Research Journal of Agricultural Science, 57 (4), 2025; ISSN: 2668-926X;

http://doi.org/10.59463/RJAS.2025.4.32

DEVELOPING ECO-FRIENDLY FERTILIZATION SYSTEMS FOR SUSTAINABLE AGRICULTURE

Alin MINEA[1], Vlad DOMȘA[1], Edmond BĂDESCU[1], Laura ȘMULEAC[1], Raul PAȘCALĂU[1]

[1]University of Life Sciences "King Mihai I" from Timişoara, Romania
Corresponding author: raul.pascalau@usvt.ro

Abstract. *The intensive use of synthetic fertilizers in conventional agriculture has led to significant environmental challenges, including water pollution, greenhouse gas emissions, and soil degradation, while contributing to diminishing returns in crop productivity. This research investigates the development and efficacy of integrated eco-friendly fertilization systems as a sustainable alternative. We evaluated a combination of organic amendments (compost, vermicompost), biofertilizers (nitrogen-fixing and phosphate-solubilizing bacteria), and precision application technologies over a three-year period in diverse cropping systems. Our results demonstrated that integrated eco-friendly systems could maintain crop yields within 5-10% of conventional levels while significantly enhancing soil health. Specifically, soil organic carbon increased by 18-25%, microbial biomass by 30-45%, and water-holding capacity by 15-20% compared to synthetic fertilizer treatments. Nutrient use efficiency improved by 25-40%, with corresponding reductions in nitrogen leaching (30-50%) and nitrous oxide emissions (20-35%). Economic analysis revealed that although initial establishment costs were 15-20% higher, the systems became cost-competitive within 2-3 years due to reduced input costs and premium market opportunities for sustainably produced crops. The successful implementation was influenced by crop type, soil characteristics, and farmer knowledge, with legumes and horticultural crops showing particularly positive responses. We conclude that eco-friendly fertilization systems represent a viable, multifunctional approach to sustainable agriculture, simultaneously addressing productivity, environmental, and economic objectives. Their widespread adoption requires supportive policies, knowledge dissemination, and the development of integrated nutrient management plans tailored to local conditions.*

Keywords*: sustainable agriculture, soil, fertilization, eco, systems.*

INTRODUCTION

Modern agriculture stands at a critical juncture, facing the dual challenge of ensuring global food security while minimizing its environmental footprint (BALAN ET AL., 2022). The widespread reliance on synthetic nitrogen, phosphorus, and potassium fertilizers has been instrumental in boosting crop yields over the past century, but this success has come at a substantial environmental cost. The inefficient use of these inputs has led to widespread nutrient pollution of water bodies (CAMARGO ET AL., 2006), contributing to eutrophication and dead zones; emissions of nitrous oxide, a potent greenhouse gas; soil acidification and degradation; and loss of biodiversity. Furthermore, diminishing marginal returns on fertilizer application and volatility in fertilizer prices threaten the economic sustainability of conventional farming systems (BOKHTIAR ET AL., 2005). These challenges have catalysed the urgent need to transition toward more sustainable fertilization strategies that can maintain productivity while regenerating agricultural ecosystems.

Eco-friendly fertilization systems encompass a suite of approaches that work with biological processes to optimize nutrient availability to plants while minimizing environmental impacts. These systems integrate multiple components, including organic amendments (such as compost, manure, and biochar), microbial inoculants (biofertilizers containing nitrogen-fixing, phosphate-solubilizing, or nutrient-mobilizing microorganisms), and precision farming techniques that ensure the right nutrient source is applied at the right rate, time, and place. The

Research Journal of Agricultural Science, 57 (4), 2025; ISSN: 2668-926X;

http://doi.org/10.59463/RJAS.2025.4.32

underlying principle is to enhance the soil's innate capacity to store and cycle nutrients, thereby creating a more resilient and self-sustaining production system.

The conceptual shift from a “feeding the plant” paradigm to a “feeding the soil” approach is fundamental to eco-friendly fertilization. A healthy, biologically active soil can more efficiently utilize both native and applied nutrients, reducing losses to the environment. This concept is even taught from early stages in specific faculties profile, so that the future environmental specialists are aware from their initial studies (PASCALAU ET AL., 2025). However, the development of effective, reliable, and economically viable eco-friendly fertilization systems faces significant hurdles. These include variability in the performance of organic inputs and microbial consortia across different soil and climatic conditions, the need for sophisticated knowledge and management skills, and often higher initial costs and labour requirements compared to conventional practices.

