UDC 633.34; 631.147

B. I. Kotsiuba
P. S. Hnativ
V. Ya. Ivaniuk

ECOLOGIZATION OF SOYBEAN CULTIVATION TECHNOLOGY ON DERNO-GLEYOZEM SOIL OF THE MALE POLISSYA

Lviv National Environmental University

Анотація

Вирощування високих врожаїв зерна сої в умовах пом'якшення клімату і розширення тривалості вегетаційного періоду на заході України в умовах Малого Полісся потребує удосконалення системи удобрення цієї зернобобової культури, особливо азотними добривами. Соя – рослина, що здатна симбіотично фіксувати атмосферних азот, тому дозування хімічних добрив для неї має велике значення. Нітратні форми азоту можуть інгібувати утворення бульбочок на коренях та погіршувати асиміляцію азоту в ході фотосинтезу. Ми дослідили дві форми азотних добрив – амонійну селітру та сульфат амонію за їхнього внесення перед сівбою (N30) та у підживлення в фазі бутонізації. Для стабілізації утворення нітратів у грунті вносили інгібітор нітрифікації N-Lock™ (нітрапірин) в нормі 1,7 л/га перед сівбою. Інгібітор продовжує період вивільнення нітратів на 4-6 тижнів та убезпечує рослини від токсичного впливу на азот фіксатори, убезпечує вимивання нітратів у грунтові води та запобігає звітрюванню атмосферу закису азоту – парникового газу. Найбільша врожайність сої отримана за внесення сульфату амонію (N30) і нітрапірину перед сівбою з підживленням (N30) у фазі бутонізації – 3,9 т/га зерна.

Ключові слова: сульфат амонію, амонійна селітра, вилугування нітратів, звітрювання закису N, нітрапірин.

Abstract

The cultivation of high soybean grain yields in the context of climate moderation and the extension of the growing season in Western Ukraine, specifically in the Male Polissya region, requires the improvement of the fertilization system for this legume crop, particularly with nitrogen fertilizers. Soybean is a plant capable of symbiotically fixing atmospheric nitrogen, making the dosage of chemical fertilizers highly significant. Nitrate forms of nitrogen can inhibit the formation of nodules on roots and impair nitrogen assimilation during photosynthesis. We studied two forms of nitrogen fertilizers — ammonium nitrate and ammonium sulfate, when applied before sowing (N30) and as top dressing during the budding phase. To stabilize nitrate formation in the soil, the nitrification inhibitor N-Lock™ (nitrapyrin) was applied at a rate of 1.7 l/ha before sowing. The inhibitor prolongs the nitrate release period by 4-6 weeks, protecting plants from the toxic effects on nitrogen fixers, preventing nitrate leaching into groundwater, and reducing nitrous oxide emissions — a greenhouse gas, into the atmosphere. The highest soybean yield was obtained with the application of ammonium sulfate (N30) and nitrapyrin before sowing, with additional top dressing (N30) during the budding phase — 3.9 t/ha of grain.

Keywords: ammonium sulfate, ammonium nitrate, nitrate leaching, nitrous oxide emissions, nitrapyrin.

Introduction

As a crop with exceptional consumer and agronomic qualities, soybeans are increasingly attracting the attention of farmers. New early-maturing varieties with improved traits, the northward shift of warmer climates, and high productive potential have contributed to the introduction of this leguminous plant into the Male Polissya region of Western Ukraine. To fully utilize these qualities and advantages, experimental information is needed on how to adapt varieties to different ecological zones. Given the moderate and humid climate of Male Polissya, soybeans here benefit from an adequate rainfall and temperature regime. In these conditions, a good mineral nutrition background that is environmentally safe is crucial. Today, farmers are achieving yields of 2.0-3.0 t/ha of grain without significant expenditures on mineral fertilizers for soybeans, which partly supply themselves with nitrogen. Plant morphology size, number of pods per plant, and grain count — positively correlates with grain yield but is closely related to the plant's nitrogen supply.

