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Enhancing Sustainable Agriculture through Innovative Soil Science Technologies

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ABSTRACT

Modern agriculture demands sustainable solutions to increase productivity while preserving environmental health. This study investigates the effectiveness of water-soluble combined fertilizers (WCF) in improving the growth, yield, and quality of winter wheat (Bezostaya 100) and potato (Marfona) under low-fertility soil conditions in Armenia. The WCF contains macro- and micronutrients, amino acids, and chelating agents, tailored to meet the nutritional needs of crops from germination to maturity. The experimental design included seed soaking and foliar application at key growth stages. Results revealed that WCF significantly increased field germination rates, enhanced root and shoot biomass, and improved crop yields compared to both control and conventional fertilizer treatments. A significant enhancement in wheat grain yield was observed, reaching up to 42.9% more than the control treatment. In the case of potatoes, production increased by 44.5%, accompanied by improved levels of dry matter and starch, and a noticeable decrease in nitrate concentration. These findings demonstrate that WCF can serve as a valuable component in sustainable nutrient management, enhancing crop performance and economic efficiency. The combination of seed priming and foliar feeding ensures nutrient availability throughout critical growth stages. This study supports the broader application of WCF in environmentally responsible agriculture and encourages further research into its benefits across diverse crops and soil types.

Introduction

Modern agriculture is facing unprecedented challenges due to the need for increased food production, resource conservation, and environmental protection. Green agriculture, a concept centered around sustainable practices, has gained prominence in addressing these challenges. This article delves into the significance of new technologies in soil science and their role in revolutionizing green agriculture (Naghdi, et al., 2022).

Soil, as the foundation of agriculture, plays a crucial role in plant growth and ecosystem health. With the global population projected to reach 9 billion by 2050, the demand for food will soar, necessitating a substantial increase in agricultural productivity. However, conventional farming practices have often led to soil degradation, loss of biodiversity, and excessive use of chemicals, impacting long-term sustainability. The integration of new technologies in soil science offers promising solutions to mitigate these issues (Yeritsyan, 2024).

One such technology is precision agriculture, which employs various tools like satellite imagery, sensors, and data analytics to assess soil health and optimize resource use. These innovations aid in precisely targeting irrigation, fertilization, and pesticide application, minimizing waste and environmental harm. Additionally, the use of drones and remote sensing helps monitor crop health and detect potential soil degradation, allowing farmers to take timely corrective measures (Trukhachev, 2024).

Advancements in soil sensors have revolutionized real-time monitoring of soil parameters such as moisture content, nutrient levels, and pH. These sensors provide farmers with valuable insights, enabling them to make informed decisions about irrigation and fertilization, ultimately reducing water and nutrient wastage. Moreover, the advent of low-cost sensors has democratized access to these technologies, benefiting small-scale farmers as well (Yeritsyan, 2024).

Cover crops and agroforestry are other eco-friendly practices gaining traction in green agriculture. These techniques improve soil structure, enhance water retention, and foster nutrient cycling, contributing to long-term soil health. Combined with innovative soil-science-driven technologies, they create a synergistic approach that optimizes yields while preserving the environment (Beglaryan, 2025).

Soil microbiology, a fascinating field within soil science, has uncovered the intricate relationships between microorganisms and plant growth. Microbial activity plays a key role in improving nutrient efficiency, controlling plant diseases, and maintaining good soil structure. Incorporating microbial-based biofertilizers and soil conditioners into agricultural practices not only reduces reliance on synthetic inputs but also promotes soil biodiversity (Gasparyan, 2023; Gasparyan, 2025; Jhangiryan, 2023; Jhangiryan, 2024; Larionov, 2024).

Furthermore, the concept of 'smart soils' is emerging, involving the modification of soil properties through the addition of organic amendments or engineered materials. These changes improve the soil's ability to hold moisture, capture carbon, and provide a steady supply of nutrients. By tailoring soil characteristics to specific crops and regions, smart soils contribute to increased resilience and productivity (Markad, 2024).

In conclusion, the integration of green agriculture and innovative soil science technologies holds immense promise for sustainable food production. The adoption of precision agriculture, soil sensors, and soil microbiology-based interventions is reshaping farming practices, optimizing resource use, and reducing environmental impact. As the world faces mounting agricultural challenges, harnessing these advancements will be essential for ensuring food security without compromising the planet's health. Through collaborative efforts between researchers, policymakers, and farmers, this paradigm shift in agriculture can pave the way for a greener and more resilient future.