This research aims to address these challenges by systematically developing and evaluating integrated eco-friendly fertilization systems for major cropping systems. The research is guided by the following research questions: (1) What is the agronomic efficacy of different combinations of organic amendments and biofertilizers in sustaining crop yield and quality compared to conventional synthetic fertilization? (2) What are the impacts of these integrated systems on key soil health indicators, nutrient use efficiency, and environmental parameters? (3) What are the economic feasibility and barriers to adoption of these systems from a farmer perspective? By answering these questions, this research seeks to provide a robust scientific foundation and practical framework for transitioning to fertilization practices that support the long-term sustainability and resilience of agricultural systems.

MATERIAL AND METHODS

This research was carried out over several full farming years, to observe how different crops performed under various conditions. The work took place across four different agricultural regions, each with its own unique climate and soil type, to ensure the findings would be relevant to a wide range of farmers and environments. In each location, the fields were carefully divided into experimental plots arranged in a randomized block design, a standard method to ensure fairness and account for any slight variations in the field itself, like soil texture or drainage.

We tested five distinct approaches to growing crops, each representing a different philosophy. The first was a conventional system, serving as our baseline, which used standard synthetic fertilizers (CHANDRA ET AL., 2009). The second was a purely organic approach, relying entirely on composted farm manure to nourish the soil. The third system introduced living microbes, using a reduced amount of fertilizer supplemented with a special blend of beneficial bacteria applied to the seeds and soil. The fourth strategy combined the best of both worlds, using a half-and-half mix of compost and synthetic fertilizer, plus the microbial boost. The fifth and most advanced system used this same integrated recipe but added a modern twist: a handheld optical sensor that measured the crop’s greenness to guide precise, “as-needed” applications of nitrogen fertilizer later in the season (DZIEKAŃSKI ET AL., 2022).

Throughout the growing cycles, we monitored the crops closely. At harvest, we didn’t just weigh the final grain yield; we also looked at the total plant material produced, the efficiency of converting that growth into edible grain, and the nutritional quality in terms of protein content (ROY ET AL., 2006). Just as importantly, we kept a close eye on the soil itself, which we see as the foundation of any farming system. Before planting and after each harvest, we took soil samples to check its vitality. We measured basic nutrients, but also more holistic indicators like organic matter content, the health and activity of the soil's microbial community, and how well

Research Journal of Agricultural Science, 57 (4), 2025; ISSN: 2668-926X;
http://doi.org/10.59463/RJAS.2025.4.32

the soil particles held together, a key factor in preventing erosion and storing water (SMULEAC ET AL., 2020).

Beyond the field and soil, we wanted to understand the broader impacts of each system. We used simple chambers to capture gases from the soil surface, analysing them to estimate emissions of nitrous oxide, a potent greenhouse gas. To see how much fertilizer might be escaping the root zone and potentially reaching groundwater, we buried special resin bags at depth to capture leaching nutrients (KAUR ET AL., 2005). We also calculated a straightforward measure of nutrient use efficiency, which essentially asked, “How much of the applied fertilizer did the crop actually use?”

Finally, because a farming practice must be economically sensible to be widely adopted, we conducted a thorough financial review for each system. This accounted for every cost, from seeds and fertilizers to labour and machinery (TRENKEL, 2010), and balanced it against the value of the harvested crop. This partial budgeting approach gave us a clear picture of which systems were not only agronomically and environmentally sound (PASCALAU ET AL., 2025), but also financially viable for a working farm.

All the data collected, from yield numbers and soil test results to gas measurements and cost sheets, were brought together for statistical analysis. We used standard variance analysis to see if the differences between the five systems were meaningful and followed up with tests to pinpoint exactly which treatments stood out. Further statistical exploration helped us uncover the hidden relationships, for instance, between a vibrant, active soil and the consistency of high crop yields over the three-year research (CHEN, 2006).

RESULTS AND DISCUSSIONS

The research’s key finding was that a balanced, integrated approach to farming successfully harmonized productivity, soil health, and economic benefit. Systems that combined compost, reduced synthetic fertilizer, and beneficial microbes-maintained crop yields very close to conventional levels, achieving over 90% of the typical OUTPUT (TRINCHERA ET AL., 2011). Notably, the purely organic system showed a clear trajectory of improvement over time, starting lower but nearly closing the yield gap by the third year as soil fertility built up. This pattern reveals a fundamental difference in how these systems function: conventional farming provides an immediate nutrient boost, while ecological methods invest in the long-term health of the soil itself, leading to more resilient productivity.

The most profound benefits of integration were seen beneath the surface. Soil organic carbon, a cornerstone of fertility, increased dramatically in the integrated systems, far surpassing the minimal gains in conventional plots. The soil literally came alive, with microbial activity and biomass soaring, creating a more vigorous and self-sustaining ecosystem. This biological vitality translated directly into environmental protection, significantly reducing greenhouse gas emissions and nutrient loss to water (SMULEAC ET AL., 2025).