Research results

Agricultural production in its modern form has largely developed through the exploitation of soils and exerts negative pressure on the environment [1]. However, without chemical inputs and sensible management of soil resources, it is impossible to provide food for humanity today [2].

Nitrogen is a critical nutrient for the optimal growth and yield of crops [3]. The invention of the Haber-Bosch process for the production of synthetic nitrogen fertilizer and its role in the "Green Revolution" of the 1960s cannot be overstated. It led to a rapid increase in crop yields worldwide. The annual global demand for synthetic nitrogen fertilizers continues to grow, driven by population growth and a global shift towards a protein-rich diet. The estimated global application of nitrogen-containing fertilizers in 2020 was 110 Mt (IFA, 2019). However, the energy-intensive Haber-Bosch process for producing synthetic nitrogen fertilizers consumes 2% of the world's fossil fuel energy reserves. This makes synthetic nitrogen fertilizers expensive to produce and represents a significant cost for grain producers [4], as well as a major challenge for maintaining high environmental quality.

Despite the importance of achieving high grain crop yields, the issue of large nitrogen fertilizer applications, particularly against the backdrop of low phosphorus and potassium levels, remains problematic. Elevated nitrogen application rates pose a risk of nitrate leaching through vertical and lateral water flows, which is particularly relevant for the Male Polissya region, where groundwater is often at a depth of just one meter. High doses of mineral nitrogen also increase the emission of nitrous oxide [6], a greenhouse gas.

In Western Ukraine, the use of nitrogen stabilizers in the soil is uncommon, and the import of industrial preparations is unstable. However, the challenge of growing high-yield crops under maximum nitrogen fertilization without nitrogen loss persists [7]. Nitrogen fertilizers play a crucial role in meeting the nutritional needs of soybeans and are the primary source of nutrients for protein formation and energy conversion. Statistics show that increased nitrogen fertilizer application has led to more than a 40% increase in global crop yields [8]. In some countries, from 1980 to 2010, the amount of nitrogen assimilated by crops in agriculture doubled, while nitrogen fertilizer application tripled. Nitrogen losses from fertilizers applied to the soil are initially estimated at 35-40% as NH3, with 10% lost as N2O emissions at the second stage, and 15-25% of NO3- leached in well-moistened soils, such as those in the Male Polissya region.

Therefore, the study of nitrification inhibitors to prevent nitrogen losses has long been relevant and is considered economically efficient. According to B. Fuchs and N. Baumgartner [7], by slowing down the conversion of ammonium from fertilizers into nitrate, plants receive the necessary nitrogen supply in line with their needs for an extended period of 10-15 days. At the same time, the plant adapts to partially ammonium-based nutrition. Nitrification inhibitors are suitable for use on most soil types, making their application effective for significantly reducing nitrogen losses through various pathways [8].

According to V. Pavlenko [9], a summary of 239 experiments conducted in 25 countries confirms the positive impact of nitrification inhibitors on nitrogen conversion in the soil and the efficient use of nitrogen fertilizers. These inhibitors reduce losses through denitrification and nitrate leaching, improve nitrogen nutrition of crops, and increase their yield and product quality.

Nitrapyrin is produced in the form of the N-Lock™ product. The active substance is an organic compound with the formula ClC5H3NCCl3. N-Lock™ is a widely used nitrification inhibitor in agriculture. It acts as a soil bactericide and has been in use since 1974. Nitrapyrin was reviewed by the EPA and was recognized as safe for use in 2005 [10].

Ukraine has actively engaged in the implementation of the European Council Directive 91/676/EEC of December 12, 1991, on the protection of waters against pollution caused by nitrates from agricultural sources [11]. The Directive outlines a series of documents that should serve as guidelines across economic sectors, including the "Methodology for Determining Nitrate Vulnerable Zones" and the "Code of Good Agricultural Practices."

In the conditions of the Western Forest-Steppe and Male Polissya regions, there is no experience in applying mineral fertilization systems for soybeans using nitrogen stabilizers in the soil. Therefore, the issue of optimizing nitrogen nutrition for plants and preventing the loss of nitrogen compounds from agroecosystems remains relevant.

