Effect of long-term application of inorganic fertilizers, farm yard manure and lime on wheat (Triticum aestivum L.) productivity, quality and nutrient content in an acid alfisol. *Journal of Plant Nutrition*, 243 (17), 2569–2578. https://doi.org/10.1080/01904167.2020.1783298

9. Oliver, Y. M., Gazey, C., Fisher, J., & Robertson, M. (2021). Dissection of the Contributing Factors to the Variable Response of Crop Yield to Surface Applied Lime in Australia. *Agronomy*, 11 (5):829. https://doi.org/10.3390/agronomy11050829

10. Hrytsaienko, Z. M. (2021). Metody biolohichnykh ta ahrokhimichnykh doslidzhen roslyn i gruntiv. [Methods of biological and agrochemical research of plants and soils]. Kyiv: ZAT "NIChLAVA", 17–18 [in Ukrainian].

11. Polovyi, V. M., & Kulyk, S. M. (2019). Vplyv zastosuvannia khimichnykh meliorantiv ta udobrennia na produktyvnist pshenytsi ozymoi za vyroshchuvannia na dernovo-pidzolystomu grunti v umovakh Zakhidnoho Polissia [The influence of chemical ameliorants and fertilizers on the productivity of winter wheat when grown on sod-podzolic soil in Western Polissia]. *Perspektyvni napriamy ta innovatsiini dosiahnennia ahrarnoi nauky:* materialy Vseukrainskoi naukovo-praktychnoi internet-konferentsii, prysviachenoi 145- richchiu vid zasnuvannia kafedry botaniky ta zakhystu roslyn. Kherson: DVNZ "KhDAU", 214–216. Retrieved from: https://dspace.ksaeu.kherson.ua/bitstream/handle/123456789/2961 [in Ukrainian].

12. Hospodarenko, H., Karnaukh, O., & Alexander, A. (2020). Mikroelementy i dobryva v zhyvlenni roslyn [Trace elements and fertilizers in plant nutrition]. H. Hospodarenko (Ed.). Kamianets-Podilskyi: TOV Drukarnia "Ruta". 348 p. [in Ukrainian].

УДК 631.8/631.821:633.11:631.445.21

РЕАКЦІЯ УРОЖАЙНОСТІ ТА ЯКОСТІ ПШЕНИЦІ ОЗИМОЇ НА РІЗНІ НОРМИ ВАПНА НА ДЕРНОВО-ПІДЗОЛИСТОМУ ҐРУНТІ

М.Й. Шевчук[1], докт. с.-г. наук, С.М. Голуб[2], канд. с-г. наук, Г.Ф. Ровна[3]

[1] Волинський національний університет імені Лесі Українки, 43025, м. Луцьк, Україна; https://orcid.org/0009-0007-0768-6550; e-mail: Shevchuk.Myhaylo@vnu.edu.ua
[2] Волинський національний університет імені Лесі Українки, 43025, м. Луцьк, Україна; https://orcid.org/0000-0001-6204-2570; e-mail: Golub.Sergiy@vnu.edu.ua
[3] Інститут сільського господарства Західного Полісся НААН, 35325, с. Шубків, Рівненський район, Рівненська область, Україна; https://orcid.org/0000-0002-7599-5650 ; e-mail: rivne_apv@ukr.net

Анотація. *Озима пшениця як стратегічна культура потребує стабільної продуктивності, якої можна досягти лише задовольняючи її потреби для росту та розвитку, особливо щодо живлення. Дерново-підзолисті ґрунти, які зазвичай мають підвищену кислотність ґрунтового розчину без додаткового поліпшення є малопридатними для реалізації потенціалу продуктивності пшениці озимої. Однією із основних умов формування урожайності та якості зерна є сумісне застосування добрив і вапнякових матеріалів. Найбільш широко для хімічної меліорації кислих ґрунтів застосовують вапно ($CaCO_3$), проте необхідним є визначення його оптимальної норми, особливо у поєднані з мінеральними добривами. Вихідний показник ґрунту pH_{KCl} 4,8 і гідролітична кислотність 2,3 ммоль/100 г ґрунту. Метою досліджень було встановити вплив 0,5–2,0 доз вапна визначених за показником гідролітичної кислотності ґрунту (Нг, ммоль/100 г ґрунту) у поєднанні з внесенням помірної норми мінеральних добрив $N_{60}P_{60}K_{60}$. Методи досліджень: польовий, лабораторний, розрахунковий, статистичний, узагальнення. Результати досліджень показали, що найнижча урожайність зерна пшениці озимої у досліді отримана у контролі та за внесення $N_{60}P_{60}K_{60}$ без вапнування. Застосування на фоні $N_{60}P_{60}K_{60}$ вапна у різних нормах сприяло підвищенню урожайності зерна на 0,74–0,89 т/га відносно контролю, кращою у цьому відношенні була 1,5 норми $CaCO_3$ за Нг. Внесення 2,0 норми $CaCO_3$ спричинило статистичне зниження урожайності на 0,14 т/га ($p \leq 0,05$). Вапнування також вплинуло на основні показники якості зерна пшениці озимої. Підвищення відносно контролю встановлено для маси 1000 зерен і вмісту білка, тоді як натурна маса зерна знизилася. Найбільш оптимальним із урахуванням показників якості зерна у досліді визнано варіант внесення 1,0 норми $CaCO_3$ встановленої за гідролітичною кислотністю ґрунту на фоні $N_{60}P_{60}K_{60}$ із урожайністю 3,54 т/га зерна пшениці озимої і підвищенням вмісту білка у ньому на 6,8 % відносно фону.*

Ключові слова: *пшениця озима, вапнування, мінеральні добрива, урожайність, білок, натура зерна, маса зерен*