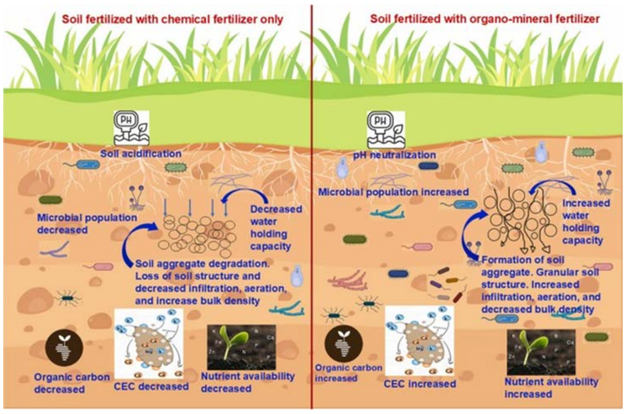

Figure. Overall effect of OMF on soil properties.

Materials and methods

The study aimed to evaluate the effect of a newly developed water-soluble combined fertilizer (WCF) on seed quality, plant growth, and yield in cereal and vegetable crops, specifically winter wheat (Bezostaya 100) and potato (Marfona). The experiments were conducted under field conditions with soils of low fertility, particularly deficient in available nitrogen and phosphorus.

For winter wheat, the experimental design included the following treatments:

1. Control (no fertilization),
2. Background application: $N_{30}P_{90}K_{60} + N_{75}$,

3.Background + water-soluble combined fertilizer (seed soaking before sowing),

4.Background + water-soluble combined fertilizer (seed soaking + foliar feeding during the tillering stage)

For potatoes, the experiment was conducted on mountain brown forest soils, characterized by low levels of available nitrogen, phosphorus, and potassium. The treatment scheme included:

1. Control (no fertilization),

2.Background application: $N_{60}P_{90}K_{90}$ + N_{60},

3.Background + water-soluble combined fertilizer (tuber soaking before planting),

4.Background + water-soluble combined fertilizer (tuber soaking + three foliar applications during the growing season)

Numerous observations and measurements were conducted during the experiments, which revealed the effect of the complex fertilizer on seed germination, plant growth, yield, and the nutritional and planting quality of the crops (grain). An assessment of field germination rates and germination energy under the influence of complex fertilizer was conducted by marking four 0.25 m² sampling areas within various zones of each experimental field on day three of sprouting. The number of germinated seeds in these plots was counted, and on the 7th day of germination, the total number of germinated seeds was recorded. Based on this data, and considering the planted seed density (500 viable seeds per 1 m²), the seed germination rate and germination energy were calculated (Arinuskina, 1962; Dospekhov, 1973).

Description of the applied organomineral fertilizer: The complex fertilizer is a multifaceted compound, the composition of which has been developed based on the fertility status of soils in Armenia and the nutrient requirements of crops starting from the seed germination phase. The fertilizer dissolves well in water and contains macro elements (nitrogen in the form of NH_2^- and NO_3^- ions, phosphorus, potassium, sulfur, iron) and micronutrients (*B, Zn, Mn, Mo, Cu, Co*), amino acids, and complex-forming agents. The fertilizer is applied as a water solution, with a concentration of 0.35-0.40%, through foliar feeding and drip irrigation, 2-3 times during the vegetative stage. It can be combined with insecticides and fungicides that do not contain copper.

The research was conducted at the laboratory of "Soil Science, Agrochemistry and Amelioration Scientific Center after H. Petrosyan" Branch of Armenian National Agrarian University Foundation.

Results and discussions

The use of fertilizers plays a crucial role in the sustainable agricultural practices in the Republic of Armenia, due to the relatively low fertility of the available soils. Our studies have shown that, in addition to the primary mineral fertilizers, the application of fertilizers containing macro and micronutrients, as well as bioactive substances, is significant for increasing the yields of winter wheat and potatoes. These fertilizers are most effective when applied through seed soaking and foliar feeding during the vegetative stage, resulting in noticeable economic efficiency. The synthesized water-soluble complex fertilizer has contributed to an increase in the field germination rate and germination energy of autumn wheat seeds, enhanced root system development, and improved yield (Table 1).

Table 1. Effect of Fertilizers on the Growth and Yield of Autumn Wheat (Bezostaya 100)

Variants	Field germination of seeds, %	Seed germination energy, %	Fresh weight of shoot biomass, 6 plants, 20 days after treatment, g	Grain yield, c/ha
Control (no fertilization)	78.6-84.9	71.4-79.1	1.13	31.2-35.4
Background application: $N_{30}P_{90}K_{60}$ + N_{75}	79.0-84.5	71.6-79.5	1.35	40.1-43.2
Background + water-soluble combined fertilizer (seed soaking before sowing)	87.5-91.5	88.5-95.1	2.41	44.9-50.6
Background + water-soluble combined fertilizer (seed soaking + foliar feeding during the tillering stage)	-	-	-	49.3-55.1