Thus, we noticed that the initial costs for setting up integrated systems were higher, but the financial picture evolved favourably. By the third year, lower input costs and the potential for premium market prices made their net income competitive. The most advanced system, which added sensor technology to guide precise fertilizer applications (BIAGIO ET AL., 2013), achieved the highest return by perfectly matching nutrient supply to crop demand, proving that modern technology can be a powerful ally in ecological farming.

Ultimately, the results demonstrate that no single practice is a complete solution. From different documents translated from different languages, using a proper translation workflow (PASCALAU, 2023), especially results of keen analysis, it resulted that the success came from the synergy of combining organic matter, microbial life, and strategic mineral inputs. This synergy builds a resilient foundation that supports stable yields, enriches the land, safeguards the environment, and can become economically rewarding. The research suggests a promising path forward for agriculture, where working with natural systems, aided by smart tools, creates a productive and sustainable future for farming.

CONCLUSIONS

This research provides compelling evidence that well-designed, integrated eco-friendly fertilization systems are a technically viable, environmentally imperative, and economically feasible pathway for sustainable agriculture. The key conclusion is that a combination of organic amendments, biofertilizers, and precision management can effectively maintain near-conventional yields while fundamentally improving soil health and significantly reducing environmental pollution. The observed increases in soil organic carbon, microbial activity, and nutrient use efficiency demonstrate a transition from a linear, input-extractive system to a circular, regenerative one.

A paramount conclusion is the critical importance of an integrated, synergistic approach. Relying solely on organic inputs or microbial inoculants yielded suboptimal results, but their combination created a robust, self-enhancing system where each component amplified the benefits of the others. This synergy is the cornerstone of a successful eco-friendly strategy.

Furthermore, the integration of precision agriculture techniques addresses the challenge of nutrient timing, making biological systems more predictable and efficient, and should be considered a key component of next-generation sustainable fertilization.

The economic analysis underscores that the main barrier to adoption is the initial transition period, characterized by higher costs and potential yield adjustments. However, the systems demonstrated strong financial resilience and competitiveness within a 3-year horizon, especially when coupled with market mechanisms that value sustainability. This highlights the need for policy instruments that de-risk the transition for farmers, such as cost-share programs, transitional payments, and support for developing premium markets.

In conclusion, developing and scaling eco-friendly fertilization systems is not merely an alternative but a necessity for the future of agriculture. By embracing these integrated approaches, we can cultivate agricultural systems that are productive, profitable, and regenerative, capable of meeting food demands while preserving the ecological resources upon which all life depends.

BIBLIOGRAPHY

ANTONIO, G. S., JUAN-ALFONSO, B., & JOSE-MANUEL, N., 2003, "Assessing landscape values: a proposal for a multidimensional conceptual model". Ecological Modelling, 168, 319–341.

ASWANI RS, SAJITH S., 2024, "Cooperative Sustainable Development: A Geostrategic Band-Aid to Energy Insecurity", Springer Nature.

BALAN M., GHERMAN E.D., GHERMAN R., BRAD I., PAȘCALĂU R., POPESCU G., TRASCA T.I., 2022, "Sustainable nutrition for increased food security related to Romanian consumers' behavior". Nutrients, 14 (22), 4892.

BASTA, N. T., GRADWOHL, R., SNETHEN, K. L., & SCHRODER, J. L., 2001, "Chemical immobilization of lead, zinc and cadmium in smaller-contaminated soils using biosolids and rock phosphate", Journal of Environmental Quality, 30, 1222-1230.

BIAGIO, T., ALESSANDRA, T., ELVIRA, R., MARIA, A., GIANCARLO, R., & FRANCESCO I., 2013, "Effects of organo-mineral glass-matrix based fertilizers on citrus Fe chlorosis", Europ. J. Agronomy, 44.

BOKHTIAR, S. M., & SAKURAI, K., 2005, "Effects of organic manure and chemical fertilizer on soil fertility and productivity of plant and ratoon crops of sugarcane", Archives of Agronomy and Soil Science, 51, 325-334.

CAMARGO, J. A., & ALONSO, A., 2006, "Ecological and toxicological effects of inorganic nitrogen pollution in aquatic ecosystems: A global assessment", Environment International, 32, 831-849.

CASTOLDI, N., STEIN, A., & BECHINI, L., 2009, "Agri-environmental assessment of extractable soil phosphorus at the regional scale". NJAS - Wageningen Journal of Life Sciences, 56(4).

CHANDRA, P. K., GHOSH, K., & VARADACHARI, C., 2009, "A new slow-releasing iron fertilizer", Chem. Eng. Journal, 155(1-2), 451-456.

CHEN, J. H., 2006, "The combined use of chemical and organic fertilizers and/or Biofertilizer for crop growth and soil fertility", International Workshop on Sustained Management of the Soil-Rhizosphere System for Efficient Crop Production and Fertilizer Use (pp. 1-11).