The aim of our research in the conditions of the Male Polissya was to investigate the effect of nitrapyrin, a nitrogen nitrification stabilizer, on the agrochemical properties of the soil, as well as the growth and development of soybeans against the background of different forms of mineral fertilizers.

The experiments were conducted on a field designated for experimentation at the "BIK AGRO" farm. Traditional agronomic methods were used in this study.

The experimental field has a derno-gley loamy soil. Before the experiments were established, the content of easily hydrolyzable nitrogen, determined by the Kornfield method, was at a medium level. The content of nitrate nitrogen (Nn) was determined potentiometrically using a nitrate ion-selective electrode in a salt extract of a 1% solution of alum-potassium alum at a soil-to-solution ratio of 1:2.5. The nitrate content in the soil, in mg/kg, was found based on the pNO3 value. The intensity of annual nitrous oxide emissions from the soil (EN2O, kg/ha) was calculated using the formula proposed by A. F. Bouwman (1996) as presented in [6]. Nitrate reserves (ZN-NO3, kg/ha) were calculated using the humus reserve calculation formula [6, 12] with conversion coefficients. The phosphorus content (P2O5) in the upper 20 cm layer was above average. The exchangeable potassium content was at a medium level.

The soybean cultivation technology used was traditional: plowing to a depth of 18–20 cm. The Mentor variety was grown. The nitrification inhibitor N-Lock™ was applied according to the experimental scheme at a rate of 1.7 l/ha. N-Lock™ – nitrapyrin completely decomposes in the soil [6].

Research conducted during 2022-2023 allowed us to make preliminary conclusions..

Conclusion

Elevated rates of nitrogen fertilizer application (N30 before sowing + N30 as top dressing during the budding phase) for soybeans, aimed at increasing grain yield, pose a threat of nitrogen loss in the form of nitrate through vertical leaching with moisture and in gaseous form through nitrous oxide emissions into the atmosphere. Both phenomena harm the natural environment by polluting water and saturating the atmosphere with greenhouse gases.

The use of the nitrogen stabilizer N-Lock™, which acts as a nitrification inhibitor in the soil, significantly reduces the concentration of nitrate ions in the 0-40 cm soil layer, thereby preventing the leaching of soluble nitrates into the subsoil and groundwater. The reduction in nitrate ion concentration limits the intensity of gaseous nitrogen release during the nitrification activity of the soil bacteriocenosis.

With an N30 nitrogen rate in the form of ammonium nitrate without the use of nitrapyrin, soybean yield was the lowest compared to other nitrogen fertilization options. When using nitrapyrin and ammonium sulfate N30, a high yield was achieved, and with additional N30 top dressing, the highest average yield in the experiment was obtained during 2022-2023.

To achieve a soybean yield of 3.6-3.8 t/ha and maximize the efficiency of nitrogen mineral fertilizers, we recommend applying N30P60K60 before sowing and N30 during the budding phase, along with the nitrogen stabilizer nitrapyrin N-Lock™ at a rate of 1.7 l/ha before sowing. Among nitrogen fertilizer forms, ammonium sulfate is preferred over ammonium nitrate.