Table 2. Effect of Fertilizers on Potato Yield and Tuber Quality Indicators

Variants	Straw yield, c/ha	Dry matter, %	Starch, %	Nitrate content, mg/kg	Leaf infestation by Colorado potato beetle, %
Control (no fertilization)	249-255	18,6	13,8	51,0	15,0
Background application: $N_{30}P_{90}K_{60} + N_{60}$	293-300	18,7	14,5	52,0	16,0
Background + water-soluble combined fertilizer (tuber soaking before planting)	305-312	19,4	14,9	50,0	14,0
Background + water-soluble combined fertilizer (tuber soaking + three foliar applications during the growing season)	328-361	21,8	17,7	27,0	0

In experiments with winter wheat, the field germination of seeds was highest when applying the combined water-soluble combined fertilizers (WCF), ranging from 78.6% to 84.9%, while the control and background treatments showed germination rates of 74.1% to 80.2%. WCF also resulted in increased yield, which, compared to the control, was on average 15.2 c/ha (42.9%), and compared to the background, it was 7.3 c/ha (16.8%). Water-soluble combined fertilizers (WCF) improved both the chemical composition and the seed quality. For example, seed germination in laboratory conditions ranged from 95.5% to 98.6%, and germination energy was between 87.6% and 90.5%, while in the control, these indicators were 85.1% to 87.6% and 61.6% to 74.6%, respectively. In the $N_{30}P_{90}K_{60}+N_{75}$ variant, germination ranged from 84.5% to 90.3%, and germination energy from 68.7% to 78.4% (Table 1, Diagram).

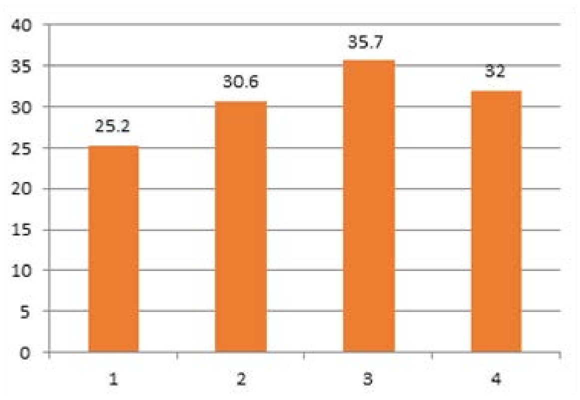

Diagram. The effect of water-soluble combined fertilizers on the yield of wheat, c/ha *Variants:*1.Control (no fertilization), 2.Background application: $N_{30}P_{90}K_{60} + N_{75}$, 3.Background+water-soluble combined fertilizer (seed soaking before sowing), 4.Background+water-soluble combined fertilizer (seed soaking + foliar feeding during the tillering stage).

The soil analysis revealed a humus content of 3.12%, a neutral pH of 7.3, and available nutrient concentrations measured at 3.14 mg of mobile nitrogen (N), 1.58 mg of phosphorus pentoxide (P_2O_5), and 47.8 mg of potassium oxide (K_2O) per 100 grams of soil sample.

Similar effects of the water-soluble combined fertilizer (WCF) were observed in the potato experiment. Tuber yields following WCF treatment varied between 328 and 361 centners per hectare, whereas the background treatment resulted in yields ranging from 293 to 300 c/ha, and the control plots produced between 249 and 255 c/ha. The content of dry matter and starch in the tubers increased significantly, while the nitrate content decreased. The spread of the Colorado potato beetle was completely prevented, which we attribute to the noticeable hardening of the leaves during foliar feeding with the fertilizer (Table 2). At the molecular level, the genetic mechanism behind certain beneficial traits in potatoes was studied using the RFLP molecular marker (Restriction Fragment Length Polymorphism). Restriction enzymes EcoRI, ScaI, and PvuI were employed to perform DNA cleavage. Mapping revealed that the gene regulating starch content is located in a recognizable site of the EcoRI restriction enzyme.

Conclusion

The conducted research demonstrates the significant positive impact of water-soluble combined fertilizers (WCF) on the germination, growth, and productivity of both winter wheat and potatoes. The application of WCF, through seed soaking and foliar feeding during key vegetative stages, led to enhanced field germination rates, improved plant vigor, increased dry matter and starch content, and reduced nitrate accumulation. Notably, the resistance to pests such as the Colorado potato beetle improved, which may be attributed to changes in leaf structure following foliar treatment. These findings highlight the potential of integrated nutrient management strategies involving macro- and micronutrients, amino acids, and bioactive compounds to sustainably boost crop yields and improve produce quality.

WCF should be adopted as part of integrated nutrient management, especially in low-fertility soils, to improve seed quality and crop productivity.

It is recommended to apply WCF through seed/tuber soaking before planting and repeated foliar applications (2–3 times) during the growing season to achieve optimal results.

Local production and accessibility of such fertilizers should be encouraged to support smallholder and large-scale farmers in achieving sustainable agricultural outcomes.

Further research should be conducted across different soil types and crop varieties, including molecular studies, to optimize fertilizer compositions and understand the genetic mechanisms behind observed agronomic improvements.

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Declarations of interest

The authors declare no conflict of interest concerning the research, authorship, and/or publication of this article.

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