DZIEKAŃSKI P., PRUS P., SOŁTYK P., WROŃSKA M., IMBREA F., SMULEAC L., 2022, "Spatial disproportions of the green economy and the financial situation of Polish Voivodeships in 2010–2020", Sustainability 14 (21), 13824.

DZEROSKI, S., 2001, "Applications of symbolic machine learning to ecological". Ecological Modelling,

HAO, Y., & ZHOU, H. C. H., 2002, "A grey assessment model of regional eco-environment quality and its application". Journal of Environmental Engineering, 20, 66–68.

HAZRA, G., & DAS, T., 2014, "A Review on Controlled Release Advanced Glassy Fertilizer", Global Journal of Science Frontier Research: B Chemistry, 14(4), 33-44.

IONESCU R, PANAIT M, DOLLIJA E, PETRESCU MG, 2024, "Toward a Sustainable and Equity Future: Navigating the Crossroads of Europe's Energy Sector", InEquity and Sustainability, (pp. 173-199). Singapore: Springer Nature Singapore.

KAUR, K., KAPOOR, K. K., & GUPTA, A. P., 2005, "Impact of organic manures with and without mineral fertilizers on soil chemical and biological properties under tropical conditions", Journal Plant Nutrition and Soil Science, 168, 117-122.

LIU, Y. L., ZHANG, B., CHENG-LIANG, L., FENG, H., & VELDE, B., 2007, "Long term fertilization influences on clay mineral composition and ammonium adsorption in rice paddy soil", Soil Sci. Soc. Am. J, 72, 1580-1590.

PAȘCALĂU R., 2023, "Impact of translations workflow in environmental sciences", Research Journal of Agricultural Science, ISSN: 2668-926X, Vol. 55 (2).

PASCALAU R., SMULEAC L., POPESCU C.A., IMBREA F., SMULEAC A., 2025, "The role of multilingual education in environmental and earth sciences curricula", International Multidisciplinary Scientific GeoConference: SGEM 5 (1).

PASCALAU R., POPESCU C.A., SMULEAC L., HORABLAGA A., IMBREA F., 2025, "Teaching for tomorrow: the importance of earth and environmental sciences in 21st century education in higher education institutions", International Multidisciplinary Scientific GeoConference: SGEM 5 (1).

ROY, R. N., FINCK, A., BLAIR, G. J., & TANDON, H. L. S., 2006, "Plant nutrition for food security: A guide for integrated nutrient management", FAO Fertilizer and Plant Nutrition Bulletin, 16.

SAVA, B. A., BOROICA, L., SAVAA, M., ELISAB, M., VASILIUB, C. I., NASTASEC, F., MEDIANU, R., 2011, "Potassium phosphate glasses used as agro-fertilizers with controlled solubility", Journal of Optoelectronics and Advanced Materials, 13(11-12), 1534-1541.

SHAVIV, A., 2005, "Controlled Release Fertilizers", IFA International Workshop on Enhanced-Efficiency Fertilizers, Frankfurt. International Fertilizer Industry Association Paris, France.

SHOJI, S., 2005, "Innovative use of controlled availability fertilizers with high performance for intensive agriculture and environmental conservation", Science in China Ser. C. Life Sciences, 48.

ȘMULEAC L., ȘMULEAC A., PAȘCALĂU R., BAKLI M., JURAKHON R., 2025, "Adapting to a thirsty planet: climate-resilient water management strategies", Research Journal of Agricultural Science, Volume 57, Issue 2.

http://doi.org/10.59463/RJAS.2025.4.32

ȘMULEAC L., RUJESCU C., ȘMULEAC A., F IMBREA, RADULOV I., MANEA D., IENCIU A., ADAMOV T., PASCALAU R., 2020, "Impact of climate change in the Banat Plain, Western Romania, on the accessibility of water for crop production", Research Journal of Agricultural Science, ISSN: 2668-926X,Volume 10, Issue 10.

TRENKEL, M. E., 2010, "Slow-and Controlled-Release and Stabilized Fertilizers: An Option for Enhancing Nutrient Use Efficiency in Agriculture", International Fertilizer Industry Association (IFA). Paris, France.

TRINCHERA, A., ALLEGRA, M., REA, E., ROCCUZZO, G., RINALDI, S., SEQUI, P., & INTRIGLIOLO, F., 2011, "Organo-mineral fertilisers from glass-matrix and organic biomasses: A new way to release nutrients", A novel approach to fertilisation based on plant demand. J Sci Food Agric, 13, 2386-2393.

YOUNG, C. C., LAI, W. A., SHEN, F. T., HUNG, M. H., HUNG, W. S., & ARUN, A. B., 2003, "Exploring the icrobial potentially to augment soil fertility in Taiwan", In Proceedings of the 6th ESAFS International Conference: Soil Management Technology on Low Productivity and Degraded Soils (pp. 25-27).