СПИСОК ВИКОРИСТАНОЇ ЛІТЕРАТУРИ

1. Lykhochvor, V., Hnativ, P., Petrichenko, V., et al. (2022b) Threat of degradation of agricultural land in Ukraine through a negative balance of nutritional elements in growing of field cultures. Journal of Elementology. 27(3), 695-707. DOI: 10.5601/jelem.2022.27.2.2290
2. Polovyy, V., Snitynskyy, V., Hnativ, P., et al. (2021) Agro-ecological efficiency of the system of crop fertilization with the use of phytomass residues in the Western Forest Steppe of Ukraine. Journal of Elementology. 26(3), 293–306. DOI: 10.5601/jelem.2021.26.1.2120
3. Chambers, B. J. & Dampney, P. M. R. (2009) Nitrogen efficiency and ammonia emissions from urea-based and ammonium nitrate fertilisers. Proc Intl Fert Soc. 657, 1–20.
4. Hege, U. & Offenberger, K. (2011) Effect of N fertilizer with nitrification inhibitors on winter wheat yield in German Bavarian State Research Center for Agriculture.. URL: http://www.lfl.bayern.de/iab/duengung/ mineralisch/09628/
5. Fan, X., Yin, C., Chen, H., Ye, M., Zhao, Y., Li, T., Wakelin, S. A. & Liang ,Y. (2019) The efficacy of 3,4-dimethylpyrazole phosphate on N2O emissions is linked to niche differentiation of ammonia oxidizing archaea and bacteria across four arable soils. Soil Biol. Biochem., 130: 82–93. doi.org/10.1016/j.soilbio.2018.11.027
6. Shestak, V. H. (2022) Znachennia fosforno-kaliinykh dobryv dlia dii azotu ta nitrapirynu pry vyroshchuvanni yachmeniu ozymoho u Zakhidnomu Lisostepu. Peredhirne ta hirske zemlerobstvo i tvarynnytstvo. 72(1), 105-134. doi: 10.32636/01308521.2022-(72)-1-8. (in Ukrainian).

7. Fuks, B & Baumhartner, N. (2020) Zastosuvannia stabilizatoriv azotnykh dobryv. Zhurnal Ahronom. URL: https://www.agronom.com.ua/zastosuvannya-stabilizatoriv-azotnyh-dobryv/. (in Ukrainian).
8. Ding, Y., Huang, X., Li, Y., Liu, H., Zhang, Q., Liu, X., Xu, J. & Di, H. (2021) Nitrate leaching losses mitigated with intercropping of deep-rooted and shallow-rooted plants. J. Soils Sediments, 21: 364–375. doi.org/10.1007/s11368-020-02733-w
9. Pavlenko, V. (2018) Vizmit vtraty azotu pid kontrol. Zeleni storinky. Diupon Ukraina, №2. URL: https://agromage.com/stat_id.php?id=991. (in Ukrainian).
10. Nitrogen Stabilizer Products that Must Be Registered under FIFRA. Substances excluded from the definition of a nitrogen stabilizer. (2022) U.S. Environmental Protection Agency. URL: https://www.epa.gov/pesticide-registration/nitrogen-stabilizer-products-must-be-registered
11. The implementation of the Nitrate Directive in Ukrainian. (2020). News. July 17 2020. URL: https://menr.gov.ua/news/35591.html?fbclid=IwAR1WcstOugFHeoyIRfk9o_Vi4z4weytSrjdqFswMIJ1TpbO8cbvG_YMzkto. (in Ukrainian).
12. Metodyka provedennia ahrokhimichnoi pasportyzatsii zemel silskohospodarskoho pryznachennia (2013). Za red. I. P. Yatsuka, S. A. Baliuka. K., 104 s.

Коцюба Богдан Ігорович **–** здобувач ступеня PhD, Львівський національний університет природокористування, Львів-Дубляни, bogdankotsuba@gmail.com.

Гнатів Петро Степанович **–** доктор біол. наук, професор, Львівський національний університет природокористування, Львів-Дубляни.

Іванюк Віктор Ярославович **–** кандидат с.-г. наук, доцент, Львівський національний університет природокористування, Львів-Дубляни.

Kotsyuba Bohdan Ihorovych — PhD student, Lviv National University of Natural Sciences, Lviv-Dubliany. e-mail: bogdankotsuba@gmail.com.

Hnativ Petro Stepanovych — D.Sc. in Biology, Professor, Professor of Department of Ecology, Chemistry and Environmental Protection Technologies, Lviv National University of Natural Sciences, Lviv-Dubliany.

Ivanyuk Viktor Yaroslavovych — PhD in Agricultural Science, associate professor, Lviv National University of Natural Sciences, Lviv-Dubliany.